# การกระจายของเพลี้ยอ่อนระหว่างสาบเสือและกะหล่ำปลีภายใต้ปฏิสัมพันธ์กับมด
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นางสาวปุณฑริกา คงเรือง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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# APHID DISPERSAL BETWEEN SIAM WEED AND CABBAGE UNDER INTERACTION WITH ANT IN WIANGSA DISTRICT, NAN PROVINCE

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for the Degree of Master of Science Program in Zoology

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ปุณฑริกา คงเรือง : การกระจายของเพลี้ยอ่อนระหว่างสาบเสือและกะหล่ำปลีภายใต้ปฏิสัมพันธ์กับมดในพื้นที่อำเภอเวียงสา จังหวัดน่าน. (APHID DISPERSAL BETWEEN SIAM WEED AND CABBAGE UNDER INTERACTION WITH ANT IN WIANGSA DISTRICT, NAN PROVINCE) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: อ.ดร.ชัชวาล ใจซื่อกุล, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ.ดร.ดวงแข สิทธิเจริญชัย, 106 หน้า.

ศักยภาพของสาบเสือในการเป็นแหล่งพักตัวของเพลี้ยอ่อนก่อนการเข้าระบาดในพืชปลูกได้ถูกสำรวจและประเมินระหว่างเดือนสิงหาคม พ.ศ.2553 ถึงเดือนกันยายน พ.ศ.2554 ที่อำเภอเวียงสา จังหวัดน่าน สาบเสือและกะหล่ำปลีได้ถูกทำการสำรวจและเปรียบเทียบความหลากชนิดและความชุกชุมของเพลี้ยอ่อนและสัตว์ขาปล้องอื่นๆ เช่น มดที่สัมพันธ์และศัตรูธรรมชาติของเพลี้ยอ่อนในพื้นที่ป่า ในแปลงกะหล่ำปลีเชิงพาณิชย์ และในแปลงทดลองที่ปลูกผสมระหว่างกะหล่ำปลีและสาบเสือในสองฤดูกาลปลูก (พฤศจิกายน 2553-กุมภาพันธ์ 2554 และ มีนาคม 2554-มิถุนายน 2554) นอกจากนี้การกระจายของเพลี้ยอ่อนระหว่างสาบเสือและกะหล่ำปลีได้มีการทดสอบโดยใช้การทดลองในกรง

การสำรวจภาคสนามพบเพลี้ยอ่อน 2 ชนิดบนสาบเสือคือเพลี้ยอ่อนฝ้าย *Aphis gossypii* และเพลี้ยอ่อนส้ม *Aphis spiraecola* ในสาบเสือและพบเพลี้ยอ่อนฝ้ายเท่านั้นบนกะหล่ำปลี เพลี้ยอ่อนฝ้ายเป็นเพลี้ยอ่อนที่มีความชุกชุมมากที่สุด (86.93 ตัว /ตร.ม.) ในทั้งสาบเสือและกะหล่ำปลีโดยเฉพาะในฤดูแล้ง (ตุลาคม-มีนาคม) ซึ่งตรงกับช่วงฤดูกาลปลูกพืชตระกูลกะหล่ำในจังหวัดน่าน มดไม้ *Camponotus rufoglaucus* เป็นมดที่เกี่ยวข้องกับเพลี้ยมากที่สุด (39.8%) โดยเป็นมดที่กินน้ำหวานจากเพลี้ยอ่อนและความสัมพันธ์ระดับสูงกับเพลี้ยอ่อน ในขณะที่ *Odontoponera denticulata* เป็นมดที่มีการล่าเพลี้ยอ่อน ส่วนแมงมุมเป็นผู้ล่าของเพลี้ยอ่อนที่สำคัญที่สุดโดยแสดงความสัมพันธ์จำกัดเชิงปริมาณต่อเพลี้ยอ่อนโดยเฉพาะบนสาบเสือ ผลการศึกษาในแปลงทดลองพบความหลากหลายและอันดับความชุกชุมเหมือนกับการสำรวจภาคสนามยกเว้น *Lipaphis erysimi* ซึ่งพบบนกะหล่ำปลีในปริมาณที่มากกว่า *A. gossypii*

ผลของความสัมพันธ์ของเพลี้ยอ่อน *A. gossypii* กับมดที่สัมพันธ์สองชนิดคือ *C. rufoglaucus* และ *O. denticulata* ที่มีต่ออัตราการเติบโตและอัตราการเคลื่อนย้ายของเพลี้ยอ่อนระหว่างสาบเสือและกะหล่ำในการทดลองในกรงพบว่ามดไม้มีผลเชิงบวกต่ออัตราทั้งสองของเพลี้ยอ่อนอย่างมีนัยสำคัญทางสถิติ ส่วน *O. denticulata* แสดงผลเชิงบวกต่ออัตราการเติบโตและตรงข้ามต่ออัตราการเคลื่อนย้ายของเพลี้ยอ่อนยืนยันการเป็นผู้ล่าของเพลี้ยอ่อนและความสามารถในการลดจำนวนประชากรเพลี้ยอ่อนให้ถึงค่าจำกัดของประชากรได้ช้าลง อย่างไรก็ดีไม่พบความแตกต่างระหว่างประชากรและอัตราการกระจายของเพลี้ยอ่อนระหว่างกลุ่มที่ไม่มีมดและกลุ่มที่มี *Camponotus rufoglaucus* แสดงถึงการความพึ่งพาระหว่างเพลี้ยอ่อน *A. gossypii* กับมดอย่างไม่ถาวร

ผลการทดลองยืนยันความสามารถในการเป็นแหล่งพักตัวของเพลี้ยอ่อนและสัตว์ขาปล้องที่เป็นประโยชน์ในสาบเสือ รวมทั้งบทบาทในรูปแบบต่างๆ ของมดที่มีปฏิสัมพันธ์กับเพลี้ยอ่อนต่ออัตราการเพิ่มประชากรของเพลี้ยอ่อนและอัตราการกระจายตัวของเพลี้ยอ่อน ดังนั้นในการจัดการสาบเสือและเพลี้ยอ่อนอย่างเหมาะสมจึงควรพิจารณาให้เกิดผลลัพธ์ที่จากความสัมพันธ์ทั้งเชิงบวกและลบเชิงนิเวศวิทยาของสาบเสือและเพลี้ยอ่อนร่วมกัน

ภาควิชา …………ชีววิทยา…………..ลายมือชื่อนิสิต...........................................................................

สาขาวิชา………..สัตววิทยา………..ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก..........................................

ปีการศึกษา ……..2554……….........ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม............................................

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PUNTHARIKA KHONGRUANG: APHID DISPERSAL BETWEEN SIAM WEED AND CABBAGE UNDER INTERACTION WITH ANT IN WIANGSA DISTRICT, NAN PROVINCE. ADVISOR: CHATCHAWAN CHAISUEKUL, Ph.D., CO-ADVISOR : ASST.PROF.DUANGKHAE SITTHICHAROENCHAI, Ph.D., 106 pp.

The potential of Siam weed serving as aphid reservoir for aphid dispersal to crops was investigated during August 2010-September 2011 in Wiangsa District, Nan Province. Siam weeds and cabbages were sampled for species diversity and abundance of aphids and other arthropods, such as tended-ants and natural enemies, in forest, commercial cabbage fields, and a field experiment of cultivating mixture of Siam weed and cabbage over two growing seasons (November 2010-February 2011 and March-June 2011). Moreover, aphid dispersal between Siam weed and cabbage was investigated by conducting a caged experiment.

From the field sampling of aphids and other arthropods, *Aphis gossypii* and *Aphis spiraecola* were both found on Siam weed, while *A. gossypii* was the only one species found in cabbage. *Aphis gossypii* was the most abundant aphid in both Siam weed (86.93, Siam weed sampling) and cabbage, and had highest population density during the dry season (October-March) which coincided with the growing season of cabbage and other *Brassica* in Nan Province. *Camponotus rufoglaucus* was the most abundant tended-ant (relative abundance=39.8%) with preference for honeydew and had the strongest relationship to *A. gossypii* while *Odontoponera denticulata* was the tended-ant with predatory role. However, the most important predator of aphids was spiders with strong negative relationship to the aphid population in Siam weed. Most aphids and other arthropods observed in the field experiment had similar diversity and rank abundance as the field sampling results, except *Lipaphis erysimi* which was the individuals $m^{-2}$dominant aphid on cabbage instead of *A. gossypii.*

The interaction of one aphid species, *A. gossypii*, and two tended-ants, *C. rufoglaucus* and *O. denticulata,* was conducted in a cage experiment to measure the population growth rate and dispersal rate of aphids, in Siam weed and cabbage. *C. rufoglaucus* treatment exhibited the positive effect on aphid abundance and aphid dispersal rate significantly while *O. denticulata* treatment exhibited the negative effect on aphid abundance and aphid dispersal rate confirming its predatory role on aphids and its ability to delay aphid population to reach carrying capacity. However, the nonsignificant difference of mean aphid abundance and dispersal rate between *C. rufoglaucus* treatment and non-ant treatment indicated that *A. gossypii* was the facultative myrmecophiles.

In conclusion, this study confirmed the potential of Siam weed serving as aphid and beneficial arthropod reservoir as well as the different role of tended ants in the population growth and dispersal of aphids between weeds and crops. Therefore, consideration of both negative and positive effects in ecological roles of Siam weed and aphids were required in formulating the suitable management for Siam weed and aphids in agroecosystem.


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| Department : Biology | Student's Signature ................ |
| Field of Study : Zoology | Advisor's Signature ................ |
| Academic Year : 2011 | Co-advisor's Signature ................ |

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# CONTENTS

Page

# List of Tables

# List of Figures

Figure Page

# CHAPTER I

# INTRODUCTION

Aphids, a group of sucking herbivorous insects (Homoptera: Aphidae) and a key pest, can cause damages both robbing the sap of plant and also transmitting virus in some species (Albajes et al., 2002). They have alternate reproductive modes between parthenogenesis and sexual reproduction in relation to their environments (e.g. photoperiod, temperature, host plant). In addition, genotypes are also associated with reproductive modes, accordingly, some clonal lines respond to each condition differently (Blackman, 1974 cited in Devonshire et al, 1998; Devonshire et al, 1998). According to these cyclical parthenogenesis and heteroecy, they can exploit efficiently on host plants, particularly agricultural crops (Blackman and Eastop, 2000).

In addition to the complex life cycle, aphids can display efficient dispersal strategies. When host plant is depleted of nutrients according to the dense aphid infestation, winged morphs (alates) are usually formed (Hardie and Powell, 2002). Alates take flight and disperse to new food sources lead to maintaining the metapopulation of aphid clone (Muller, Williams, and Hardie, 2001). Crowded condition could also induce late instar apterous aphids moving to new place of same host plant or move down on the ground to new host plant (Hodgson, 1991).

Moreover, the mutualistic relationship with ants in some aphid species, which createadvantages on defense against their natural enemies (Stadler and Dixon, 2005) were also associated with aphid dispersal. Ants transport aphids directly by carrying them to high-quality host plants within ant colonies foraging range, and ants beneficially feed on honeydew or the high sugary content excretion from aphids (Collins and Leather, 2002). However, ants can also limitaphid dispersal which benefits ants by forming aphid aggregation resulting in more honeydew (Oliver et al., 2007). Furthermore, aphid-ant relationship temporally increases the developmental rate or colony growth in some aphid species (Dang, Buffa, and Delfino, 2005). Additionally, ant-tended aphid colonies are likely to be more stable and persist longer (Dixon, 1998). It can be concluded that the presence of mutualistic ants could strongly affect aphids both ecologically and evolutionarily. All these major evolutionary developments of aphid lead to more widespread and uncertain aphid outbreaks.

Chemical insecticides are the common method controlling aphids in crop cultivation. Accordingly, there are a number of harmful impacts of pesticides on health and environment (Dang et al., 2010). Therefore, biological control was gaining popularity as a potential tool for controlling aphid population, minimizing pesticide usage and avoiding the indirecteffects from pesticide usage as well as coping high level of pesticide resistance in some aphid species (Albajes et al., 2002; Furk and Hines, 1993). Residual toxicity of insecticidesmay also kills beneficial organisms, such as pollinators and natural pest-controlling agents (Bhatia, Uniyal, and Bhattacharya, 2011).

Moreover, due to high capability of aphid producing offspring, it is difficult to successfully control them in all situations with just insecticidal control. Good cultural practicesand suitable management strategies on agricultural adjacent areas, such as fallow and catch preys, may increase beneficial natural enemies of aphids resulting in a reduction in rate of aphid population growth (Albajes et al., 2002). Moreover, controlling of weeds had been reported to both reduce and increase population of both pests and natural enemies (Wratten et al, 2007).

Siam weeds (*Chromolaena odorata*), an invasive species, are widespread in central and western Africa, tropical America, India and Southeast Asia including Thailand (The State of Queensland, Department of Employment, 2009: online). They grow in many soil types, forming dense stands and found widely in abandoned cultivation and surrounded agricultural area (IUCN, 2006: online). Consequently, they have become a major weed of arable and plantation crops thus aphids usually found contaminated in the presence of weeds, old crops or year-round crops. Aphids and tending –ants were easily found infested on Siam weed. There are three aphids species, *Aphis gossypii* (Glover), *A. spiraecola* Patch, and *A. craccivora* (Koch), reported on Siam weed in Thailand. Interestingly, they are all key pests in many crops (Napompeth and Winotai, 1991). The availability of Siam weeds as the host of aphids may serve Siam weed as a reservoir plant and induce aphid outbreak to nearby cropping area (Napompeth, Hai, and Winotai, 1988). Surprisingly, the study on the diversity and ecological role of aphid, tending-ants, and arthropods on Siam weed were limited.

Cabbage, one of the most important vegetable crops in many regions of the world, is cultivated in extent area including Nan province, northern of Thailand (Office of Agricultural Economics, 2009: online). Losses in yield of cabbage due to aphids by both directly robbing plant sap as well as transmitting pathogens were commonly reported as *A. gossypii* (Bhatia et al., 2011). Consequently, pesticide uses on growth and productivity of these crops were highly detected on Nan province (Janpong, 2008). Including, blood test results showed high level of pesticide contamination of randomly tested 59 from 60 individuals in Amphur Muang, Nan province (Ministry of Public Health, 2009: online).

In order to evaluate and reduce the risk of aphid outbreak that causes economically significant damage, the basic information in diversity and ecological interaction of aphids, tended-ants and other arthropods on both Siam weed (reservoir) and cabbage (crop) are necessary. Furthermore, aphid dispersal completely affects the fluctuation of aphid population size that leads to aphid outbreak. Thereby, focusing on aphid-ant relationship effects on aphid dispersal should alsobe included. Thus, to achieve the effective and sustainableaphid management strategy, integrated management of both Siam weed and other beneficial arthropods on Siam weeds and cabbages are required.

Therefore, Nan province is the suitable study area to examine the ecological interactions of aphid and other arthropods, particularly tending ants in between cabbage and Siam weed that could provide information in evaluating Siam weed as plant reservoir and sustainably managing both aphids and Siam weeds.

**1.1 Objectives**

1. To study and compare diversity of aphids and tended-ants on Siam weeds and cabbages between two seasons of crop (October-December and January-March) in Wiangsa district, Nan province

2. To study and compare growth rate and dispersal rate of aphids on Siam weeds and cabbages under interaction with ants

# CHAPTER II

# LITERATURE REVIEW

## 2.1 General features and taxonomyof aphids

Aphids are small soft-bodied insects with or without wings and are commonly known important pests in agriculture. They belong to series Sternorrhyncha within the order Hemiptera along with scale insects, psyllids, and whitefly (Hennig, 1980). Aphids are in the superfamily Aphidoidea and differentiated from the other groups in the Aphidoidea in that females, of at least few generations, do not require fertilization for their embryos development (Dixon, 1973) or parthenogenesis. Family Aphididae is large insect family, including eight major groups, which are mostly well known for being serious pests in agricultural area such as a large group of aphids, plantlice, greenfly, and black fly.

## 2.2 Causes of aphid problems in agriculture

Aphids show many evolutionary characteristics leading to be an extremely successful group which occur all over the world (Blackman and Eastop, 2007). Their evolved-feeding behavior, complex life cycle, and effective migration enable to exploit their host plants and can respond to various environmental conditions (Dixon, 1998).

### 2.2.1 Life cycle and polymorphism

In temperate zone, aphids produce offspring from both sexual reproduction as well as cyclical parthenogenesis while in tropical zone as Thailand aphids are commonly exist parthenogenetically throughout the year (Dixon, 1977). In temperate zone at beginning of autumn, the day becomes shorter and cooler, then sexual morphs are produced, and the oviparous females lay the overwintering eggs after mating (Dixon, 1973). Eggs gradually hatch on spring when plants resume growing and subsequent parthenogenetic development starts (Dixon, 1973). Most aphids live on only one species of host plant called monophagous (Van emden and Harrington, 2007). They spend the winter months in egg stages, egg hatching on spring and the nymphs develop into the winged adults of first generation. These adults are parthenogenetic virginoparae, and many parthenogenetic generations reproduce until the onset of autumn then they develop sexual morph. After mating, the oviparae lays the overwintering eggs (Dixon, 1973).

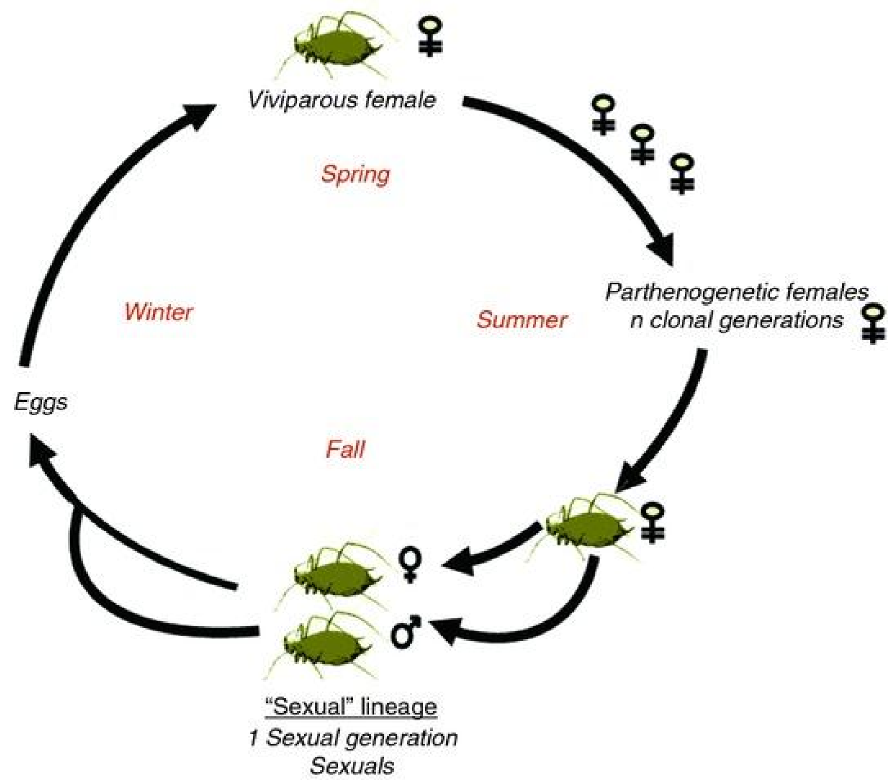



**Figure 2.1** Life cycle of aphids (Ollivier and Rispe, 2010)

Contrastingly, some aphids feed on more than one species of host plants or called polyphagous. They spend autumn, winter and spring on the primary host and migrate to the secondary host in summer (Dixon, 1977). The capacity of changing in host plant of aphids is called host alternation (Dixon, 1977). In addition, aphids which cause damages on agricultural crop are mainly host alternating.

Changing of external environmental conditions (e.g. day-length, temperature and host plant) triggers the internal changes in aphid, and influences their morphological development seasonally (Dixon, 1985). Consequently, there are many different forms of aphid called polymorphism (Blackman and Eastop, 2000). Short day-length and low temperature influence production of sexual morphs, this process was synchronized to host plant growth and development (Dixon, 1977; Le Trionnaire et al., 2008; Simon, Rispe, and Sunnucks, 2002).

Crowding, quality of host plant, ant attendance, temperature, and photoperiod are factors implicating in the development of parthenogenetic morphs, the alate virginoparae. High degree of tactile stimulation in dense aphid colonies and poor quality of host plant are important factor enhance alate formation (Bale, Ponder, and Pritchard, 2007; Muller, Williams and Hardie, 2001). On the other hand, tactile stimulation from ants delays or inhibits wing production of alate in ant-tended aphid colonies. High temperature and long day length may also inhibit this development. After all, aphids respond to each environment changing to prevent overcrowded condition, poor nutrition and to persist their metapopulation (Dixon, 1998).

### 2.2.2 Feeding behavior

Hemipterans are the only insect group that have developed the ability to nourish from plant sap through their piercing and sucking mouthparts. Aphids feed on plant sap by inserting their mouthparts, the stylets, into phloem tissue of plants. The stylet bundle consists of a pair of mandibular stylets and a pair of maxillary stylets. Between maxillary stylets, there are food and salivary canals. The alternative protraction of first mandibular and then maxillary stylets assemble stylet bundle penetrates through sieve tube of phloem (Dixon, 1973).

Turgor pressure in sieve tube of plant phloem plays an important role in the regulation of plant sap movement to aphid body (Dixon, 1973; Miles, 1999). This high level pressure drives the cell contents up to aphid food's canal into guts, where nutrients were absorbed and metabolized. However, in the condition that plant cells are not under this pressure, aphids use the cibarial pump to suck up sap instead (Chapman and Boer, 1995).

Phloem sap is composed of mainly sucrose and free amino acids but deficient in essential amino acids (Volkl et al., 1999). Conversely, most insects including aphids need essential amino acids for their growth and reproduction. As a result, they have to ingest large amount of sap and symbiont with symbiotic bacteria to obtain sufficient essential amino acids (Chandler, 2008).

Aphids defecate unassimilated and synthesized components of phloem sap in form of honeydew. The components of honeydew are not the same as those taken up by aphids from phloem, mainly composed of a variety of saccharides (e.g. melezitose, glucose, fructose, sucrose and maltose), waste products (e.g. nitrogenous compounds, uric acid and ammonia), microorganisms, and probably volatiles (Leroy et al., 2011; Volkl et al., 1999). The primary sugar found in aphid honeydew is melezitose, a trisaccharide, to which tending ants respond most intensively (Fischer and Shingleton, 2001; Volkl et al., 1999). Thus, honeydew composition is an important factor in mediating aphid-ant mutualisms (Fischer and Shingleton, 2001; Fischer, Volkl, and Hoffmann, 2005). Additionally, melezitose also plays a key role in aphid-parasitoid interactions (Wackers, 2000), osmoregulation of aphid hemolymph (Fischer, Wright, and Mittler, 1984; Petelle, 1980) and can provides a carbon source for free-living nitrogen fixing bacteria (Owen, 1978).

While aphids are probing, they also secrete their saliva which pass down the salivary duct and are projected from tip of the stylet bundle. Aphids secrete two types of saliva. The first is salivary sheath, an insoluble lining of the stylet bundle. It protects the feeding area from plant defense responses (Miles, 1999). The other is soluble saliva, containing a number of enzymes which possible relate to maintaining feeding area, depress plant defense, induce changes in plant physiology, and prevent sieve tube plugging in phloem which supporting continuous flow of phloem sap during aphid feeding (Giordanengo et al., 2010; Miles, 1999; Will et al., 2007).

### 2.2.3 Dispersal

The other characteristic beside life cycle and reproductive patters which influence aphid as a great adaptive herbivorous was a dispersal strategies. Dispersal mostly occurs when the colonies population was detected the poor quality of their exploiting host plant. Moreover the tactile stimulation associating with crowding from high density of population in colony, induced some individuals to develop wing and becoming alates (Dixon, 1998).

The host plant quality is the main factor determining dispersal of aphids because the host plant determine and limit the size, survival, and reproductive rate of aphids. In other words, host plant quality indicated the survival of each aphid colonies. The host plant quality was more important especially for heteroecious species which have to change their host plant according to season.

In many aphid species, alates are produced according to day length (Matsuka and Mittler, 1978). This can observe from the different appearance and characteristic of aphids seasonally. The response which influenced changing in environmental factor is a potential adaptive strategies for survival to each conditions. The biological clock inside each aphid is the main factor which determines how to respond to each extrinsic factor. These detected also involve with alate developmental process.

## 2.3 Aphids and host plants

### 2.3.1 Aphid infestation on Siam weed

The potential of weeds as alternative host for some aphid species in surrounding crop field were reported (Smith, Kentall, and Wright, 1984). The aphid infestation on these weeds contributed weeds to playan important role as the linked-plant between the primary host and the crop (Harrewijn and Minks, 1989). Moreover, they also serve as the virus source as virus-transmissible aphids reservoirs (Rabasse and Steenis, 1999). Siam weed, *Chromolaena odorata* (L.), is a perennial scrambling shrub native to Central and South America, and the Caribbean. It has become a major weed in parts of Asia and West, Central and South Africa

(Muniappan and Marutani, 1988). Siam weed distribution was limited mainly by the rainfall amounts to 2000 mm in location (Muniappan and Marutani, 1988).

Siam weed has been found invading in forest gaps, agricultural fields, cleared forest land and fallows, open grasslands and savannas as an early stage successional plant, particular in burned area (Norgrov et al., 2008). They flower in the beginning of the dry season. The new emerged seeds mostly are induced by moisture from rainfall during wet season.Siam weed was reported to harbor some important pests of crops, mostly were *Zonocerus variegatus* (L.) (Orthoptera: Pyrgomorphidae) and *Aphis spiraecola* (Patch) (Homoptera: Aphididae) (Oigicangbe et al., 2007).

Siam weeds were infested from both nymph and adult stages of aphids. They feed on young, succulent terminal shoot-tips at the first range of infestation resulting in the mottling of *C. odorata* leaves. Stunting of tree growth from aphid infestation was also reported (Pfeiffer, Brown and Varn, 1989). *A. spiraecola* and *A. gossypii* are commonly aphids reported on Siam weed in diverse areas including other predators which related in suppress this aphid population.

Siam weed was also reported in decreasing the carrying capacity and species diversity in grassland and forests (Macdonald, 1984) and it also negatively associated with agricultural productivity (Timbilla and Braimah, 2000). Considering that the concerned problem of *C. odorata* is too ecologically and economically important to be ignored, an integrated strategy is needed to control and management of theweed in each habitat data.

### 2.3.2 Aphid infestation on cabbage

Cabbage (*Brassica oleracea* var. *capitata*), the main vegetable in family Brassicaceae, is considered as an important crop worldwide. In Thailand, there is high level of cabbage consumption all through the year. Consequently, to complete the excessive demand, there are many cabbage cultivated area particularly in northern and central region of Thailand.

In the North of Thailand including Nan province, cabbages are the seasonal crops. Their cultivating season is typically only in dry season (October-January) when the low air-temperature encourages their development. While growers in central region usually produce cabbages in high quantity for commercial for the whole year by cultivating the cultivars which tolerate hot-condition.

The cabbage injury which may lead to economic yield loss usually resulted from both diseases and insects damages. Since there is intensively cultivation, the pest infestation on cabbage is in high level. The insect pests on cabbages are commonly lepidopterans, such as Diamondback moth, *Plutellaxylostella* (L), cabbage butterflies, *Pieris rapae* (L), and cabbage looper, *Trichoplusia ni* (Hubner), beetles, such as flea beetle, *Phyllotreta brassicae*, and aphids, such as turnip aphid, *Lipaphis erysimi* and cabbage aphid, *Brevicoryne brassicae*.

According to their ability to attack cabbage at any growth stage, aphid infestation was reported consistently. They commonly infest on the underside of leaves and suck plant juice. This may result in distorted and turning-yellow color leaves, stunting growth, produce unmarketable head, and in heavily infested that could kill young plant. In addition, some aphids could transmit viruses that increasing risk of broadly large yield loss.

Chemical control is the most effective mode for controlling many insect damages. On account of exposing to the high level of pesticide to pest population, the consecutive problems affected by their excessive application on cabbage were reported. Moreover, due to most commonly application chemicals used for controlling insects are broad-spectrum insecticides, not only target pests have been killed but also beneficial insects as pollinators have been eliminated (Bhatia et al., 2011). Hence, there are no generalist predators to control pests and sustain the ecological balance causing pest outbreaks, particular secondary pest outbreaks. Furthermore, the inappropriate insecticide-treating time, as applying in upper economic threshold, could increase the risk of re-pest outbreak. For these reasons, the alternative management strategies are required to sustain the environment and vegetable production. However, there are still many questionable comprehensive information of aphid infestation on cabbage in Thailand. The progress studies should be focused more particularly on obtaining basically pest-host plant association data.

**2.4 Aphid and ant relationship**

Ant and aphid evolve together their attendance evolution and also determine for each other whether form this attend relationship. The aphid species which have poor developmental strategies in defense against natural enemies tend to form relationship with ants (way, 1963). The total net of aphid-ant relationship will provide the benefits or cost which mostly influenced by the relationship between them and also environmental factors such as aphid feeding capacity, predators and host plant quality.

There are both negative effects and positive effects from these relationships according to experiment conditions. Many reports supported the high abundance of aphid colonies when ant-attendance occurs, however, many species have greater aphid number in the absence of tended-ants (Whittaker, 1991).

Ant also alter aphid to develop and improve the quality of honeydew they produced and also in some studies show the increase of aphid feeding rate on host plants (El-Ziady, 1960) which delay aphid dispersal. Ant semiochemicals which emitted when ant presence in aphid colonies have tranquillizing effect, and this phenomenon limit apterous aphid dispersal (Oliver et al., 2007). In contrast, some aphids with the absence of tended-ant feed and use their all energy for dispersal to complete searching for new high quality source plants (Bank, 1958; El-Ziady, 1960).

Most studies on this relationship show the longer colony persistent in ant-tended colonies over than un-tended colonies. Interestingly, the higher aphid abundance in some ant-tended colonies is affect from decreasing of ant-tended number, in the condition that showed the stable number of predators. This showed the density-dependent mutualism which formed the direct effects between ant and aphid abundance (Breton and Addicott, 1992).

**2.5 Aphid and natural enemies**

The successfully suppressed and stable aphid population depends mostly on the biology, life cycle, foraging behavior of natural enemies and specificity on their preys, which influence the natural enemies' ability to control aphid population. The natural enemies of aphids play roles in reducing rate of increase of aphids, occasionally and dramatically (Dixon, 1998). The first success in biological control was the useof a lady beetles (Coleoptera: Coccinellidae). Lady beetles feed on wide range of food, both larvae and adults feed on the same type of prey species and occur in the same habitat (Van emden and Harrington, 2007). They performed a high potential as being aphid suppressors on their high capacity for prey searching. However, a lack of synchronization and the restriction to one or two generations per year limit the capacity of lady beetles as biological control agents (Dixon, 1997).

Hover flies (Diptera: Syrphidae) show the high specific ability for aphid. Due to their high fecundity, they immediately feed after hatching andare specific to aphid species. Their specificity to aphid species reflect to the preference of hover females which prefer to lay eggs in limited number of aphid colonies, causing the disadvantages of hover flies for being biological control agent in some conditions (Ito and Iwao, 1977). Lacewings (Neuroptera: Chrysopidae) are the polyphagous predators that commonly prey on aphids. They do not only attract to aphid but also attract to aphid’s honeydew (Van Emden and Hagen, 1976). The high sensitivity to toxin and altered environmental conditions were the poor characteristics of lacewings in performing as a good biological control predators. Furthermore, the preying capacity in laboratory were reported at high level while most studies found that the very large number of lacewings were highly required to successfully reduce aphid population (Hagley, 1989). There are also many general polyphagous predators such as spiders and other beetles preying on aphids. Although aphids were not only these polyphagous predators main food items, some studies reported the significant suppression of aphid population (Sunderland and Samu, 2000). The generalist predator abundance and efficiency of generalist predators can be increased significantly by a diversification of cropping system (Sunderland and Samu, 2000). To provide the efficient integrated aphid management, the ecological roles among these predators should also be examined.

# CHAPTER III

# SPECIES DIVERSITY AND ABUNDANCE OF APHIDS AND OTHER RELATED ARTHROPODS ON SIAM WEEDS IN FOREST AREA AND ON CABBAGES IN AGRICULTURAL AREA

## 3.1 Introduction

A number of weeds around agricultural area often serve as host plants of migrating aphids, other arthropods, and plant viruses. These weeds have been shown to be hosts for colonizing aphids and may harbor other arthropods (Alvarez and Srinivasan, 2005; Harrewijn and Minks, 1989; Nentwig, Frank and Lethmayer, 1998). Siam weed, a perennial weed, usually grows along the edges of agricultural fields. It was reported as the preferred weed host for some aphid species particularly *Aphis gossypii and Myzus persicae* that cause damages and transmit viruses in many crops including Brassicaceae (Blackman and Eastop, 2007; Pike, Miller, and Stary, 2000). Cabbage, one of the most important vegetable crops in family Brassicaceae, had also been reported to have the damages from both *A. gossypii* and *M. persicae* (Bhatia, Uniyal, and Bhattacharya, 2011). Although Siam weed has been reported as a host for aphids, its potential as an aphid reservoir and its role as potential source for aphid spreading to crops in cultivating season have yet to be investigated.

To determine the efficacy of Siam weed as aphid source, the diversity and abundance of aphid as well as of associated insects infesting both in Siam weed and in cabbage as a target crop were examined throughout the year covering two cabbage growing seasons. Furthermore, the assessment of aphid and other arthropod abundance and diversity in both areas could also estimate the population fluctuation, economic threshold, and also future outbreak status of aphids.

## 3.2 Methodology

### 3.2.1 Diversity and abundance of aphid and other related arthropods on Siam weed

**Field site**

The study was conducted in the forest area of Chulalongkorn University Forest and Research Station in Wiangsa district, Nan province, Thailand. The study area was approximately 1.5 ha, located in UTM zone 47Q: N2052221 and E689463 and 221 meters above sea level (Appendix A, Figure 1-A). It was the mixture of land covered and categorized as uncultivated land (mostly pastures) adjacent to mango plantation and mixed dipterocarpous forest.

**Arthropods sampling**

To investigate the potential of Siam weed as aphid reservoir, aphid abundance on Siam weed was estimated between August 2010 and September 2011. Six (1x1m$^2$) quadrats for aphid infestation on Siam weed were sampled monthly. In each quadrat, aphids and other arthropods from three plants at 30-55 cm in height, three plants at 55-80 cm in height and three plants at more than 80 cm in height were censused. The number and developmental stage of aphid as well as the number of other arthropods were recorded. The number of ant exposing to each sampling plant in one minute was total counted or estimated as tending ant in multiple of ten for ants with small size. Plant height (cm) and leaf stage of Siam weeds were also recorded.

**Identification**

Adult apterae and alates were preserved in microcentrifugal tubes or vials filled with 95% ethyl alcohol as well as ants and other arthropods. The immature stages of aphids and other arthropods were collected and reared in laboratory. The preservation of emergence arthropods was the same as previous. The clearing-mounting methods are basically followed Blackman and Eastop (2000). The genus and species of aphids were identified using keys by Blackman and Eastop (1984) and Sirikajornjaru (2002). Ants and other arthropods were identified using keys by Bolton, 1994 and Borror et al., 1981, respectively.

**Environmental factors**

The records of meteorological data were sourced from two stations in Nan province, Synoptic Station (331201, Dutai subdistrict, Muang Nan) and Hydrological Meteorological Station (lat 18.5725 / long 100.782583, Lainan Subdistrict Administration Organization, Wiangsa district), obtained from Hydrometeorological Academic Group, Meteorological Development Bureau, Thai Meteorological Department.

**Data analysis**

Mean numbers of aphids, ants and other arthropods were calculated per (1x1m$^2$) quadrat. The correlation between environmental factors and abundance of aphids were examined.

### 3.2.2 Diversity and abundance of aphids and other arthropods on cabbage

**Field sites**

The study was conducted at two approximately 25x25 m$^2$ cabbage growing fields in Ban Khung sub-district, Wiangsa district, Nan province from October to December 2011. Farmers usually cultivate Virginia or hybrid cultivar-cabbage seasonally. The cultivating season of cabbage in Wiangsa district and nearby areas was between early October and January every year. Both fields were located near Sa-River surrounded by various crop cultivated areas, such as pumpkin, cucumber and Chinese kale, which methomyl (a carbamate compound) was applied to control lepidopteran pests. Siam weed was observed around both fields.

**Arthropod sampling**

Yellow sticky traps were used to sample the abundance of aphid and other arthropods on cabbages in the cultivating season between October and December 2010. Yellow sticky traps were made from yellow plastic coated by sticky water glue. Nine yellow sticky traps (10x20 cm$^2$) were used to sample arthropods at each site during October 2011 at seedling stage until harvesting time. The sticky trap was placed on the corner and middle of cultivating area at 2 m apart for both study sites (Figure3.1). The bottom edge of the trap was approximately 50 cm above the ground. The sticky traps were collected and placed weekly throughout the sampling period. The number and developmental stages of aphids and the number of natural enemies on each plant were recorded. The number of ants presented on each sampling plant in one minute was counted as the tending ants. Cabbage growth stage during each sampling time was also recorded.

**Identification**

The collected sticky traps were preserved for further identification analysis at $3^{o}C$ temperature in refrigerator. The arthropod specimens were identified the same as previous procedures described in 3.2.1.

**Environmental factors**

The records of meteorological data were sourced from the same station as previously described in 3.2.1.

**Data analysis**

To evaluate the abundance of aphid and other related arthropods in cabbage fields, the number caught per trap in each site was estimated visually. The correlation between mean number of aphids and environmental factors was also examined.

## 3.3 Results

### 3.3.1 Diversity and abundance of aphid and other related arthropods on Siam weed

**Aphid abundance**

Two aphid species, *Aphis gossypii* and *A. spiraecola* in suborder Sternorrhyncha, family Aphididae, were found on *Chromolaena odorata* between August 2010 and September 2011 (Figure 3.1). A significant difference (*Mann-Whitney U*-test, U=2.385, $p$<0.05) was observed between the number of *A. gossypii* and *A. spireacola* . *Aphis gossypii* was generally more abundant than *A. spiraecola* throughout the study period.

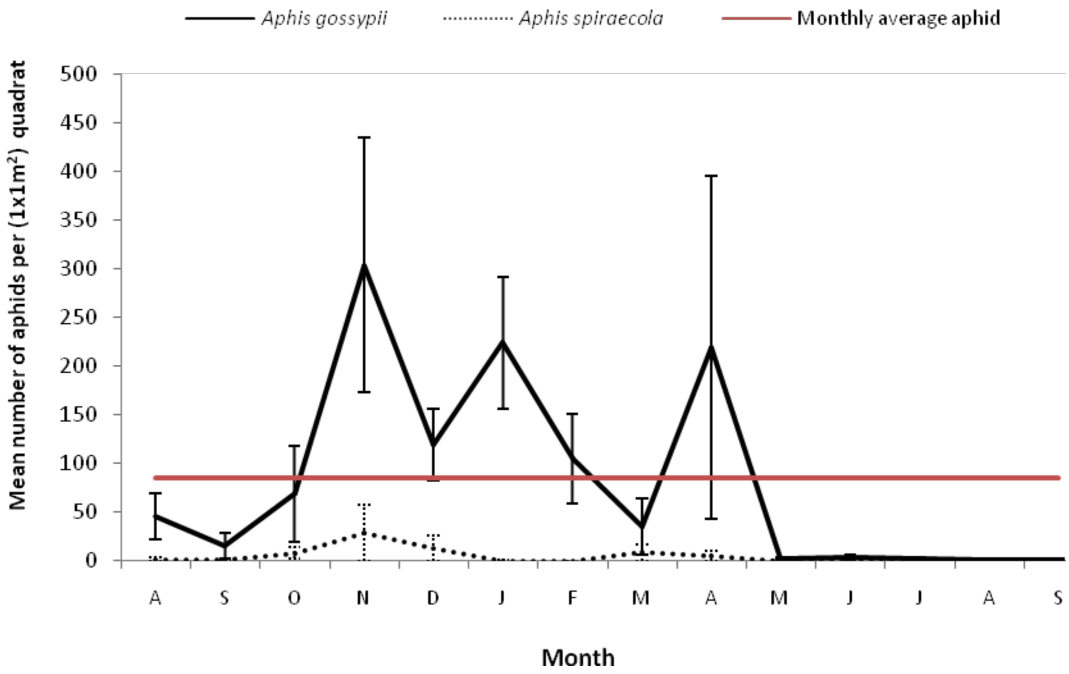



**Figure 3.1** Abundance of aphids on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province (Mean±SE)

The monthly average of aphids found on Siam weed was 86.93 individuals $m^{-2}$ (Figure 3.1). The aphid abundance tended to be higher on October and was greatest in November 2010. The period of aphid abundance can be separated into two phases such as the highly abundant phase from October to April and the lowly abundant phase from May to September.

In 2011, several early severe monsoons had taken place in Thailand particularly since March onwards. Some northern part of Thailand including Nan province were experienced with unusually heavy rain and consequence flash floods in March. Hence, the new and unusual amount of rainfall was recorded during March, June and July. However, the wet and dry seasons of this study period (August 2010-September 2011) were determined by monthly total rainfall based on climodiagram. Climodiagram (Figure 3.2) represents the comparison between total rainfall (mm) obtained from Hydrological Meteorological Station (Lainan subdistrict) and average air temperature ($^{o}C$) obtained from Synoptic Station (Dutai subdistrict) The bar graph area of rainfall crossed by the line of air temperature were included as the wet season.

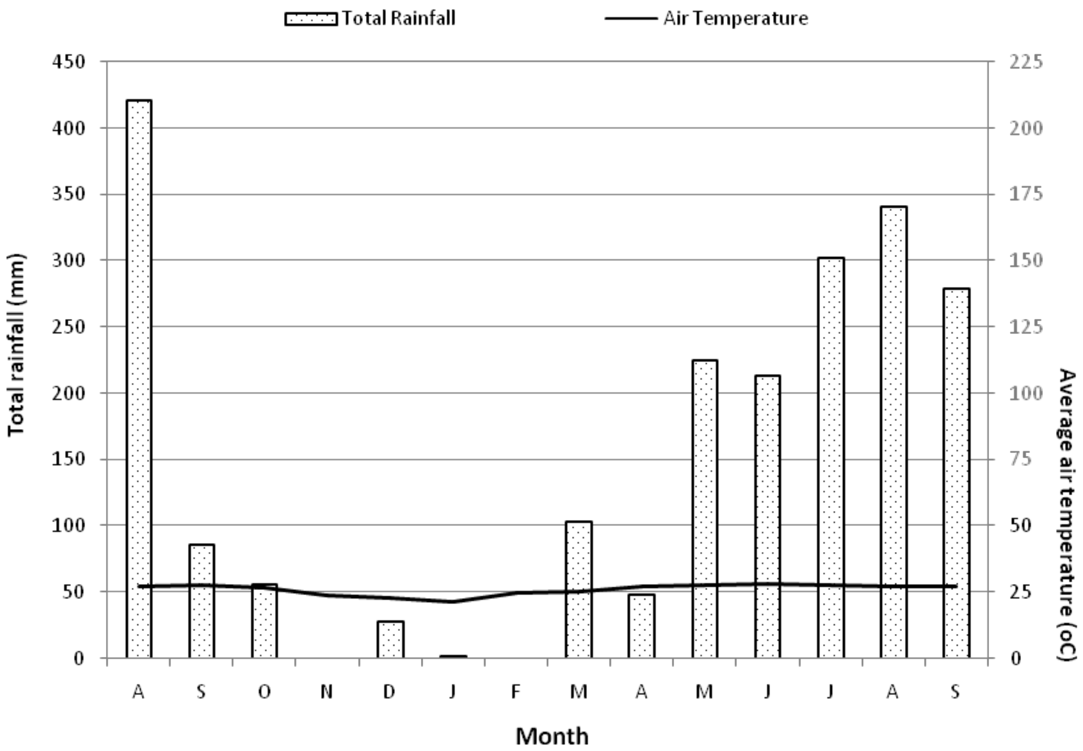



**Figure 3.2** Climodiagram, August 2010-September 2011, Wiangsa district, Nan province.

Moreover, compared with the last three year-meteorological data, the wet season in this chapter period was from May 2010 to October 2010 while the dry season was from November 2010 to April 2011. For the determination of March 2011 as dry season, was due to the unusual high recorded amount of rainfall in this month consequence from high pressure extending from China causing heavy rainfall.

The mean ranks of aphids on dry and wet season were 11.17 and 4.75, respectively. Consequently, the mean rank of aphids on dry season was significantly higher than in wet season (*Mann-Whitney U*-test, U=2.000, *p*=0.005), and those significant differences between wet and dry seasons were found in both aphid species.

The results were consistent with the correlation analysis which shown the corresponding between aphid number and two environmental factors. There was a significant negative association between the number of aphids per quadrat and the amount of rainfall (Spearman's rank correlation, r= -0.629, $P \leq 0.05$) (Figure 3.3, Figure 3.5).

Additionally, there was also a significant negative association between the number of aphids and the relative humidity measured in each quadrat sampling (Spearman's rank correlation, r= -0.415, $P \leq 0.05$) (Figure 3.4, Figure 3.5). However, there was no association between the number of aphids and air temperature measured in each quadrat sampling. This indicates that the aphid abundance was not influenced by the amount of air temperature. After wet season, particularly on early September, the newly emerged Siam weed plants were infested with higher aphid abundance. Regarding to the sampling height, no statistically significant differences found on aphid abundance among three height ranges of Siam weed (*Kruskal–Wallis* test: $\chi 2 = 7.8$, d.f. = 2, P=0.635).

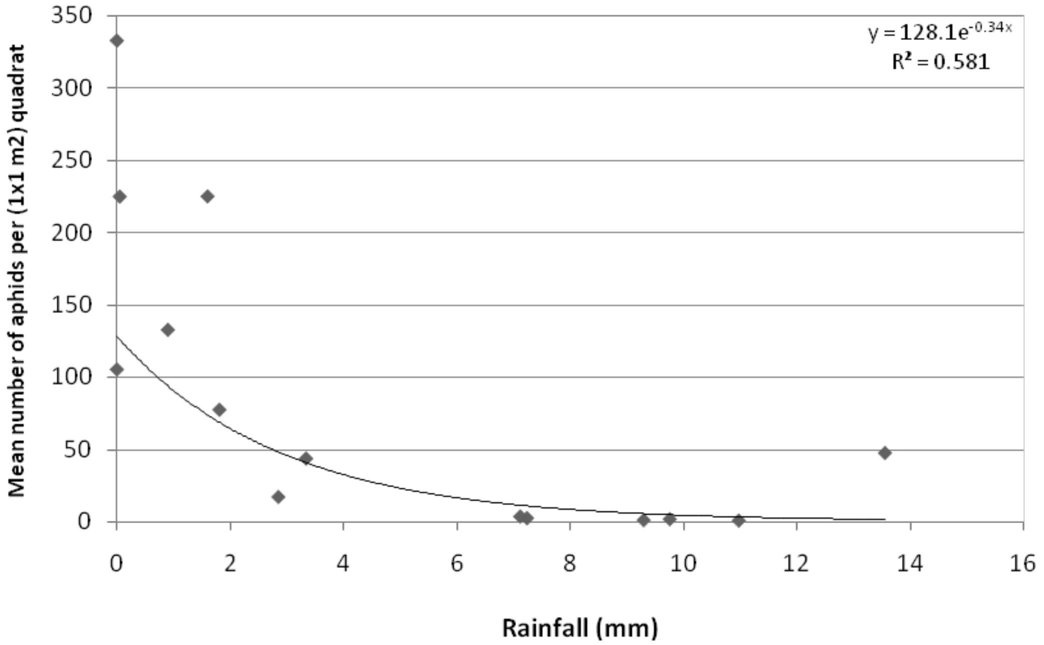



**Figure 3.3** Comparison of aphid abundance on *Chromolaena odorata* and average rainfall (mm), August 2010-September 2011, Wiangsa district, Nan province.

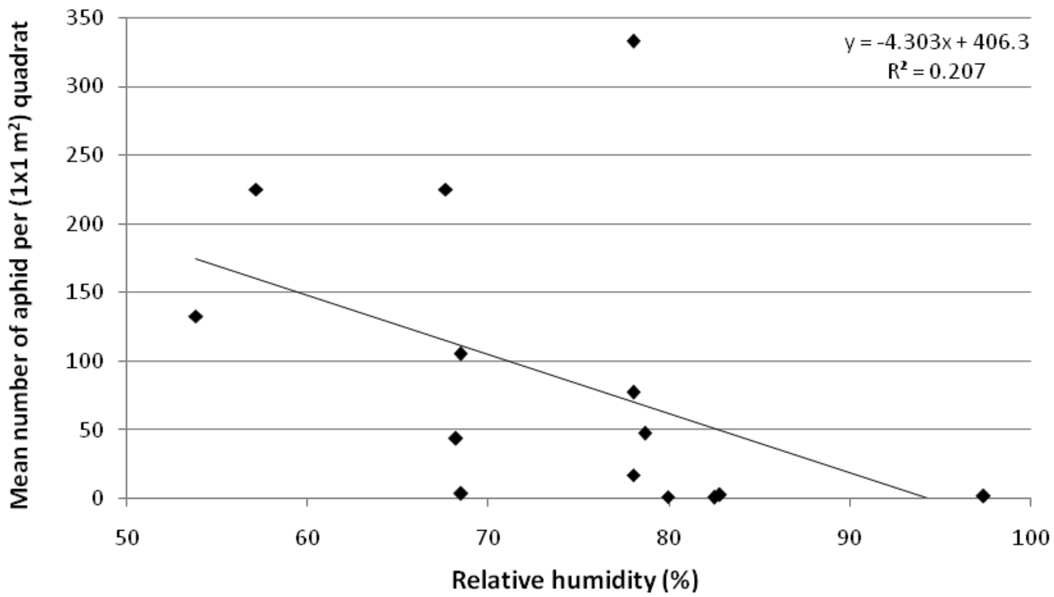



**Figure 3.4** Comparison of aphid abundance on *Chromolaena odorata* and average relative humidity (%), August 2010-September 2011, Wiangsa district, Nan province

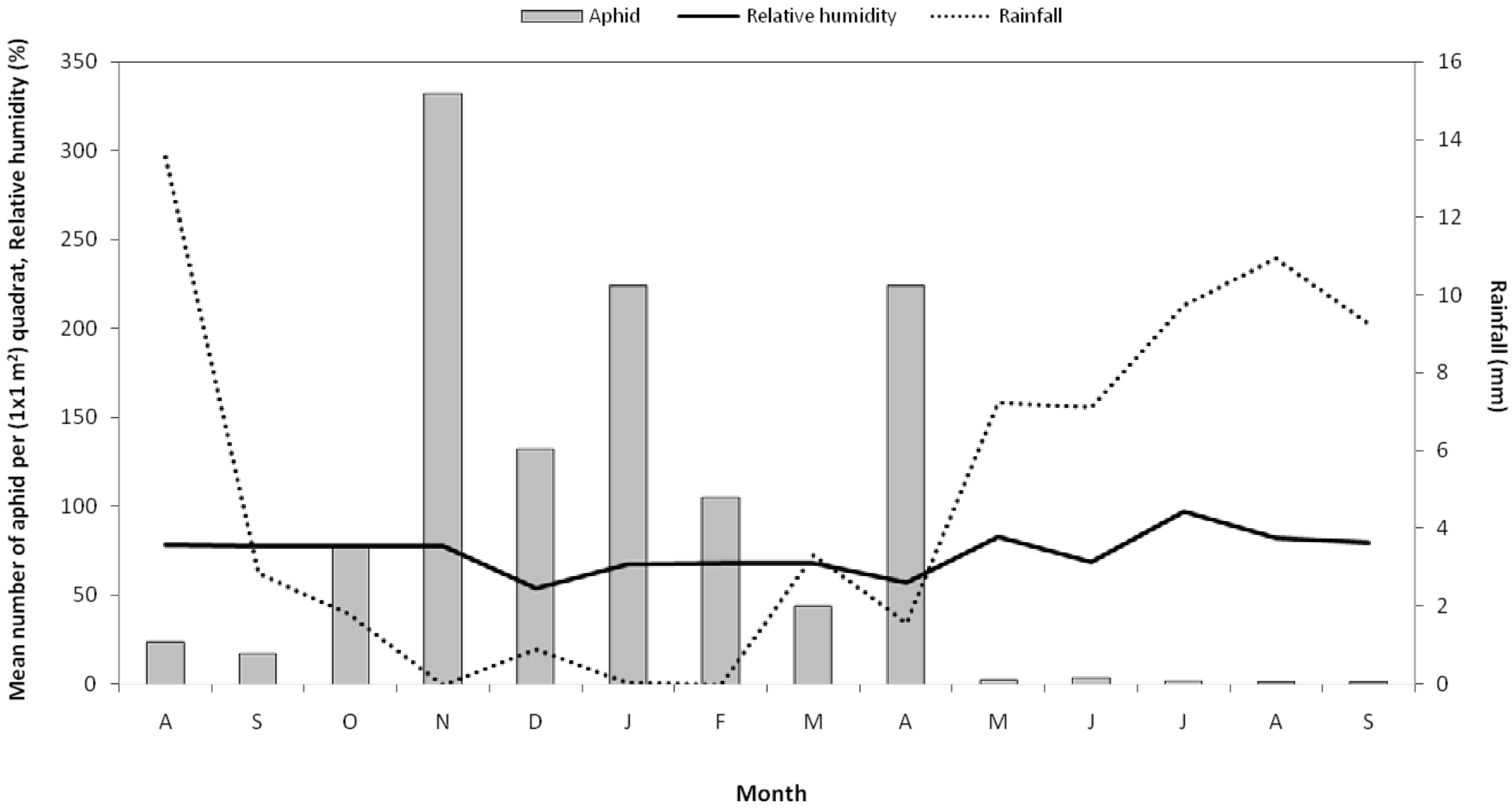



**Figure 3.5** Comparison of environmental factors and aphid abundance on *Chromolaena odorata,* August 2010-September 2011, Wiangsa district, Nan province

**Abundance of tended-ants**

There were 13 ant species associated with the two aphid species on Siam weed sampling during the study period (Table 3.1). All ant species are represented in four subfamilies, Formicinae, Dolichoderinae, Myrmicinae, and Ponerinae. Out of these four subfamilies, Formicinae is the most abundant subfamily having five species, followed by Myrmicinae (six species), Dolichoderinae (one species), and Ponerinae (one species).

**Table 3.1** Diversity and abundance of ants by subfamily, on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

| Ant | Month | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2010 | | | | | | | | | 2011 | | |
| | A | S | O | N | D | J | F | M | A | M | J | J | A | S |
| **Subfamily Formicinae** | | | | | | | | | | | | | | |
| *Anoplolepis gracilipes* | | | | | 20 | 20 | | | | | | | | |
| *Camponotus rufoglaucus* | 1 | | | | 50 | 45 | 30 | 30 | 45 | 55 | 55 | 20 | 20 | 10 |
| *Camponotus* sp. | | | 3 | | | | | | | | | | | |
| *Paratrechina longicornis* | 1 | | | | | | | | | | | | | |
| *Oecophylla smaragdina* | | | 11 | 3 | | | | | 10 | | | | | |
| **Subfamily Dolichoderinae** | | | | | | | | | | | | | | |
| *Tapinoma melanocephalum* | 78 | | | | | | | | | | | | 20 | |
| **Subfamily Myrmicinae** | | | | | | | | | | | | | | |
| *Monomorium destructor* | | 10 | | | 20 | 20 | 50 | 10 | 20 | 20 | 30 | 40 | 5 | 5 |
| *Monomorium* sp. | | | 38 | | | | | | | | | | | |
| *Monomorium pharaonis* | | | | 20 | | | | | | | | | | |
| *Pheidologeton diversus* | | | 50 | | | | | | | | | | | |
| *Crematogaster rogenhoferi* | | 20 | | | | 10 | | | | | | | | |
| *Crematogaster* sp. | | | | 11 | | | | | | | | | | |
| **Subfamily Ponerinae** | | | | | | | | | | | | | | |
| *Odontoponera denticulata* | 1 | | | | | | | | | | | | | |

*Camponotus rufoglaucus* was the most abundant ants observed on Siam weed in this study (Appendix B, Table 1-B), the percentage of relative abundance was 39.80. Consequently, the strong significant positive association between the ant abundance found per quadrat and *Camponotus rufoglaucus* population was shown (Spearman's rank correlation, r= 0.444, P<0.01), followed by *Monomorium destructor* population (Spearman's rank correlation, r= 0.349, P=0.001) and *Tapinoma melanocephalum* population (Spearman's rank correlation, r= 0.219, =0.045).

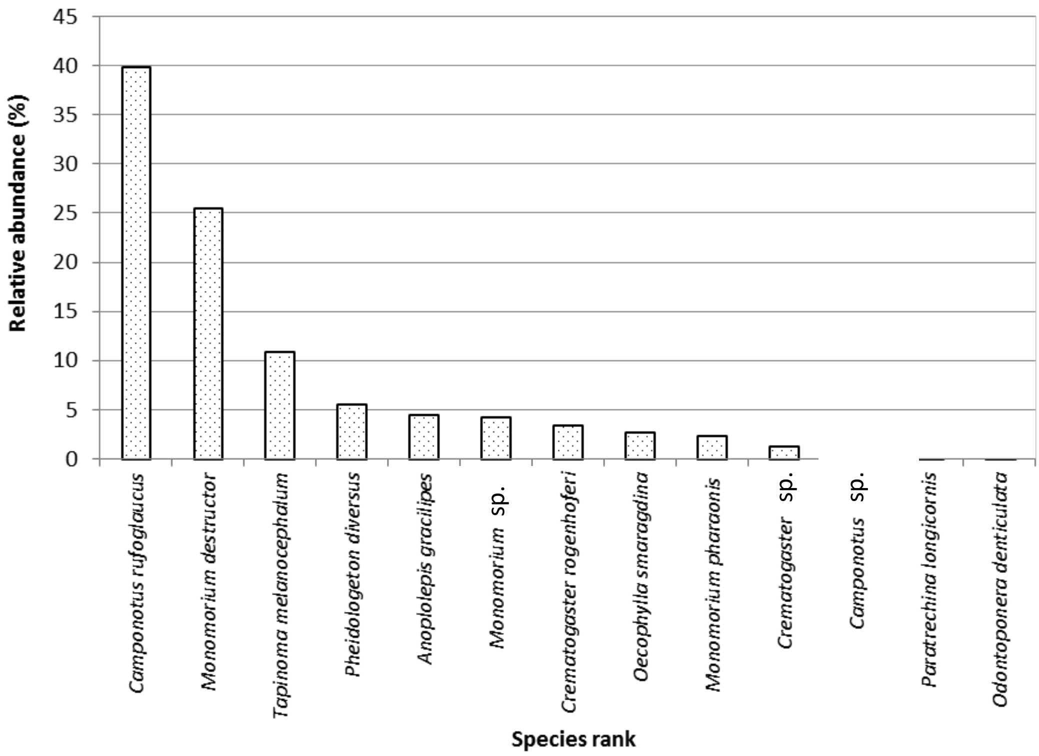



**Figure 3.6** The relative abundance of ants on *Chromolaena odorata* as species rank, August 2010-September 2011, Wiangsa district, Nan province

The total mean number of ants in one square meter quadrat was 10.80 individuals, shown in Figure 3.7. The greatest abundance of ants was on October 2010, which was the early time of dry season and also the early growing season of cabbage.

The mean rank of ants in dry and wet season was 8.08 and 7.06, respectively. Consequently, there was no significant difference of ant abundance between wet and dry season (*Mann-Whitney U*-test, U=20.5, $p$=0.651).

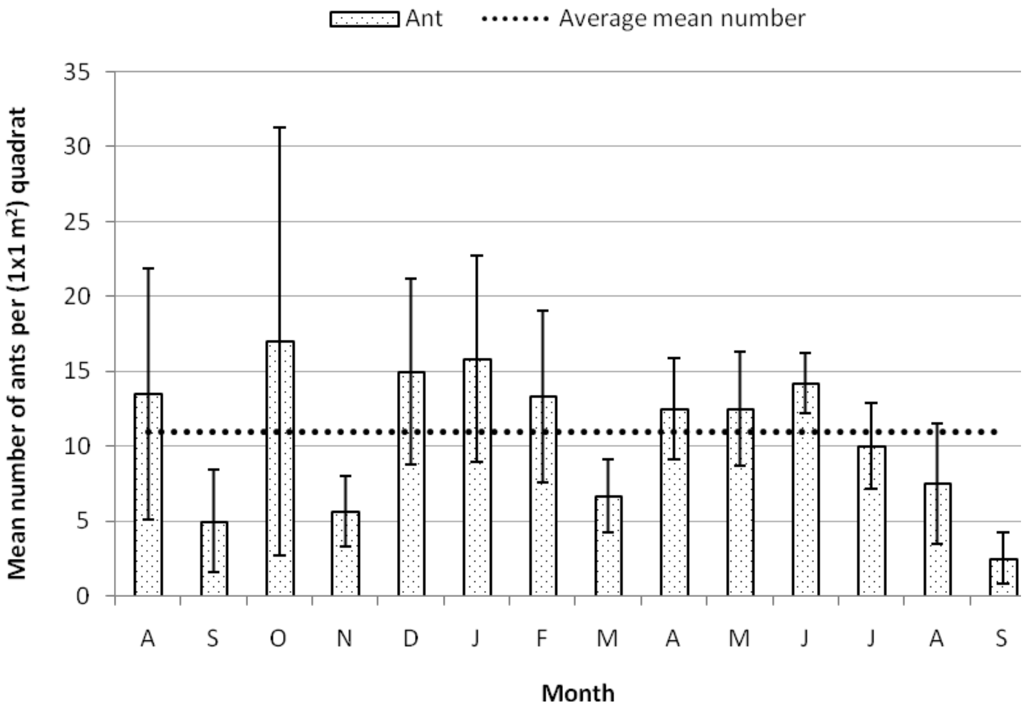



**Figure 3.7** Mean number of ants per one square meter quadrat on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province.

However, *Camponotus* sp., *Monomorium* sp., *Tapinoma melanocephalum*, *Odontoponera denticulata*, *Paratrechina longicornis*, and *Pheidologeton diversus,* were only six ant species found in wet season. While the abundance of three ant species; *Crematogaster* sp.*, Monomorium pharaonis* and *Anoplolepis gracilipes* were only found in dry season (Figure 3.8).

The results were consistent with the correlation analysis, which show the corresponding between ant number and two environmental factors. There was significant positive association between the mean number of *Tapinoma melanocephalum* and the amount of rainfall (Spearman's rank correlation, r= 0.347, *p=0.001*), while *Monomorium destructor* negatively associated with rainfall (Spearman's rank correlation, r= -0.233, *p=0.33*). Moreover, there was a significant negative association between the mean number of *Anoplolepis gracilipes* and mean relative humidity (Spearman's rank correlation, r= -0.226, *p*=0.039)

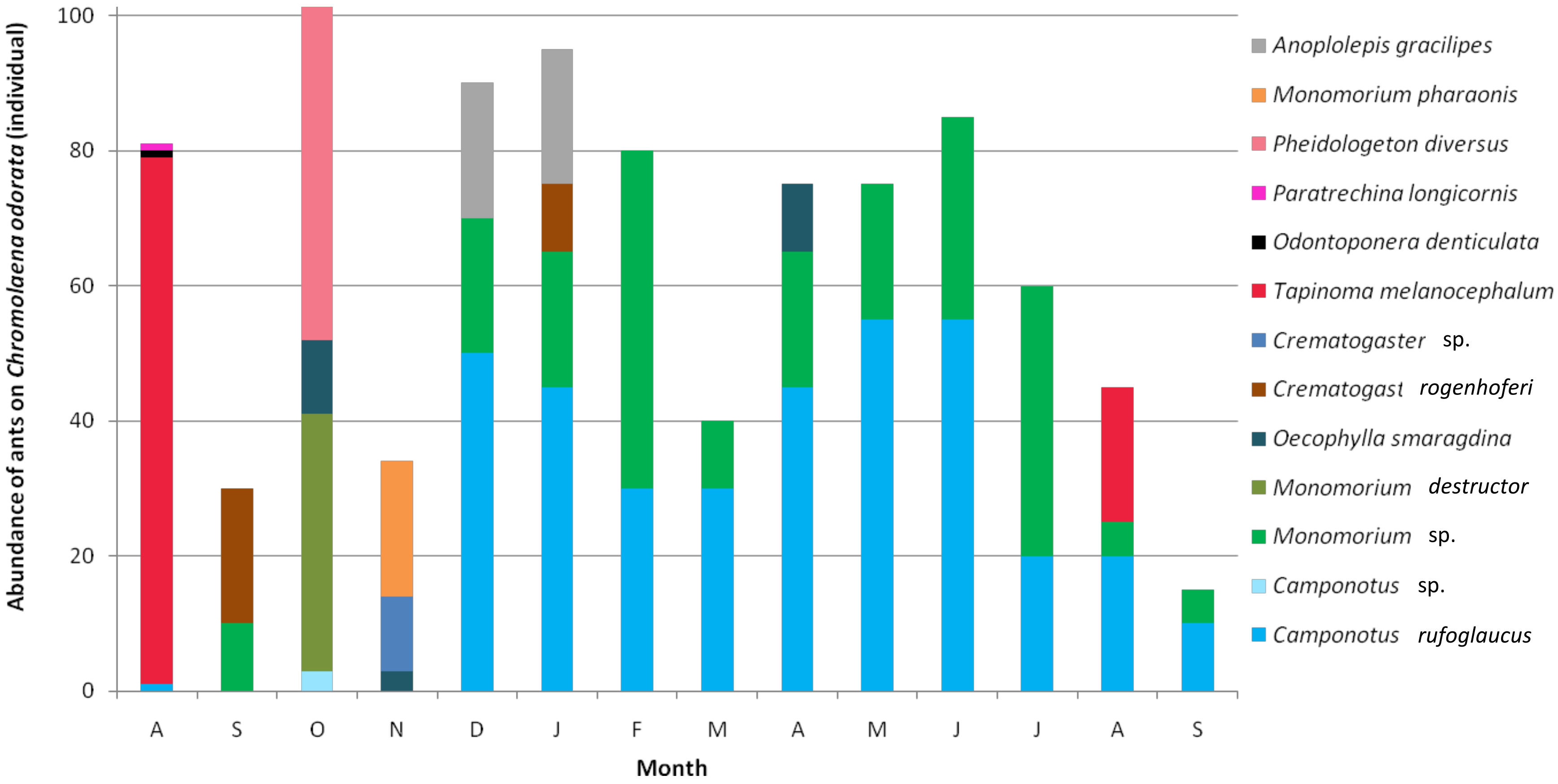



**Figure 3.8** Abundance compositions of ants on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

Moreover, there was a significant negative association between the mean number of *Anoplolepis gracilipes* and mean relative humidity (Spearman's rank correlation, r= -0.226, *p*=0.039)

Furthermore, the correlation analysis also shows the significant negative relationship between the mean number of *Camponotus rufoglaucus* and *Monomorium destructor* (Spearman's rank correlation, r= -0.217, *p*=0.048). Consequently, the population of *Camponutus rufoglaucus* can be accounted for the *Monomorium destructor* population.

There are no significant associations between mean total of aphids and mean total of ants per quadrat. Therefore the aphid abundance on Siam weed in study site was not influenced by the local ant abundance (Figure 3.9).

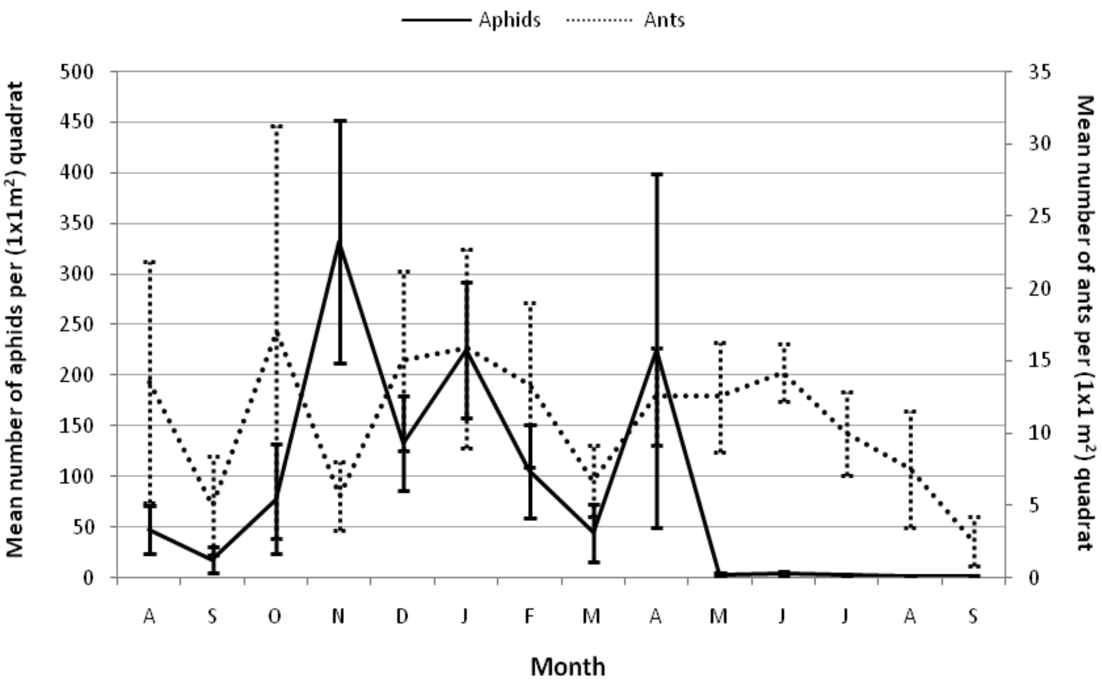



**Figure 3.9** Comparison of the total mean of aphid and ants on*Chromolaena odorata* August 2010-September 2011, Wiangsa district, Nan province

Three ant species, *Oecophylla smaragdina*, C*rematogaster rogenhoferi*, and *Monomorium pharaonis*, correlated with the abundance of aphid species (Figure 3.10). The abundance of *A. gossypii* was positive correlated with *Oecophylla smaragdina* (Spearman's rank correlation, r= 0.234, *p*=0.032), and positively correlated with *Monomorium pharaonis* (Spearman's rank correlation, r= 0.262, *p*=0.016). Whereas, *Crematogaster* sp. was positively correlated with the abundance of *A. spiraecola* (Spearman's rank correlation, r= 0.350, *p*=0.001) (Figure 3.11).

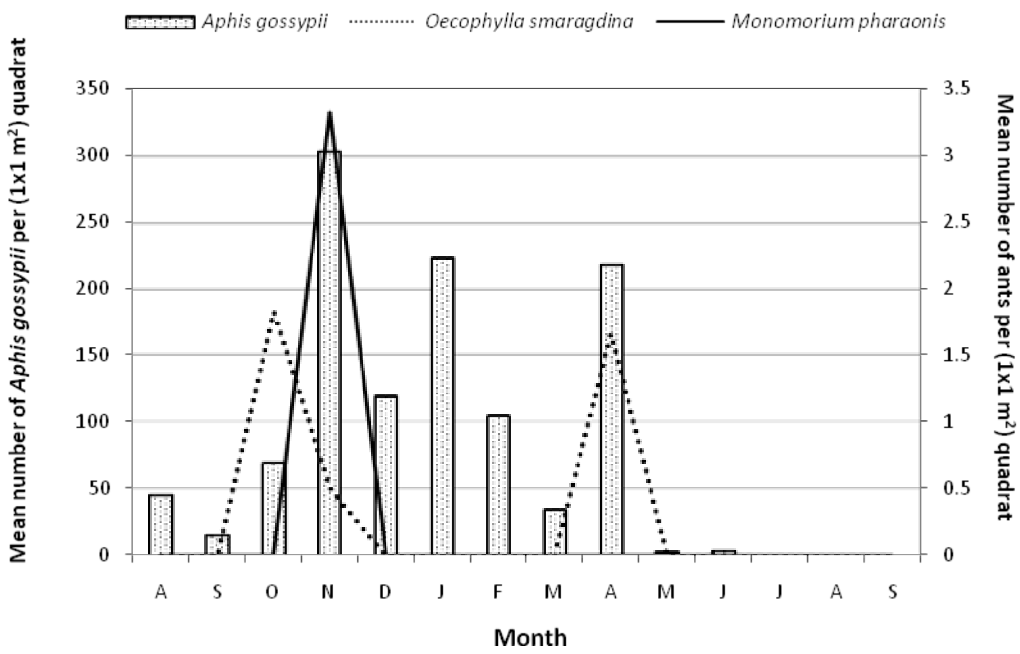



**Figure 3.10** Comparison of mean number of *Aphis gossypii* and positive correlated ants, on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

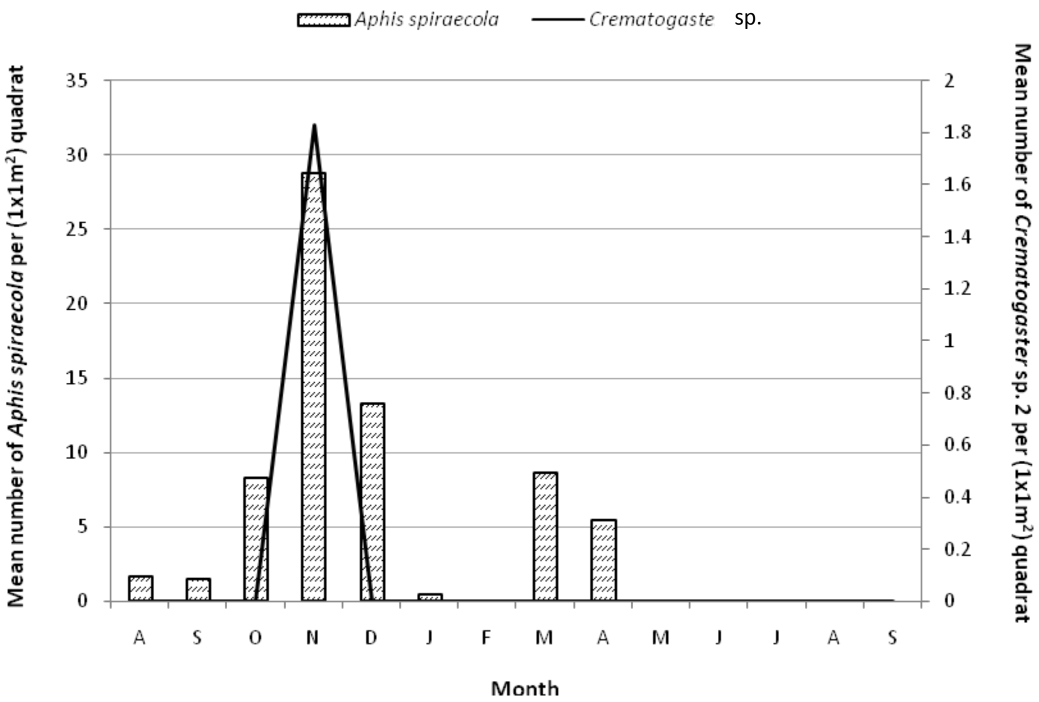



**Figure 3.11** Comparison of mean number of *Aphis spiraecola* and ant, on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

The abundance of *A.gossypii* was positive correlated with *Oecophylla smaragdina* (Spearman's rank correlation, r= 0.234, *p*=0.032), and positively correlated with *Monomorium pharaonis* (Spearman's rank correlation, r= 0.262, *p*=0.016). Whereas, *Crematogaster* sp. was positively correlated with the abundance of *A. spiraecola* (Spearman's rank correlation, r= 0.350, *p*=0.001) (Figure 3.11).

**Other arthropods abundance**

There are mainly four groups of other arthropods found on Siam weed, which were spiders, lady beetles and grasshoppers (Figure 3.12). Spiders were the most abundant arthropods found on Siam weed per one square meter quadrat, followed by lady beetles and grasshoppers. The total mean number of all arthropods was 1.5 individuals $m^{-2}$ while total mean number of aphids was 85.23 individuals

$m^{-2}$. It indicates that 1.5 individuals of predator could control 85.23 individuals of aphid.

There was statistically significant greater mean abundance of arthropods in dry season than in wet season (*Mann-Whitney U*-test, U=8.5, *p=0.045*) (Figure 3.12), the average rank of dry and wet season were 10.08 and 5.56, respectively. Similarly, the mean number of lady beetles was significantly higher in dry season (mean rank=10.33) than wet season (mean rank=5.38) (*Mann-Whitney U*-test, U=7.000, *p=0.026*). However, there was no significantly difference found on mean number of spiders and grasshoppers between dry and wet season.

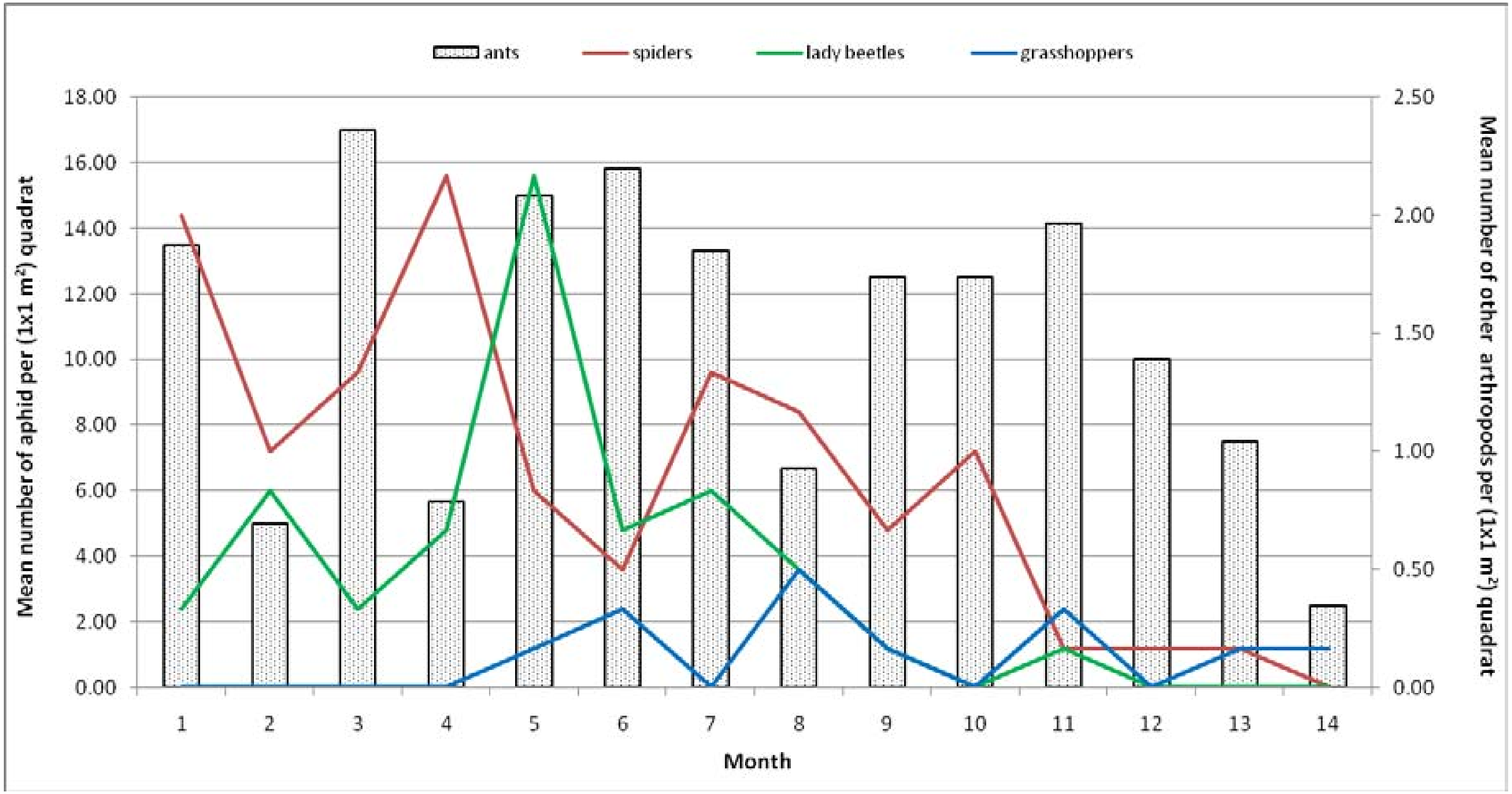



**Figure 3.12** Comparison of mean number of ants and other arthropods, on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

From the correlation analysis, all relationships between mean arthropods and environmental factors were negative association. A statistically significant weak association between the total mean number of other arthropods and relative humidity was found (Spearman's rank correlation, r= -0.259, *P*=0.018) and also associated with the rainfall amount (Spearman's rank correlation, r= -0.322, *P*=0.003) (Figure 3.13, 3.14).

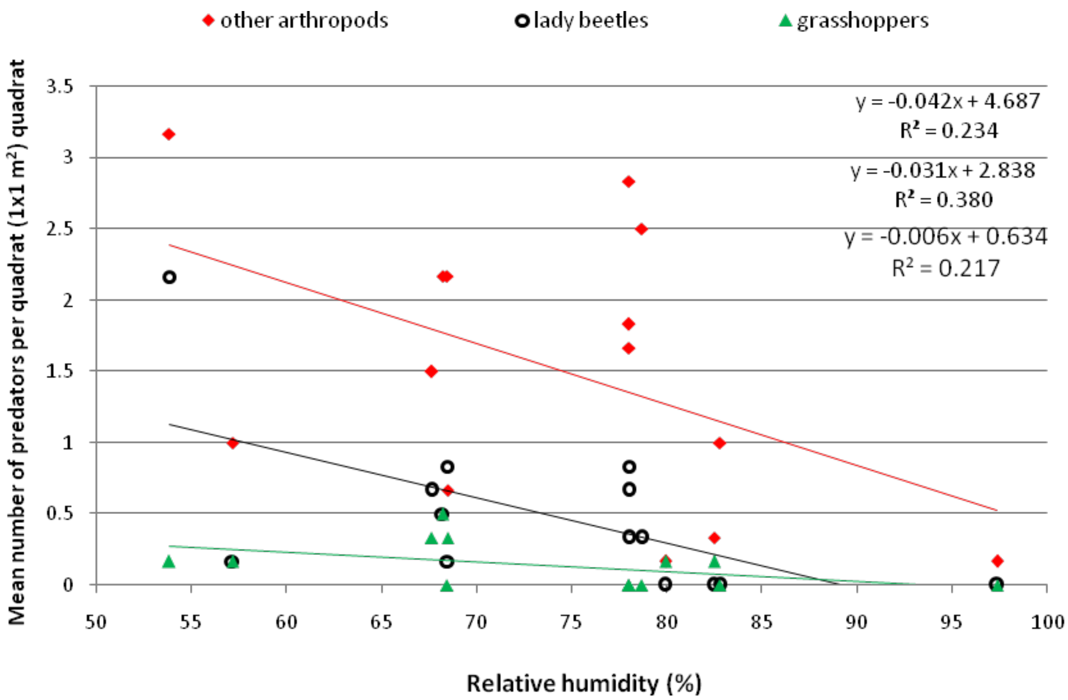



**Figure 3.13** Comparison of mean number of other arthropods, lady beetles and grasshoppers and relative humidity (%) on *Chromolaena dorata*, August 2010-September 2011, Wiangsa district, Nan province

Similarly, the abundance of lady beetles was significant negative associated with relative humidity (Spearman's rank correlation, r= -0.325, *P*=0.003), and also the rainfall amount (Spearman's rank correlation, r= -0.330, *P*=0.002) (Figure 3.13, 3.14). In addition, there was a significant negative association between grasshoppers and relative humidity (Spearman's rank correlation, r= -0.291, *P*=0.007) (Figure 3.13).

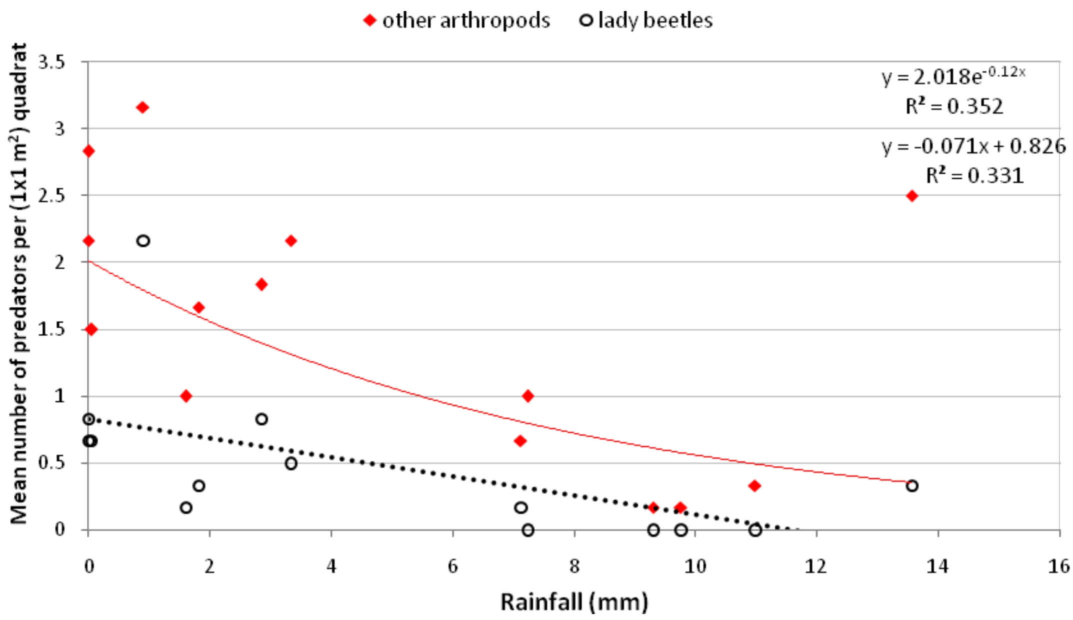



**Figure 3.14** Comparison of mean number of other arthropods and lady beetles and rainfall (mm) on *Chromolaenaodorata*, August 2010-September 2011, Wiangsa district, Nan province

**The relationship between aphids and other arthropod abundance**

The association between abundance of aphids and other arthropods were entirely positive. There was a weak positive association between total mean number of aphids and other arthropods (Figure 3.15, Figure 3.17) (Spearman's rank correlation, r= 0.394, $P$=0.000). A significant positive association was found between the abundance of both spiders and lady beetles and also abundance of *Aphis gossypii* (Spearman's rank correlation, r= 0.388, $P \leq 0.05$; r= 0.275, $P$=0.011), respectively.

**The relationship between ants and other arthropods abundance**

The correlation analysis on total mean number of other arthropods showed no statistically discernible relationship to total mean number of ants (Figure 3.16, Figure 3.17). However, there was the weak positive relationship between three ant species and other arthropods. There was a weak positive association between the abundance of spiders and *Tapinoma melanocephalum* (Spearman's rank correlation, r= 0.219, *P*=0.046). Grasshoppers were significantly associated with *Camponotus rufoglaucu*s and *Anoplolepis gracilipes* (Spearman's rank correlation, r= 0.249, *P*=0.023; r=0.402, *P*=0.00014), respectively. Additionally, there was a significant relationship between *Anoplolepis gracilipes* and lady beetles (Spearman's rank correlation, r= 0.267, *P*=0.014).

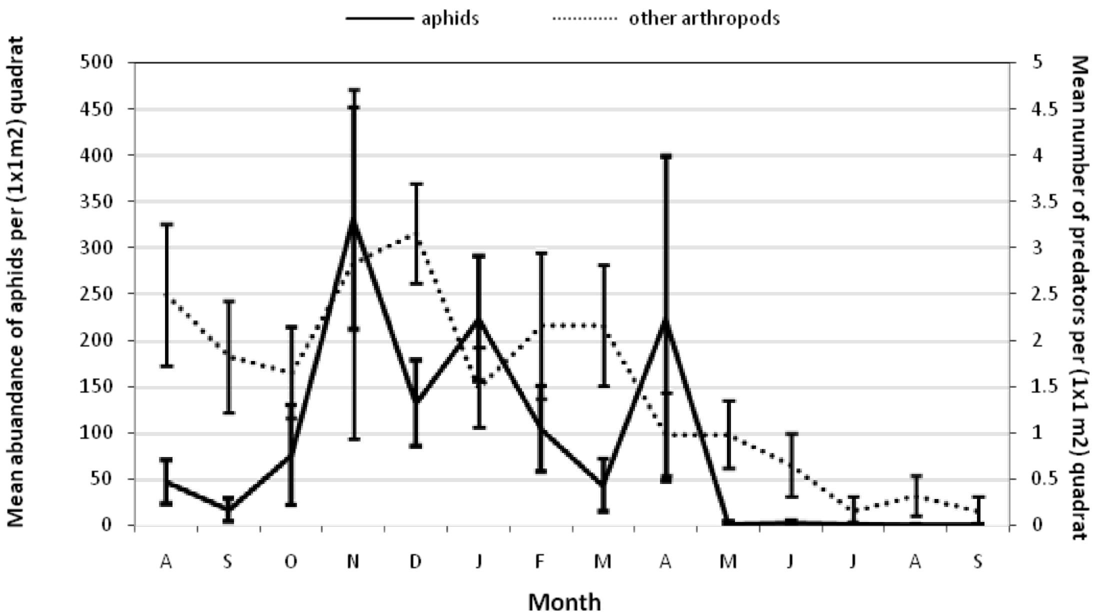



**Figure 3.15** Comparison of mean number of aphids and other arthropods on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

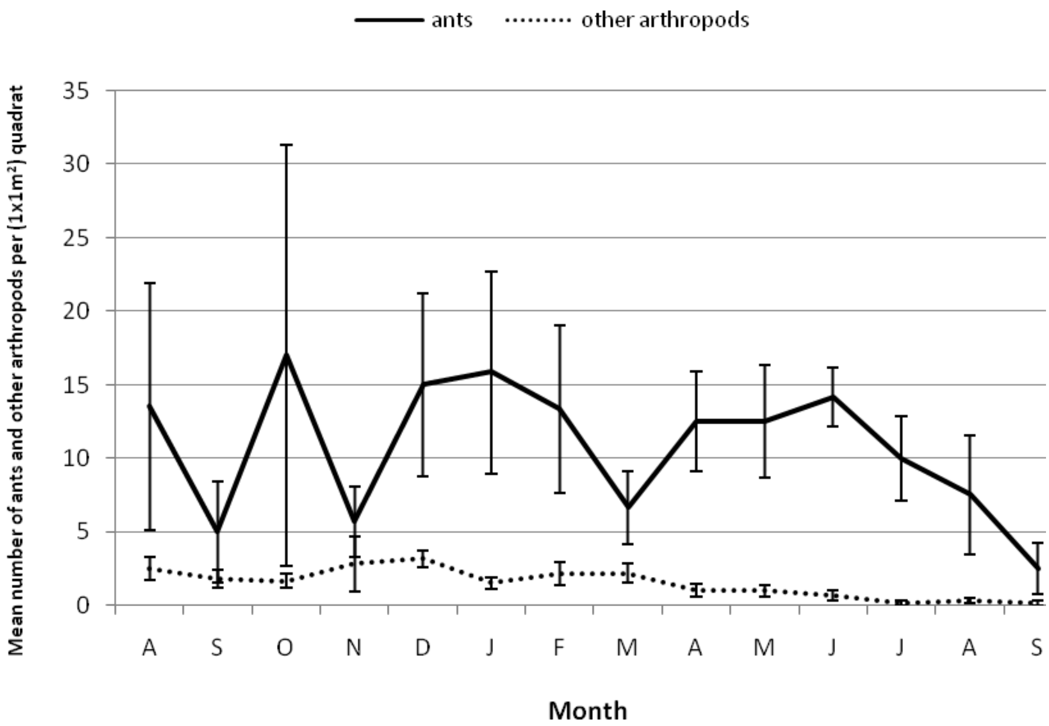



**Figure 3.16** Comparison of mean number of ants and other arthropods on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

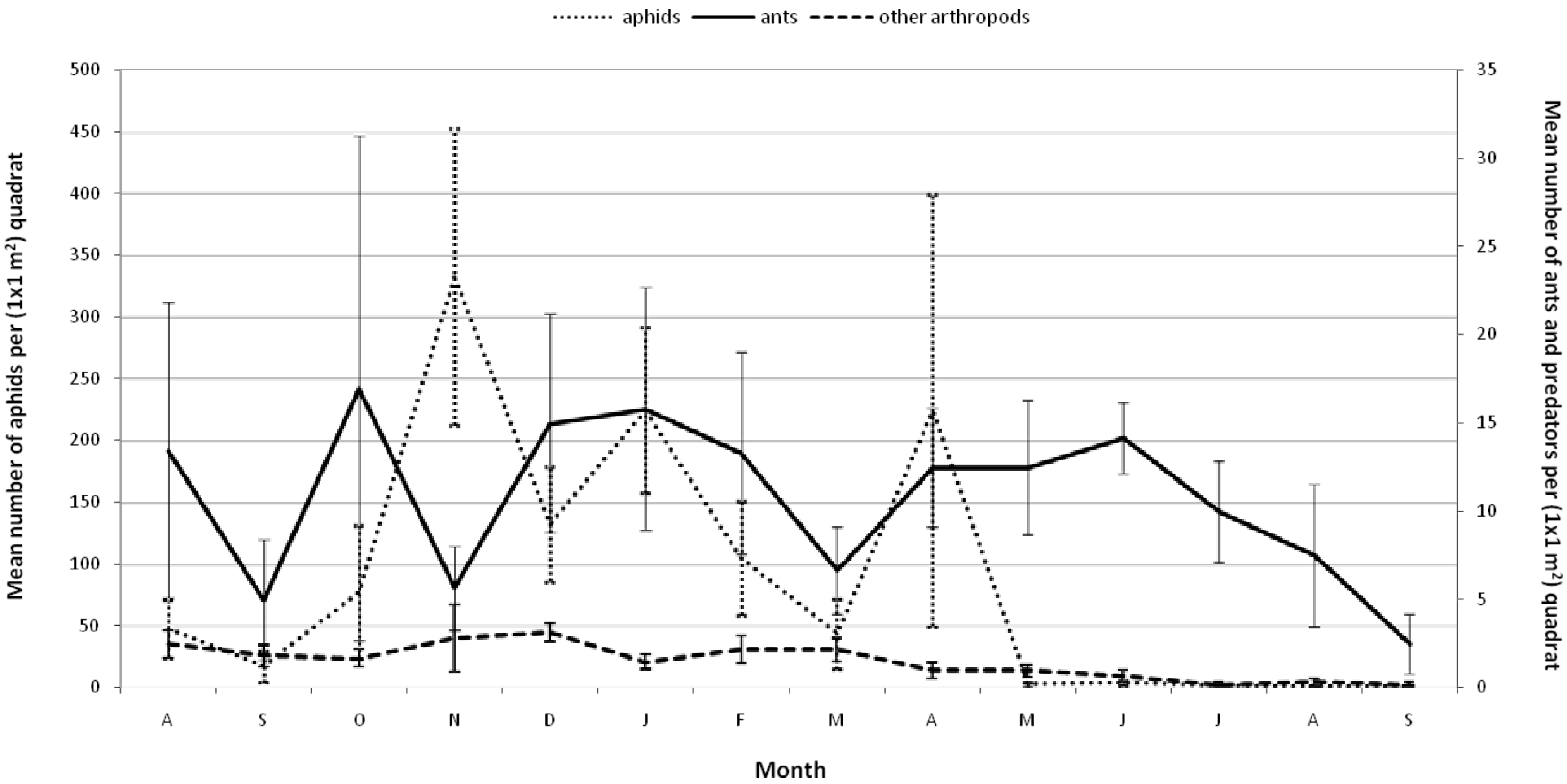



**Figure 3.17** Comparison of mean number of aphids, ants and other arthropods on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

### 3.3.2 Diversity and abundance of aphid and other arthropods on cabbage

**Aphid abundance**

*Aphis gossypii* was the only aphid species caught on sticky trap sampling in both growing sites of cabbage. The mean number of *A.gossypii* in cultivating site 1 was slightly higher than site 2 and the mean number of *A. gossypii* of both sites was also showed in Figure 3.18.

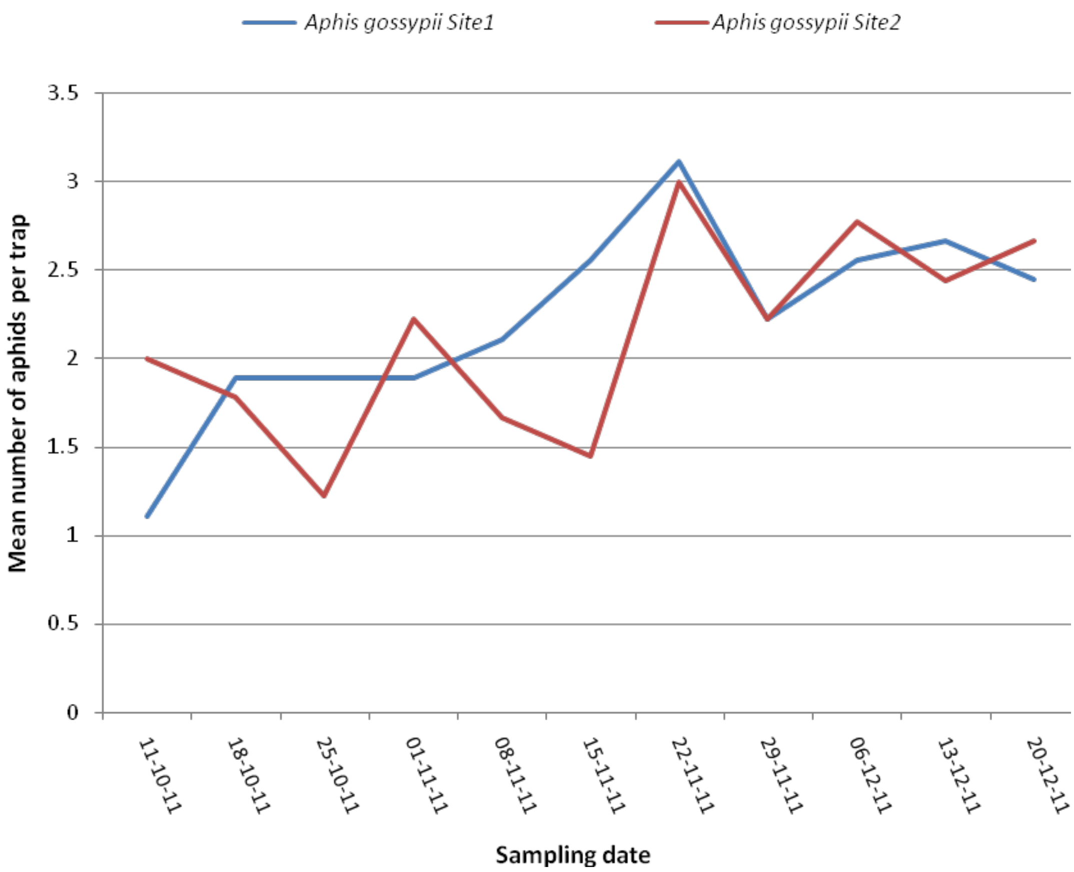



**Figure 3.18** Comparison of abundance of *Aphis gossypii* per trap between two cabbage cultivating sites, October-December 2011, Wiangsa district, Nan province

The abundance of A. *gossypii* on sticky trap sampling from cabbage cultivating site 1 show a significant negative association with the mean air temperature (Spearman's rank correlation, r= -0.202, p=0.045) (Figure 3.19).

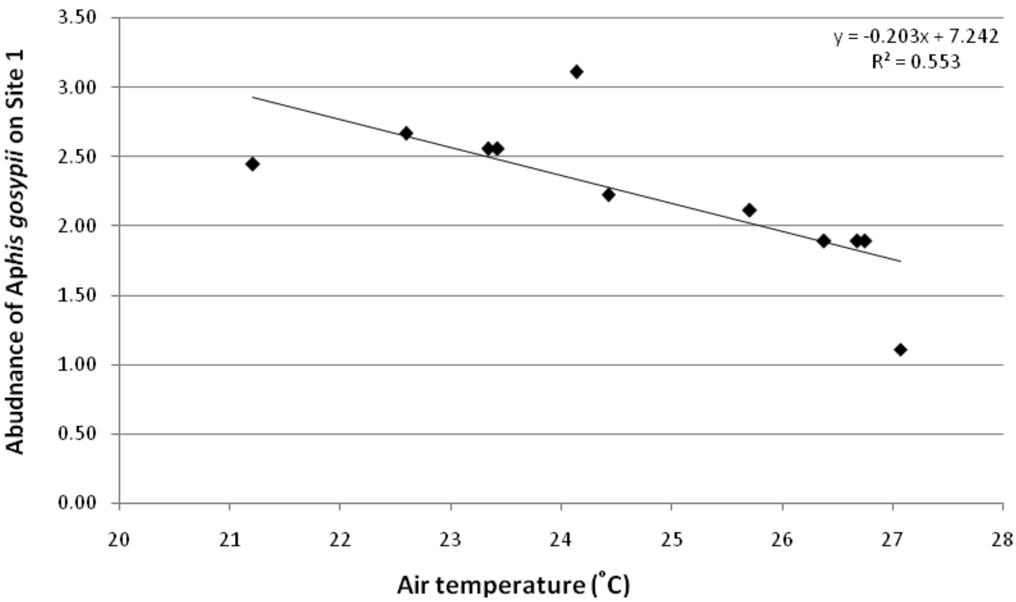



**Figure 3.19** Comparison of abundance of *Aphis gossypii* per trap on cabbage cultivating site 1 and mean air temperature (°C), October-December 2011, Wiangsa district, Nan province

**Ant abundance**

*Camponotus rufoglaucu*s and *Odontoponera denticulata* were the only two ant species found in both cabbage cultivating sites. The number of *O. denticulata* was mostly greater than *Camponotus rufoglaucu*s in both sites throughout growing season (Figure 3.18, Appendix B, Figure 1-B, Figure 2-B). There were significant positive association between the number of *Camponotus rufoglaucu*s on site 1 and the mean of air temperature and relative humidity (Spearman's rank correlation, r=0.597, p=0.000; r=0.454, p=0.000) (Figure 3.20, 3.21).

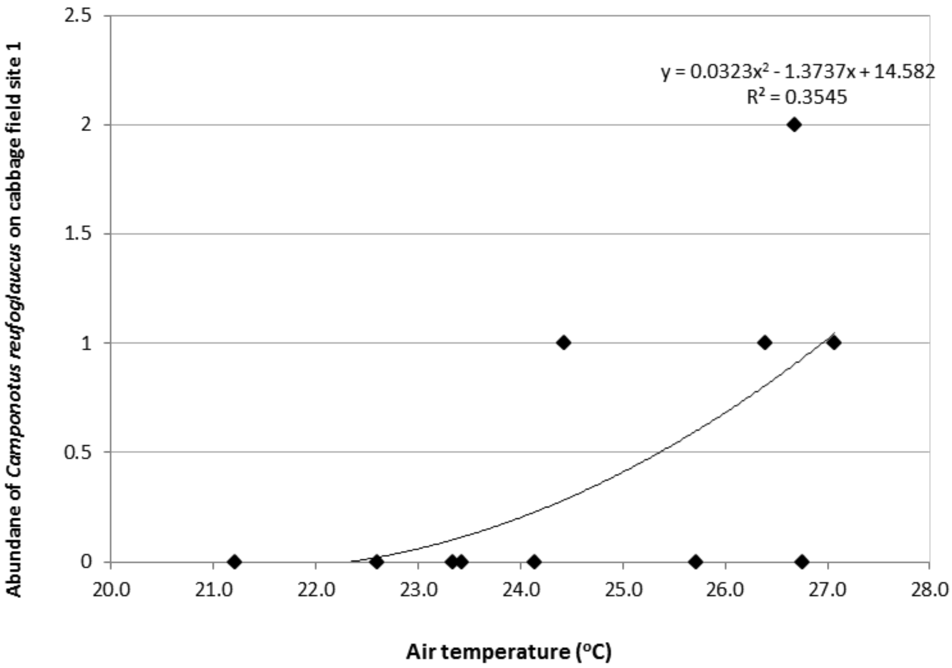



**Figure 3.20** Comparison of mean number of *Camponotus rufoglaucus* caught per sampling time on cabbage cultivating sites 1 and mean air temperature ($^{o}$C), October-December 2011, Wiangsa district, Nan province

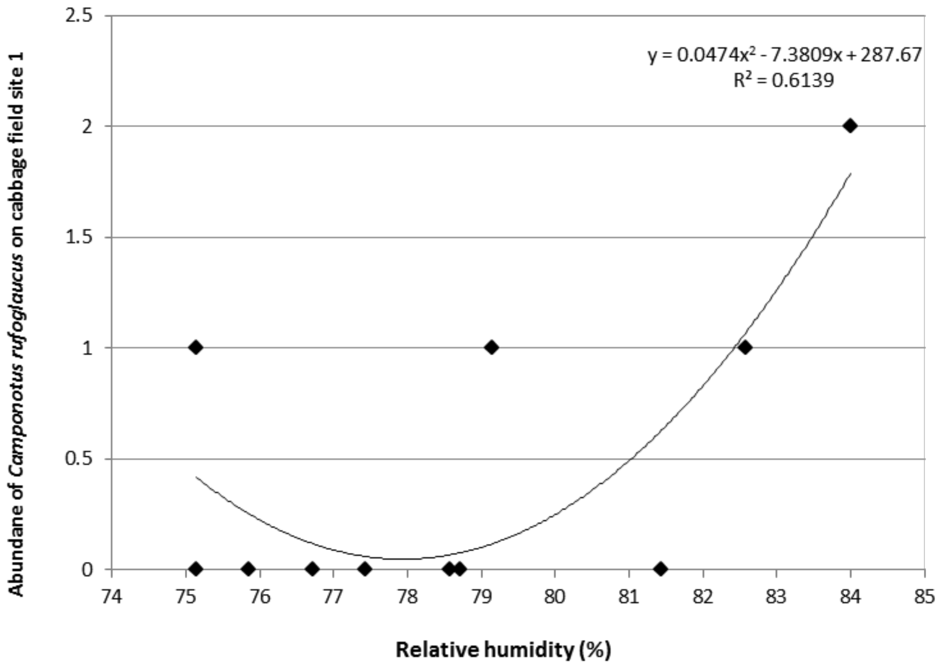



**Figure 3.21** Comparison of mean number of *Camponotus rufoglaucus* caught per sampling time on cabbage cultivating site 1 and mean relative humidity (%), October-December 2011, Wiangsa district, Nan province

Additionally, there was a significant positive weak association between the number of *O. denticulata* on site 2 and the mean of air temperature (Spearman's rank correlation, r=0.260, p=0.009) (Figure 3.22).

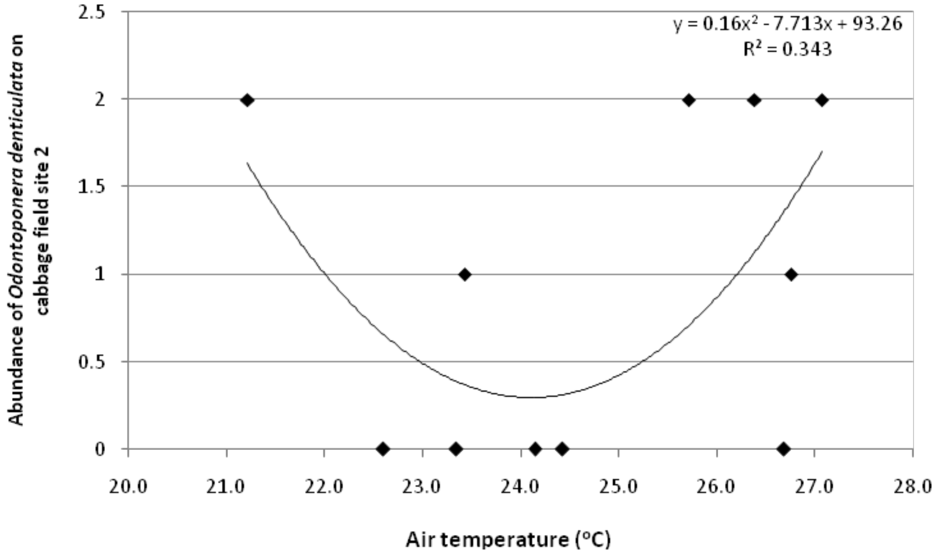



**Figure 3.22** Environmental factors, October-December 2011, Wiangsa district, Nan province

The environmental factors between October and December 2011, Wiangsa district, Nan province were shown on Figure 3.23.

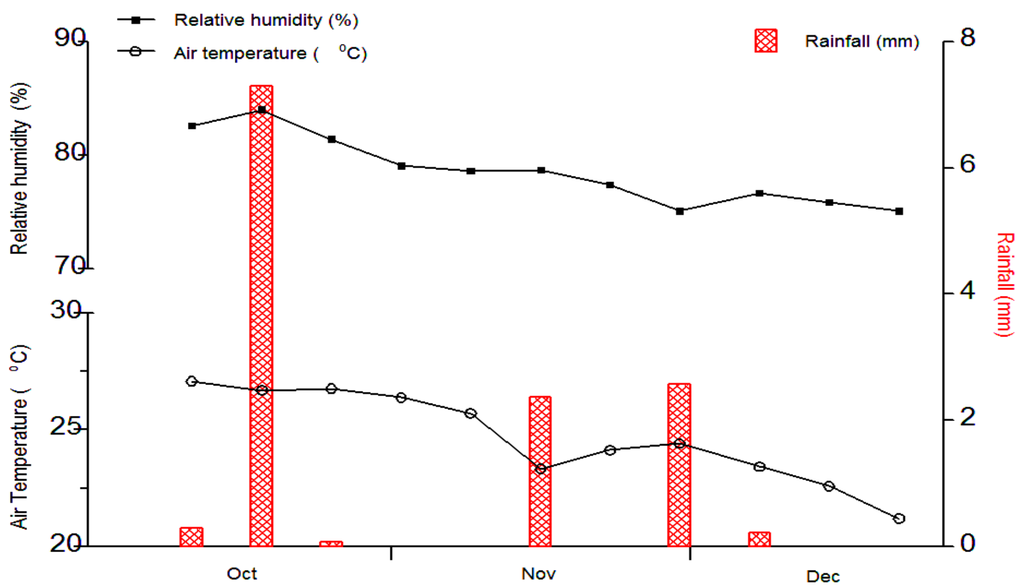



**Figure 3.23** Comparison of environmental factors on two cabbage cultivating sites, October-December 2011, Wiangsa district, Nan province

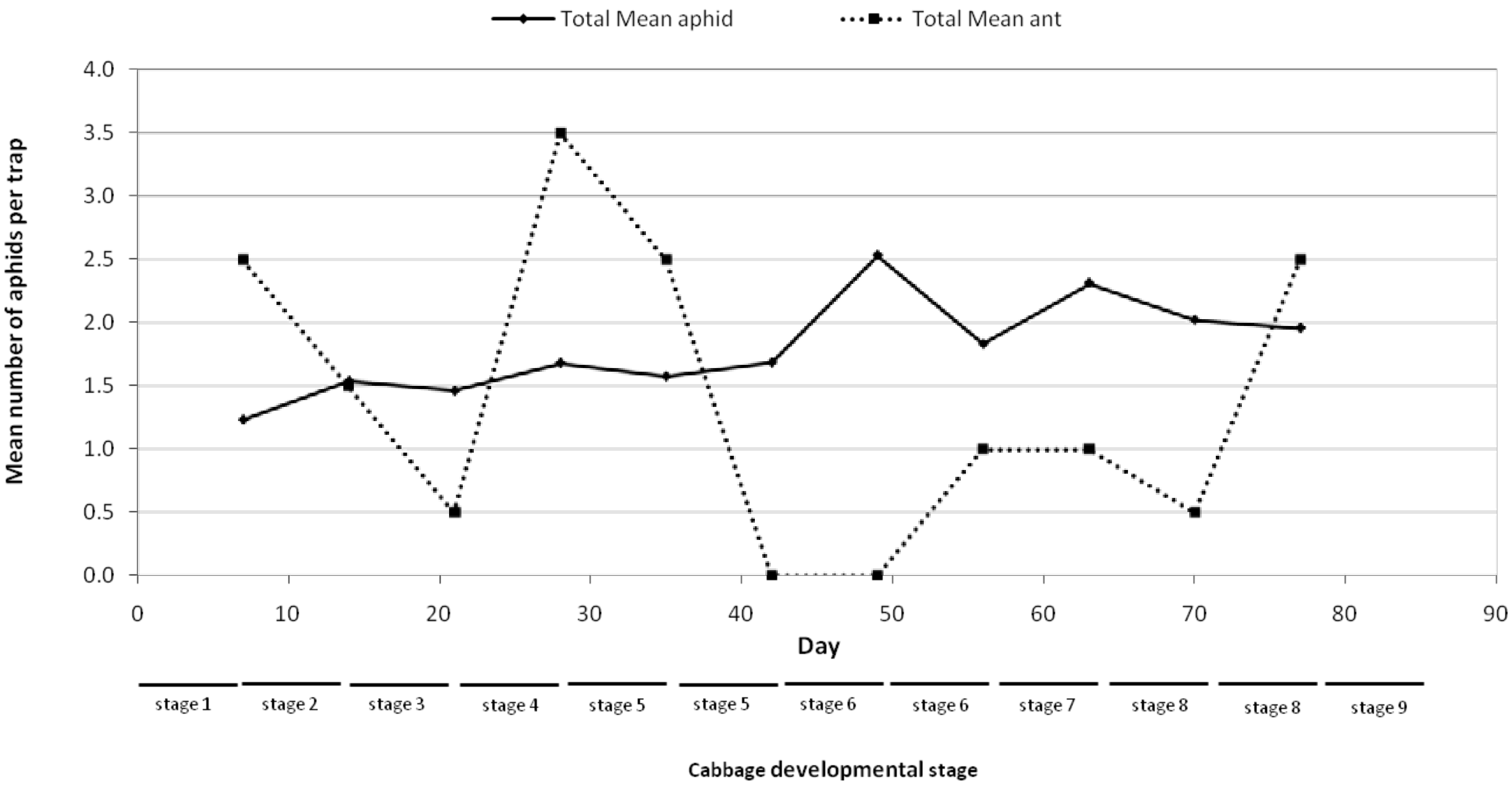



**Figure 3.24** Comparison of abundance of mean aphid and ants and developmental time of cabbage, October-December 2011, Wiangsa district, Nan province

The aphid abundance on sticky trap sampling of both cultivating sites showed the increasingly trend along the cabbage growing time. The greatest number of aphids was on 22nd November in the sixth stage (49th day) of cabbage developmental time. Contrary to the aphid abundance, there was no ant found on the peak of aphid abundance, 22nd November in both cabbage cultivating sites (Figure 3.24).

## 3.4 Discussion

### 3.4.1 Diversity and abundance of aphids and other arthropods on Siam weed

#### Aphid abundance

In Thailand both *Aphis gossypii* and *Aphis spiraecola* have been reported to be commonly found on Siam weed (Napompeth and Winotai, 1991), which also resemble to other reports. Both species were found on ornamental plants, weeds, and crops (Idechiil et al., 2007; Oigicangbe et al., 2007). The total aphid abundance found in this study, which was 86.93 individuals $m^{-2}$, was similar to the study from Hall et al. (1972) who reported the abundance of aphid on Siam weed to vary greatly from 16 aphid $m^{-2}$, during low infestation to over 150 aphid $m^{-2}$ during critical infestation.

The most common aphid species encountered in this study, *A. gossypii,* are polyphagous damaging nearly a hundred crop plants such as cotton, cucurbits, coffee, cabbage, peppers, and many ornamental plants (Van Emden and Harrington, 2007). Consequently, the greater abundance of *A. gossypii* may due to their wide range of host plant resulting in greater population. While *A. spiraecola* was also reported as a common species but they were found to have limited host plant range particularly in shrubby habitat such as citrus (Van Emden and Harrington, 2007). Moreover, the process of host plant selection by aphid was basically due to visual and olfactory responses mechanism (Schoonhoven, Van Loon, and Dicke, 2005; Van Emden and Harrington, 2007). Obviously, aphids were found to land significantly more frequently on yellow color-plants and releasing volatile-plant than in non-volatile plant. Furthermore they responses to volatiles in each host plant differently (Schoonhoven et al., 2005; Van Emden and Harrington, 2007). This may indicate that reflectance intensity and volatiles which were from Siam weed may attract *A. gossypii* more than *A. spiraecola* (Van Emden and Harrington, 2007). Additionally, the greater abundance of *A. gossypii* throughout the study period showed a distinct ability of Siam weed to harbor for *A. gossypii* better than *A. spiraecola.* In other words, *A. gossypii* was able to exploit from Siam weed better than A. *spiraecola.* The consistency aphid population observed throughout the year also showed the high efficiency of Siam weed as annual aphid reservoir plant.

In tropical zone as Thailand, *A. gossypii* reproduces continuously by parthenogenesis (Dixon, 1977). Consequently, their populations were abundant all year and consistently distributed to new host plants. There were reports on a sexual phase of *A. spiraecola* on *Spiraea* (family Rosacea) (Van Emden and Harrington, 2007), this resulted in less offspring-produced duration. Additionally, *A. gossypii* was reported by Muller et al (2001) which was typically unreacted to host plant quality. Although they exploited on deteriorating host-plant conditions, *A. gossypii* generally did not disperse to a new host plant (Van Emden and Harrington, 2007). Consequently, it is possible to observe *A. gossypii* on Siam weed more frequently than *A. spiraecola.*

The greater number of *A. gossypii* was observed during dry season which was commonly cultivating season of several crops in Nan province. In dry season, there was low temperature optimizing to cultivate seasonal crops particularly family Brassicaceae including mustard green, cabbage, Chinese kale, Chinese cabbage, and broccoli. The economic crops cultivated in Wiangsa district typically correspond to the local climate. Since *A. gossypii* was a common pest in Brassicaceae, there was high probability to find high aphid abundant during this cultivating season of Brassica host plants. Mostly aphid populations are negatively influenced by amount of rainfall (Ali and Gebremedhin, 1990), resembling to the negative relationship between *A. gossypii* abundance and rainfall which observed in this study. Sanchez et al (2000) also reported the same association between *A. spiraecola* and rainfall.

However, after the wet season particularly at the early point of dry season, the aphid populations were sharply increased (Perez and Robert, 1984) as observed in this study on November 2010. This is resembles to the reports which detected the delay in abundance of *A. gossypii* and *A. spiraecola* in 2-3 weeks after rainfall period (Mcdonald et al., 2003; Sanchez et al., 2000). This showed the positive association between aphid abundance and rainfall amount which was contrast to this study result.

During wet season, there was the lower abundance of both aphid species particularly *A. gossypii.* The heavy and consistent rain in wet season resulted in knocking the aphid off the plants leading to death, hardly un-established on host plants, inhibit aphid flight (Rohitha and Penman, 1986) and delay the first feeding arrival date of aphids (Van Emden and Harrington, 2007). Furthermore, from the onset of the wet season, farmers started preparing to cultivate seasonal rice and other seasonal crops, which there was less host plant for *A. goysspii*.

According to their efficacy of producing offspring and widely distributing on many host plants, both aphid species are great exploiting pests and great virus transmitters. Thus, it implied that the large damaging from aphid outbreak could occur at any time, depending on the suitable environmental factors as well as the lag time of being untreated by insecticides or predators.

**Ant abundance and relationship with aphids**

There were 13 ant species associated with *A. gossypii* and *A. spiraecola* on Siam weed. The results agree with the result previously reported by Idechiil et al. (2007) who examined the relationship between *A. gossypii* and 14 ant species on Siam weed in Republic of Palau. Six of those were found in this study which were *Anoplolepis gracilipes*, *Camponotus rufoglaucus*, *Monomorium destructor*, *Paratrechina longicornis*, *Pheidole* sp., and *Tapinoma melanocephalum*. An observation presented the plasticity of tending ability by any ant species, showing the specific association between aphid and these ant species.

Although there was no significant association between the mean abundance of aphids and of ants, the specific association between three ant species and aphids were shown, implying that only *Oecophylla smaragdina*, *Monomorium pharaonis*, and C*rematogaster* sp. which could influence aphid population by tended-relationship. There are some aphid species which evolve their excreted-honeydew quality attracting to specific ant attendance (Volkl et al., 1998). This co-evolution determined the different attendance hierarchies in relationship between aphid and ant species. This indicate that those three ants have more suitable specific developed adaptation for exploiting honeydew from *A. gossypii* than other ant species found in this study. Moreover, the tending-ants declined when aphid density on colony increased (Breton, 1992). Consequently the correlation between aphid and ant were not apparent consistently. In addition, predator abundance could determine the level of relation between aphid and ant. When spiders and lady beetles are present as natural enemies in the environment, then tended ants may have little effect on aphid abundance (Billick et al, 2007). Aphid abundance were affected simultaneously positively ants and negatively from predator while the obvious correlation between aphid and ant abundance were hardly observed.

The positively correlated relationship between abundance of *Monomorium destructor* and *A. gossypii* allow *A. gossypii* to produce more offspring and resulting in larger aphid colonies (Way, 1963) or maybe limited their growth rate which resulting in negative effect (Fischer and Shingleton, 2001; Yao et al, 2000). Moreover, tending ants also influenced aphid to colonize a wider area than in the absence of tending ants. Although there were many reports in relationship between *A. gossypii* and any ant species, *A. goss*y*pii* is not always dependent obligatorily on the attending ants.

The dominant abundance of *Camponotus rufoglaucus* on Siam weed might be due to the ant preference to feed on honeydew. The main food source of *Camponotus rufoglaucus* is commonly honeydew of aphids tended on adjacent vegetation (Alsina, 1988). In agreement to Delfino and Buffa (1996) which reported *Camponotus rufoglaucus* as an ant genus associated with the highest number of aphid species even when aphid attended by other ant species. This ant species also has a wide range of tolerance to various environmental conditions. Moreover, the high efficacy of defending to other ant species and predators may cause *Camponotus rufoglaucus* to be one of the potentially aggressive tending ant. The abundance of *Camponotus rufoglaucus* was found quite high throughout the year may due to their high foraging behavior. Alsina (1988) reported that *Camponotus rufoglaucus* has high foraging behavior. They forage diurnally in spring and autumn and also highest foraged in summer.

*Monomorium destructor*, the second most abundant in this study, was negatively correlated with rainfall amount and *Camponotus rufoglaucus* abundance. According to the potential of being tending ant as previously mentioned, *Monomorium destructor* had low level in rainy season resembling to the low level of aphid in heavy rain. The negative relationship between those two species may be due to the large size of *Camponotus rufoglaucus* to impose the strong competitive pressure on *Monomorium destructor.* However, both ant species are mainly and highly exploited from aphid honeydew on Siam weed in the study area. The similarity of diets between *Monomorium destructor* and *Camponotus rufoglaucus* may consist primarily of aphid honeydew rather than protein sources. There are some seasonally specific ant species in both dry and wet seasons, but there are no significant differences on mean abundance of ant between two seasons. *Tapinoma melanocephalum,* which was on the third rank of relative abundance, positively correlated with rainfall amount, resembling to the result that they were present only in the wet season. While *Anoplolepis gracilipes* had a negative association to the relative humidity, this species was found only in the dry season. Due to being generalist forager, they have a wide food range (Brown, 1999). The exploitation of aphid honeydew from this species maybe rarely found, causing their abundance on Siam weed throughout the year was low.

**Other arthropods abundance and relationship with aphids**

The trend of relationship between the abundance of spiders and lady beetles as predators and aphids showed the high potential of predators preying upon aphid. The predator abundance peaked during the peak in aphid abundance (Brown, 1999). The delay peak of prey-predator abundance was due to the broad feeding habits of predatory arthropods. Typical predators have longer generation time comparing to the herbivorous prey such as aphids. Consequently, there is a numerical response to changes in the density of a single herbivore species (Symondson, Sunderland, and Greenstone, 2002). The results of preying on aphids by predators were potentially high but it is unlikely to occur quickly enough to leading to the immediately suppression of aphid outbreaks. Furthermore, the additive effect between parasitism from parasitoids and predation from predators was influenced the delayed density dependence in aphid dynamics or aphid density-dependent immigration of predators. Although predators typically cause an immediate decrease in aphid population, the level of predator remains consistent throughout the year. Comparing to parasitoids, they execrate aphid population mostly in low level but cause population peak some time later (Snyder, 2003). The shared-habitat between predators and aphids in host plant can also influence to the suppression of aphid number (Harrewijn and Minks, 1989). The additional positive association between aphid and predator on Siam weed also confirmed the previous abundance trend, representing the abundance of all predators was density dependent with greater responses to aphid populations.

The strong correlation between spiders and *A. gossypii* in this study indicated that spiders have potential as most effective predatory arthropods on aphid population. In agreement to most previous reports which examine spiders to significantly reduce prey densities including leafhopper, thrips and aphids (Lang et al., 1999). The high density of spiders might due to their ability to prey on aphids in diverse environment, such as on Siam weed plant or even settling their nest under plant on soil materials and also climbing up to prey on plants. Moreover, there are both spiders which were both diurnal and nocturnal foraging activity insect, increasing their probability to preying on aphids. They could also prey on grasshoppers which was other arthropods similarly found on Siam weed. Moreover, the relatively constant spider abundance throughout the year implied the high efficiency for stabilizing aphid population all year. In general, spiders are more sensitive to pesticide than many pests as aphids, resulting in the decrease of spider population (Holland et al., 2002; Tanaka et al., 2000). There was high level of spiders found in this study since there was no pesticide application in the sampling and surrounding area.

According to lady beetles' ability to perform as predators in both adults and larvae stage (Rabasse and Steenis, 1999), the strong association was also found between *A. gossypii* and lady beetles. Lady beetles played an important role in suppressing aphid population and other insect pest populations by consuming large quantity of aphids (Van Emden, 1995). Lady beetles were found in greater abundant in the dry season of this study might be due to their activity which was highly increased in high temperature. The negative association found between lady beetles and rainfall amount indicated that rainfall may inhibit their foraging behaviors, since lady beetles in adult stage fly to prey upon aphid as well as rainfall reduces aphid abundance. The heavy rain may disrupt the flight behavior resulting in reducing the prey-detecting mechanism, and also landing–establishment capacity on host plant. Adult stage of lady beetles also can switch to consume pollens as their main food (Rabasse and Steenis, 1999).

**Other arthropods-ant relationship**

There was no significant association between the ant and the total other arthropods abundance, which similar to relationship ant performed to aphids. However, there were some specific relationships between ants and other arthropods species. The positive association between other arthropods and the three ant species may be due to the low level of competition and interspecific between them. This is contrary to some studies which reported the negative association between ants and predatory arthropods, such as *Camponotus compressus* Fabricius (Formicidae: Hymenoptera) and *Menochilus sexmaculatus* (Fabricius) (Coccinellidae: Coleoptera) (Verghese and Tandon, 1987). Since aphids were generally benefited from tended-ants in protection from natural enemies (Stadler and Dixon, 1998;

Stadler, 2004), there was previous report on weak negative association between other arthropods and ants (Billick et al., 2007).

Lack of correlation may be due to the absence of the non-specific tending relationship by ants on *A. gossypii*. *A. gossypii* may develop their own mechanisms to avoid natural enemies or may develop indirect mechanisms such as producing more offspring to sustain their colonies. Consequently, the correlation between ants and other arthropods were not obviously observed.

### 3.4.2 Diversity and abundance of aphids and ants on cabbage

#### Aphid abundance

The seasonal crops which grow in dry season were commonly served as *A. gossypii* host plants. Seasonal crops include plants in the family Brassicacae*,* which were broccoli, cabbage, Chinese broccoli, and mustard cabbage. This allowed *A. gossypii* to utilize Brassicacae as a source food and produce more population. Consequently, *A. gososypii* was the first species found on the cabbage field in both sites.

#### Ant abundance

*Odontoponera denticulata* and *Camponotus rufoglaucus* were the only two species found in sampling sites. *Odontoponera denticulata* were predatory arthropods preying on aphids as they were on Siam weed observation. The morphology of cabbages which has lower height and performed enlarged area for ant access comparing to Siam weed, increase the tending and preying probability of both ant species. Consistent abundance of *Camponotus rufoglaucus* found in this study may be due to their preference of aphid honeydew as food sources. Moreover, due to their aggressive behavior, they could defend on the other related ant species, such as *Odontoponera denticulata.* The abundance of *Camponotus rufoglaucus*, which was found to be consistent to *Odontoponera denticulata*, implies that there was interspecific interaction between them.

# CHAPTER IV

# SPECIES DIVERSITY AND ABUNDANCE OF APHID AND OTHER ARTHROPODS ON SIAM WEED AND CABBAGE IN FIELD EXPERIMENT

## 4.1 Introduction

Aphids not only have evolvedto reachhigh potentials in feeding processand reproduction, but also develop the high efficiency in searching mechanisms. Aphid dispersal was influenced by intrinsic and extrinsic factors. Aphids disperse and search for a new host plantby detect and evaluate host plants under their visual and olfactory mechanisms (Schoonhoven et al., 2005; Visser, 1986). Therefore, aphids respond to plants with different color, morphology and volatile compound. Extrinsic factors, such as seasonality (Shaposhnikov, 1987), temperature (Schalk, Kindler, and Manglitz, 1969), predation risk (Beckerman, Uriarte, and Schmitz, 1997), and adjacent plant species (Nault et al., 2004) also play an important role on aphid dispersal process.

Winder et al. (1999) reported the higher density of aphid dispersal influenced by adjacent plant which serves as aphid reservoir source near crop field comparing with the plant absence condition. The aphid outbreak in cabbage also may due to the dispersal of aphid from surrounding aphid-reservoired plants, such as Siam weed.

This experiment is carried out to determine if the presence and varied located-patterns of adjacent aphid reservoir plant (Siam weed) to crop (cabbage) affected the diversity and abundance and also the dispersal pattern of aphids and other arthropods in a field experiment.

### 4.2Methodology

#### 4.2.1 Experimental field

The study was conducted at Chulalongkorn University Forest and Research Station in Wiangsa district, Nan province, Thailand, during two cultivating seasons (October 2010-February 2011 and March-May 2011). The experimental plot was approximately 0.4 ha, located in UTM zone 47Q: N2052221 and E689463 and 221 meters above sea level (Appendix A, Figure 2-A). The plot was surrounded by mango plantation, and adjacent to mixed deciduous forest and a vegetable plot.

**Cultivation of Siam weed**

One hundred of three-leaf seedlings were cultured in seedling grow bags with sterile well drained soil and fertilizer at the bottom under seed bed preparation. The seed bed preparation was a cultivating house with medium shading, watered daily and prevented from infestation from any pests.

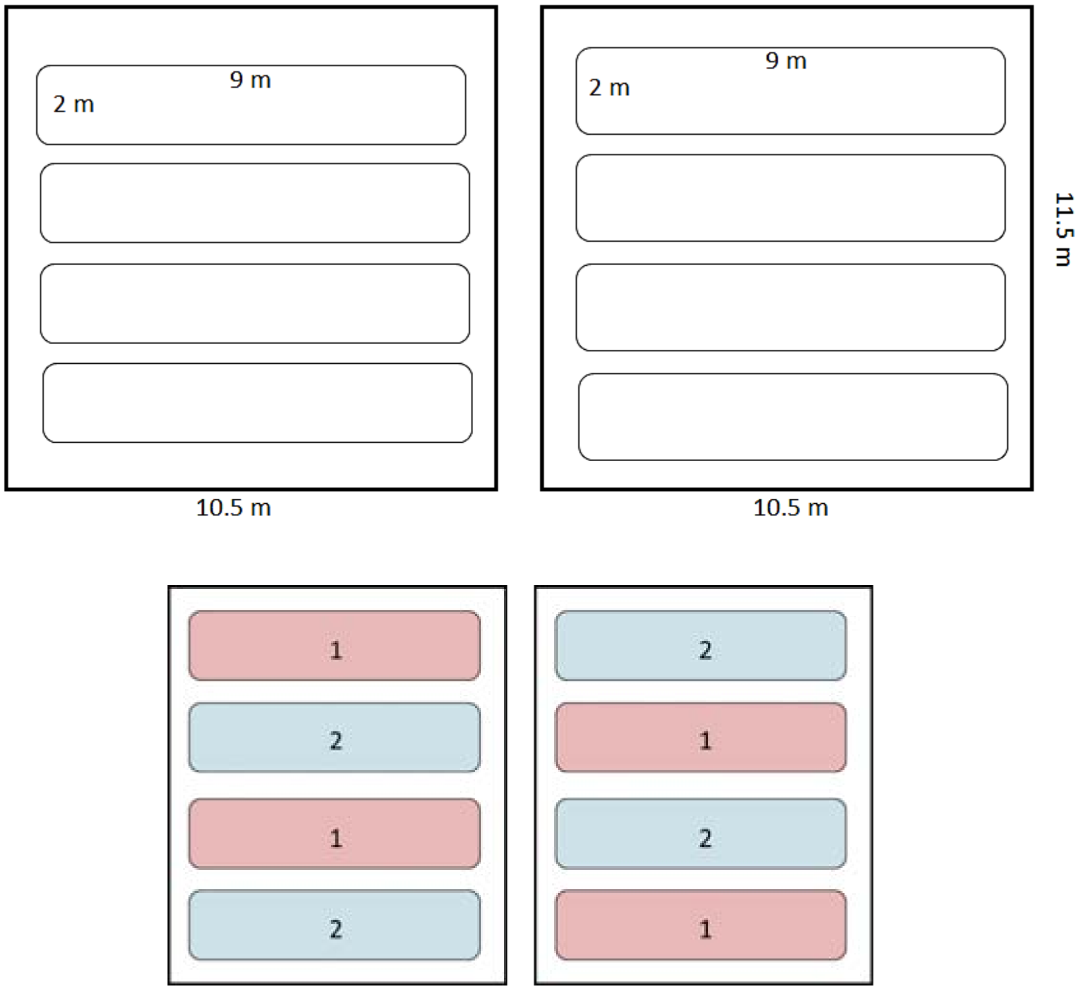
**Cultivation of Cabbage**

Cabbage (Virginia cultivar) was used in this experiment. It generally required 60 days from sowing to reach maturity with great tolerance to high temperature and susceptible to disease commonly found in cabbage cultivar grown in Wiangsa district, Nan province. One hundred cabbage seeds were germinated on moist cotton and were placed in darkness for three days. Germinated seeds were placed in 104-cell seedling trays filled with potting media, and covered by 1 mm cloth to prevent pest infestation. The seedlings were watered twice a day, in the morning and evening, to maintain the steady temperature and optimal moisture until transplanting.

**Experimental plots**

Soil in the plot was turned and solarized three weeks before transplanting. About five weeks after sowing, 5-6 true leave-seedlings of cabbage and 15 cm in height of Siam weed were transplanted. Seedlings were transplanted into 0.04 ha plot on 20 October 2010 and 8 March 2011 for the first and second growing season, respectively. Transplanting was conducted on moist soil and during evening time.

The experimental plots were divided into eight (2x9 m) plots with two replicates (Figure 4.1, Appendix A, Figure 2-A).Cabbage seedlings were planted 60 cm apart between rows and 20 cm apart within row.

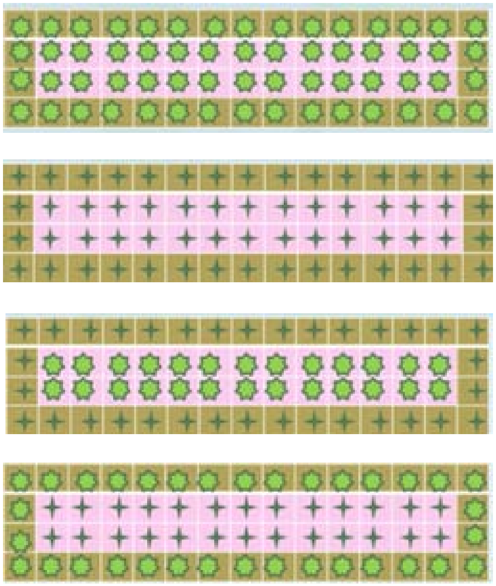



1=replicate 1

2=replicate 2

**Figure 4.1** The eight (2x9 m) RCBD experimental plots with two replicates, in experimental field, during two cultivating seasons (October 2010-February 2011 and March-May 2011), Wiangsa district, Nan province

There were two placements of plants on experimental plot; (bordered-plants) and (inner-plant). The sub-pattern of experimental plots were pattern CC (border/inner plant: cabbage/cabbage), pattern SS (border/inner plant: Siam weed/Siam weed), pattern CS (border/inner plant: cabbage/Siam weed) and pattern SC (border/inner plant: Siam weed/cabbage). Seedlings were transplanted on plot by these four different patterns with two replications (Figure 4.2).



**Pattern CC** (inner/border plant: cabbage/cabbage)

**Pattern SS**(inner/border plant: Siam weed/Siam weed)

**Pattern CS**(inner/border plant: cabbage/Siam weed)

**Pattern SC**(inner/border plant: Siam weed/cabbage)

**Figure 4.2** The four experimental patterns in experimental field, during two cultivating seasons (October 2010-February 2011 and March-May 2011), Wiangsa district, Nan province

**Cultural practice**

Drip irrigation (arrow dripper) was applied to each plot to maintain soil moisture at a relatively constant level of moisture. Irrigation was supplied daily on the first growing season. Plants had been irrigated approximately 3 lt/plant /day water three hours in the morning and evening. For the second growing season, to provide the deficit in soil moisture needed for optimum cabbage growth, plot had been irrigated for five hours in the morning and three hours in the evening. Plants in each plot were fertilized at the bottom of furrow with two applications of nitrogen ($NH_4NO_3$) during the growing season. The soil between the rows was tilled regularly with a hoe, and weeds were mechanically controlled weekly. In both growing seasons, especially in the first wet season, there were numerous Siam slugs (*Cryptozona siamensis*) infesting the cabbages inside the plot. They were mechanically removed at two durations (8pm-9pm and 12am-1am). For protecting seedling losses, the plot was surrounded by a 1.5 m height-nylon net. There was no pesticide application to the plot.

**Arthropod sampling**

To investigate thecombined effect between the presence of Siam weed and cabbage on aphid and arthropod abundance as well as dispersal pattern, aphid abundance on Siam weed and cabbages in experimental plot was estimated by randomly sampling weekly on ten border plants and ten inner plants in each experimental pattern until the cabbage harvesting time. In each sampling time, the number and developmental stage of aphid as well as the number of other arthropods on sampling plants were recorded. The number of ants exposing to eachplant in one minute was total counted. Plant stage of both Siam weeds and cabbages were also recorded. The experiments were conducted in two cultivating seasons to compare the aphid and other arthropod abundance and dispersal pattern according to seasonality.

**Harvesting**

The cabbages were harvested when they had a firm head. It was noticed that they provided the harvest only in the first season due to the failure to develop of cabbagecaused by high insect infestation. Cabbage yields were recorded in kilogram unit.

**4.2.2 Identification**

Study organisms were collected and preserved under the same previously described methods. The identification keys used were also the same as previous.

**4.2.3 Environmental factors**

The records of meteorological data were sourced from the two stations in Nan province, Synoptic Station (331201, Dutai subdistrict, Muang Nan) for air temperature, relative humidity and wind speed. Rainfall amount was sourced from hydrological meteorological station (lat 18.5725 / long 100.782583**,** Lainan Subdistrict Administration Organization, Wiangsa district), obtained from Hydrometeorological Academic Group, Meteorological Development Bureau, Thai Meteorological Department.

### 4.2.4 Data analysis

Experimental pattern, host plant and plant location were tested for relationships on the mean abundance of aphids, ants, and other arthropods

## 4.3 Results

### Experimental pattern

Only in first season showed that the mean *A. gossypii* abundance on cabbage of pattern CS was significantly less than pattern CC ($F=9.020$, $df = 1, 7$, $p<0.05$). The different experimental pattern on host plant species affected the abundance of aphids due to different edge-effect host plant.

### Aphid and arthropod abundance

The diversity and abundance of aphid was significantly greater in the second growing season than the first growing season. *Lipaphis erysimi* was found only on cabbage and had a significantly higher abundance than *A. gossypii* in both growing seasons and experimental patterns (CC and CS) while *A. gossypii* were found only on Siam weed (Table 4.1, Figure 4.3).

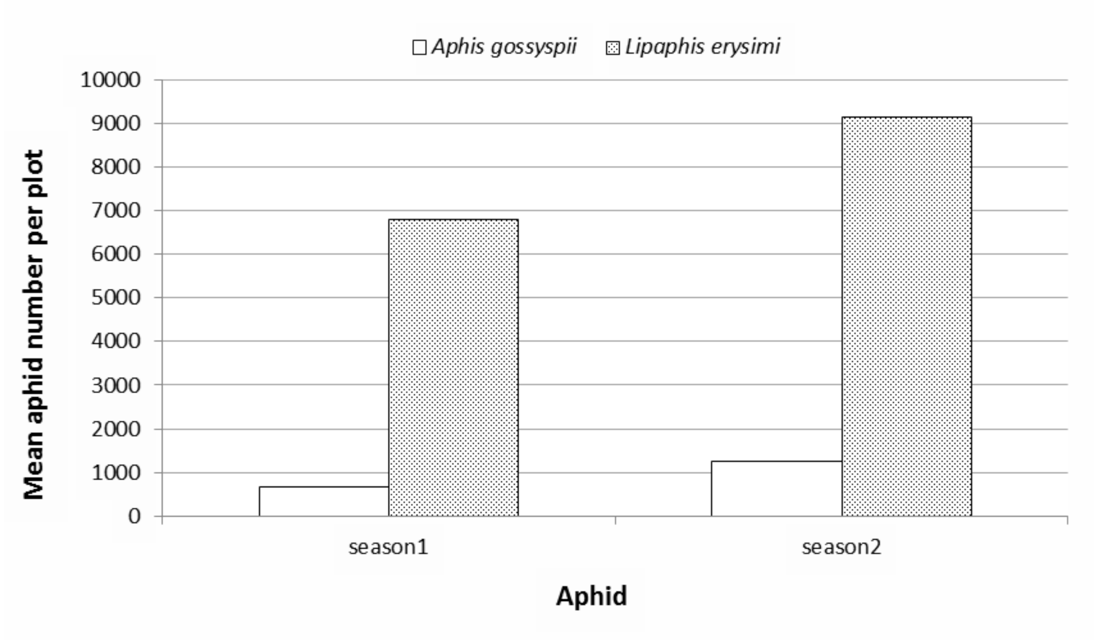



**Figure 4.3** Comparison of mean aphid number in field experiment, between two cultivating seasons (November 2010-February 2011, March-June 2011)

*Camponotus rufoglaucu*s was the most abundant ants on the cabbage in both seasons, followed by *Odontoponera denticulata.* In the first growing season, *Camponotus rufoglaucu*s was also the dominant species in Siam weed, followed by *Anoplolepis gracilipes* and *Monomorium* sp. In the second growing season, *Camponotus rufoglaucu*s was still the dominant ant species on Siam weed (Figure 4.4).

The other prominent arthropod found on cabbages in both growing seasons was flea beetles, *Phyllotreta sinuate* (Family*:* Chrysomelidae). They fed on cabbage leaves and were found to have greater numbers in the second growing season than in the first growing season (Table 4.1).

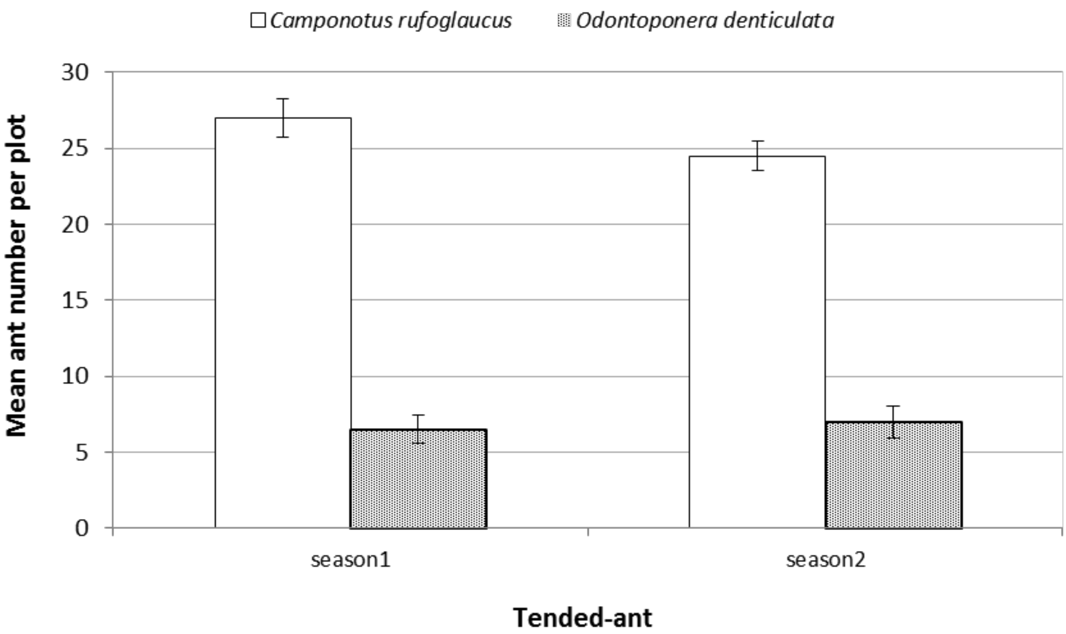



**Figure 4.4** Comparison of mean ant number in field experiment, between two cultivating seasons (November 2010-February 2011, March-June 2011)

The mean abundance of lady beetles was highest in the first growing season, particularly on cabbage while the mean abundance of spiders was significantly greatest in the second season, particularly on Siam weed (Table 4.1, Figure 4.5).

The cabbage worms, *Spodoptera exigua*, *Plutella xylostella*, *Spodoptera litura*, and *Trichoplusia ni*, caused the most damages on cabbages in both growing season, but they were more abundant in the first growing season. They infested cabbage earlier in the first growing season comparing to the second season and also suppressed the forming of cabbage head causing a very low yield (Table 4.1).

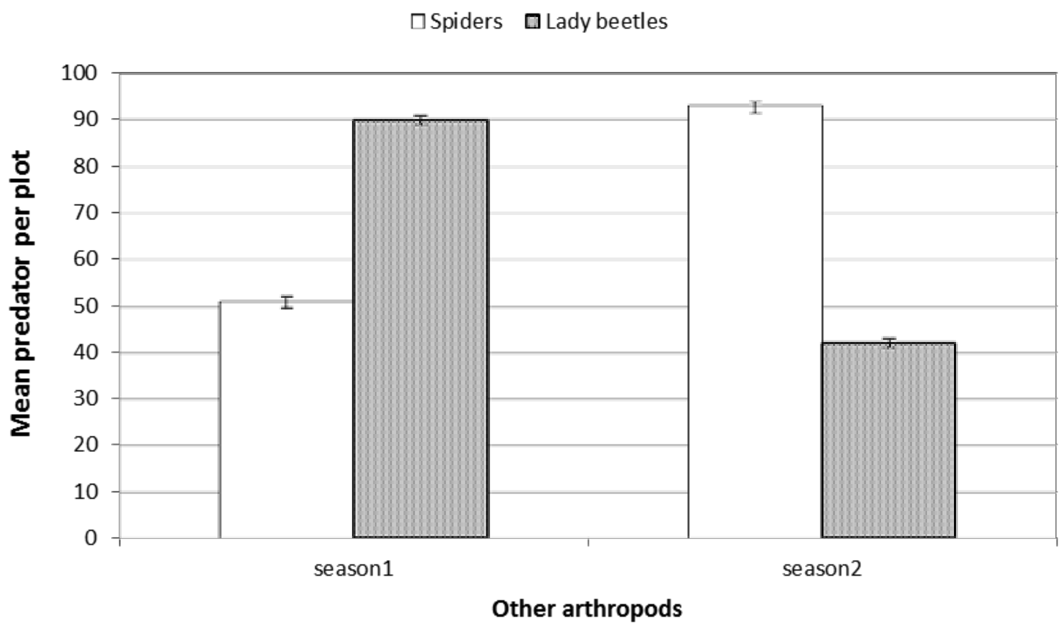



**Figure 4.5** Comparison of mean other arthropods number in field experiment, between two cultivating seasons (November 2010-February 2011, March-June 2011)

**Table 4.1** Comparison of the aphid, ant and other arthropods diversity on Siam weed and cabbage between two cultivating seasons (November 2010-February 2011, March 2011-June 2011), Wiangsa district, Nan province

| | Cabbage | | | Siam weed | | |
|---|---|---|---|---|---|---|
| **Season** | **Aphids** | **Ants** | **Other arthropods** | **Aphids** | **Ants** | **Other arthropods** |
| **1**<br>(November 2010-February 2011) | *Lipaphis erysimi*<br>*Aphis gossypii* | *Camponotus rufoglaucus*<br>*Odontoponera denticulata* | spiders<br>lady beetles<br>*Phyllotreta*<br>*sinuate* grasshoppers<br>*Spodoptera exigua*<br>*Plutella xylostella*<br>*Spodoptera litura*<br>*Trichoplusia ni* | *Aphis gossypii* | *Camponotus rufoglaucus*<br>*Anoplolepis gracilipes*<br>*Monomorium* sp. | spiders<br>rove beetles<br>lady beetles<br>grasshoppers |
| **2**<br>(March 2011-June 2011) | *Lipaphis erysimi*<br>*Aphis gossypii* | *Camponotus rufoglaucus*<br>*Odontoponera denticulata* | spiders<br>lady beetles<br>*Phyllotreta sinuate*<br>grasshoppers<br>*Spodoptera exigua*<br>*Plutella xylostella*<br>*Spodoptera litura*<br>*Trichoplusia ni* | *Aphis gossypii* | *Camponotus rufoglaucus*<br>*Monomorium* sp. | spiders<br>lady beetles<br>rove beetles<br>grasshoppers |

## 4.4 Discussion

### Experimental pattern

Many studies showed that vegetative diversity in the form of intercropping of edge host plant effect can result in reducing pest densities and increasing the resistance of the environment (Jankowska, Poniedzialek, and Jedrszczyk, 2009; Sarker, Rahman, and Das, 2007). During the experiment from November 2010-June 2011, plant infestation by cotton aphid, *Aphis gossypii* abundance differed between the experimental patterns. All results were in the same trend, but the mean abundance of aphid landing on plants differed. Only in first growing season, there were significant differences of mean *A. gossypii* abundance between cabbage with Siam weed as border plant (CS) and cabbage with also cabbage as border plant (CC). There are significant interaction effect ($F=9.020$, $df = 1, 7$, $p \leq 0.05$) between inner host plant and border host plant, which indicates the experimental pattern playing an important role in *A. gossypii* abundance. This confirmed the potential of Siam weed as the aphid reservoir and also showed the potential as a border plant to decrease the pest density of inner plant.

### Aphid and arthropod abundance

The mean abundance of aphids and arthropods were more diverse than the annual sampling on Chapter III, but still was in the same trend. The greater mean abundance of arthropods was due to the higher temperature condition and lower rainfall amount in the second growing season than in the first growing season.

Only in cabbage sampling which *L. erysimi*, the specific aphid to cabbage was found. Although *A. gossypii* was still found on cabbage, there are greatly lower than *L. erysimi* abundance. This showed the high host plant specific of this species. The fluctuated abundance of lady beetles on the last month of the first growing season was due to the lag time of density-dependent between lady beetles and aphids.

# CHAPTER V

# APHID DISPERSAL IN RELATION TO ANT ON SIAM WEED AND CABBAGE IN A CAGED EXPERIMENT

## 5.1 Introduction

Aphid dispersal was determined by many factors such as population density, deteriorating host plants, predators, intrinsic factors, and also mechanisms influenced by tended-ants in ant-tended colonies. Negative effects from the relationship formed between aphids and ants were reported including ants may frequently or even mostly eat rather than tend aphids (Stadler and Dixon, 1999; Fischer et al., 2001). Moreover, ants were reported to reduce the growth rate of aphids in ant-tended aphid colonies (Yao et al. 2000; Stadler et al. 2002) and also limit aphid dispersal by tranquillizing effect (Oliver et al., 2007).

Since there are many factors influencing the dispersal of aphids, there is a need to study and clarify the effects of aphid-ant interaction which may play role on aphid dispersal between a crop (cabbage) and a possible aphid reservoir plant (Siam weed) in a caged experiment comparing between aphid colonies with non ant-tended and ant-tended treatments. The results from Chapter III found *Camponotus rufoglaucus* to be the most abundant tended-ant on Siam weed while *Odontoponera denticulata* was the only predatory ant, furthermore, the comparison of effects influenced by two ant species with different roles were also examined.

## 5.2 Methodology

### 5.2.1 Experimental site

The experiments were conducted in a laboratory at Chulalongkorn University Forest and Research Station in Wiangsa district, Nan province during October 2011 to synchronize with the local cabbage growing season.

### 5.2.2 Study organisms

**Siam weeds and cabbages**

Two-hundred and fifty of each plant was propagated from seeds in 5 inch-diameter plastic pots with 2 g of slow release fertilizer (*Osmocote* 14-14-14) at the bottom. Plants were irrigated at the base of plant daily, maintained at 12:12 (L:D), 27±31$^{o}$C and 70±5% relative humidity condition, and prevented from any infestation by 80x80x120 cm$^3$ cage covered with translucent white nylon sheer fabric with 0.5 mm mesh (Figure 5.1). Siam weeds used in the experiment were at approximately 15-20 cm in height and cabbages were 40-45 day-old approximately 10-15 cm in height.

**Aphids**

*Aphis gossypii*, the commonly important pest of economic crops and also found in both Siam weeds and cabbages as previously reported in Chapter III, was used as an aphid model to investigate the potential of Siam weed as aphid reservoir under aphid dispersal experiment.

Aphids were reared on Siam weeds as stock culture prior to the start of the experiment for six months. In this experiment, one apterous, three 4$^{th}$ instar, three 3$^{th}$ instar, and four 2$^{nd}$ instar (Lombaert**,** Boll, and Lapchine, 2007), were transferred and reared on approximately 15-20 cm height Siam weed and 40-45 day-old-cabbage in 80x80x120 cm$^3$cage covered with translucent white nylon sheer fabric with 0.5 mm mesh (Figure 5.1) to maintain in uninfested colonies. The colonies were reared under the same condition as previously described until the aphid number on each individual plant was established and reached density of 50-65 individuals per plant. This aphid density rang was adapted from Collins and Leather (2002) study, which is the suitable population distribution avoiding the confounding effects of host quality on aphid activity which can affect the dispersalin short-term experiments (Collins and Leather, 2002).

**Ants**

Forty workers of *Camponotus rufoglaucus* and *Odontoponera denticulata* were obtained from the field site explained in Chapter III. Individuals from the same colony were separated to avoid the negative effect as preying or defending and reared in 9 cm diameter plastic glasses which provided with 70% sucrose syrup on cotton as food source. The ant colonies were maintained in the same condition as previously described for 20 days before experiment, dead ants were removed from the rearing glasses. Four days prior to the experiment, ants were starved to induce the sensitivity of their requirements in aphid honeydew.

### 5.2.3 Experimental design

The dispersal experiments were conducted under the previously described-nylon containers (Figure 5.1) and conditions as the above rearing conditions. Each plant with established 65 aphids was placed in four experimental designs (Figure 5.2) which were pattern SS (inner-border plant: Siam weed-Siam weed), pattern CC (inner-border plant: cabbage-cabbage), pattern CS (inner-border plant: cabbage-Siam weed), and pattern SC (inner-border plant: Siam weed-cabbage).

**Figure 5.1** Nylon sheer fabric cage (80x80x120 cm)

An inner plant was aphid source plant which was cultured in culturing time while eight border plants were aphid target plants. Each pattern was interacted by three treatments: non-tending ant, *Camponotus rufoglaucus*, and *Odontoponera denticulata* tended-colonies with four replicates.

### 5.2.4 Dispersal experiment

For ant-tended colony treatments, six workers of each *Camponotus rufoglaucus* and *Odontoponera denticulata* were released on aphid colonized plants and set on the boundaried container to limit the foraging area for ants in each replicate (Figure 5.2). Ants were provided for non-tending ant treatment, no ants were released. Plants were irrigated at the base at 8 a.m. and 5 p.m. daily.

The number of aphids was recorded on each border-plants and inner-plant daily until the aphid number in colony on inner-plant reached the maximum number. Number of ants presented on each plant at one minute was counted. The data collection was done at the same time daily. Environmental factors, such as air temperature and relative humidity, were recorded.

**5.2.5 Data analysis**

The mean number of aphids and ants were compared in both source plant and target plant between experimental patterns and between ant treatments.

The population growth rate was calculated from the logistic growth equation of Verhulst (1838), then compared between day periods, experimental patterns, and ant treatments.

$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

The dispersal rate was estimated by dispersal rate equation adapted by Lombaert et al. (2006), then compared between day periods, experimental patterns, and ant treatments

$$\text{Dispersal rate} = \frac{\text{No. aphid on target plant}}{\text{No. aphid on source plant}}$$

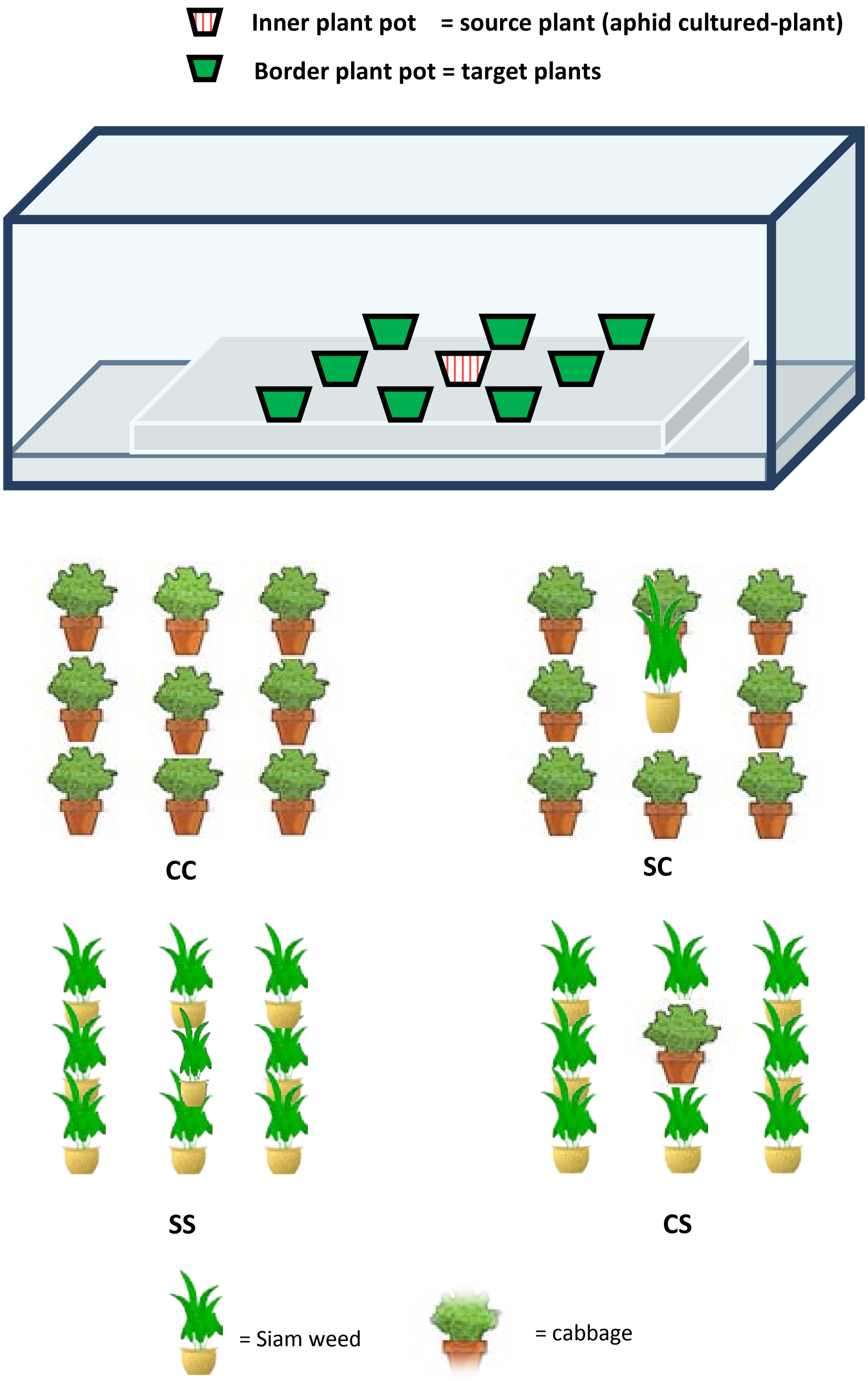



**Figure 5.2** Experimental designs:

Pattern CC (inner/border plant: cabbage/cabbage)

Pattern SS (inner/border plant: Siam weed/Siam weed)

Pattern SC (inner/border plant: Siam weed/cabbage)

Pattern CS (inner/border plant: cabbage/Siam weed)

## 5.3 Results

### Aphid and ant abundance and interactions

The mean number of aphid colonies on source plant reached maximum number in five days. There was no significant difference found (*Kruskal–Wallis* test: $\chi 2 = 5.525$, df = 3, *P*=0.137); (*Kruskal–Wallis* test: $\chi 2 = 3.043$, df = 3, *P*=0.385).in the mean number of aphids and ant tended-colonies among four experimental patterns in source plants.Similarly, there was no significant difference of the mean number of aphids and tended-ants betweenthe four experimental patterns in target plants (*Kruskal–Wallis* test: $\chi 2 = 7.578$, df = 3, P=0.056); (*Kruskal–Wallis* test: $\chi 2 = 0.303$, df = 3, *P*=0.959).

Aphid and ant mean number for both source plants and target plants were significant between ant treatments. There were significant differences of aphid mean number on source plants between ant treatments (*Kruskal–Wallis* test: $\chi 2 = 20.194$, df = 2, $P<0.05$) (Figure 5.3, Table 5.1).

**Table 5.1** Mean number of *A. gossypii* on each source and target plants, four experimental patterns, in three ant treatments (N= non-ant tended colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies)

| Day | Pattern CC | Mean No. aphids | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | Cabbage | | | Cabbage | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | 74.25 | 72.50 | 75.5 | 0.188 | 0.094 | 0.094 |
| 2 | | 92.25 | 94.75 | 84.0 | 0.500 | 0.500 | 0.125 |
| 3 | | 111.0 | 109.5 | 107.75 | 0.969 | 1.156 | 0.438 |
| 4 | | 129.0 | 125 | 117.5 | 1.031 | 1.531 | 1.563 |
| 5 | | 154.25 | 154.5 | 149.25 | 2.188 | 3.281 | 2.656 |
| Avg. | | 112.15 | 111.25 | 106.80 | 0.975 | 1.313 | 0.975 |

**Pattern CC** (inner/border plant: cabbage/cabbage)

| Day | Pattern SC | Mean No. aphids | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | Siam weed | | | Cabbage | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | 75.00 | 75 | 75.75 | 0.094 | 0.219 | 0.125 |
| 2 | | 89.25 | 9.00 | 87.50 | 0.125 | 0.281 | 0.125 |
| 3 | | 104.75 | 108.5 | 104.0 | 0.375 | 0.188 | 0.375 |
| 4 | | 127.00 | 124.75 | 120.25 | 0.438 | 0.688 | 0.313 |
| 5 | | 151.75 | 152.25 | 141.0 | 1.438 | 1.875 | 0.406 |
| Avg. | | 109.55 | 110.50 | 105.80 | 0.494 | 0.650 | 0.269 |

**Pattern SC**(inner/border plant: Siam weed/cabbage)

| Day | Pattern SS | Mean No. aphids | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | Siam weed | | | Siam weed | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | 75.00 | 76.25 | 75.00 | 0.125 | 0.156 | 0.125 |
| 2 | | 91.00 | 92.25 | 88.25 | 0.344 | 0.438 | 0.125 |
| 3 | | 108.25 | 109.75 | 106.75 | 0.875 | 0.688 | 0.250 |
| 4 | | 128.75 | 127.75 | 125.00 | 1.281 | 1.250 | 0.781 |
| 5 | | 151.75 | 155.5 | 149.75 | 2.250 | 1.969 | 1.75 |
| Avg. | | 110.95 | 112.30 | 108.95 | 0.975 | 0.900 | 0.606 |

**Pattern SS** (inner/border plant: Siam weed/Siam weed)

| Day | Pattern CS | Mean No. aphids | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | Cabbage | | | Siam weed | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | 73.50 | 76.25 | 73.00 | 0.250 | 0.281 | 0.219 |
| 2 | | 94.50 | 92.25 | 86.00 | 0.375 | 0.406 | 0.344 |
| 3 | | 111.0 | 109.75 | 106.75 | 1.000 | 0.655 | 0.594 |
| 4 | | 129.0 | 127.75 | 121.5 | 1.906 | 1.313 | 0.594 |
| 5 | | 154.25 | 155.5 | 150.75 | 2.875 | 2.406 | 0.500 |
| Avg. | | 112.45 | 112.30 | 107.60 | 1.281 | 1.019 | 0.450 |

**Pattern CS** (inner/border plant: cabbage/Siam weed)

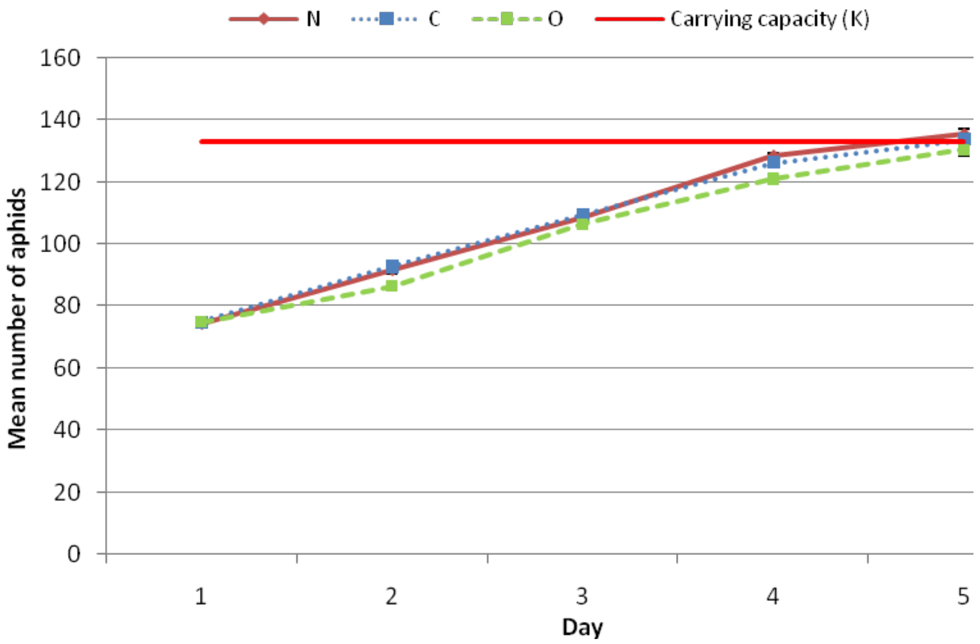



**Figure 5.3** Comparison of aphid mean number using four experimental patterns on source plant between ant treatments, (N= non-ant tended colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies) (mean±SE)

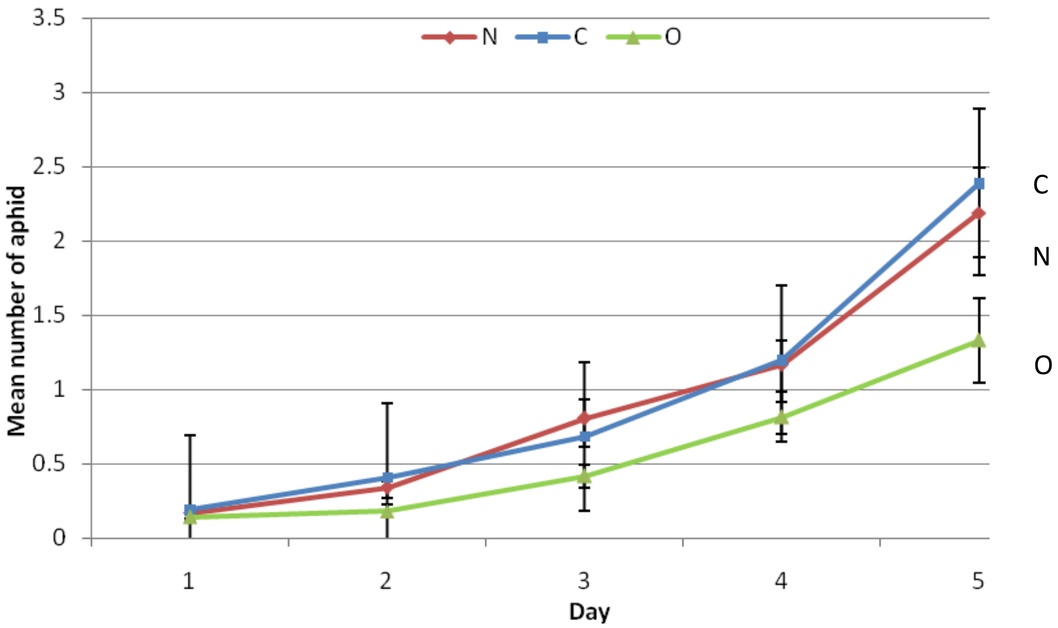



**Figure 5.4** Comparison of aphid mean number using four experimental patterns on target plants between ant treatments, (N= non-ant tended colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies) (mean±SE)

Table 5.2 shows that the mean aphid abundancewas significantly different between non-tended and*O. Denticulata* tended colonies in source plant (*Tamhane*-T2 *test*, $p \leq 0.05$). Moreover, the mean abundance of aphid was also significantly different between *O. denticulata* tended and *Camponotus rufoglaucus*-tended colonies (*Tamhane*-T2 *test*, $p \leq 0.05$).The mean rank were greatest in *Camponotus rufoglaucus* treatment (mean rank=30.50), followed by non-tended ant treatment (mean rank =31.31) and *Odontoponera denticulat*a (mean rank = 11.69).

**Table 5.2** Comparison of mean abundance of aphids and ants between ant treatments on source plant and target plant, in cabbage experiment on October 2011, Wiangsa district, Nan province

| | Mean abundance (mean±SE) | | | |
|---|---|---|---|---|
| | Aphid | | Ant | |
| Ant treatment | Source plant | Target plant | Source plant | Target plant |
| N | 107.76±0.54[a] | 0.93±0.18[ab] | - | - |
| C | 107.43±0.432[a] | 0.97±0.12[a] | 0.65±0.081[a] | 0.67±0.066[a] |
| O | 103.8±0.60[b] | 0.575±0.097[b] | 0.15±0.06[b] | 0.07±0.03[b] |

*The mean abundance of aphid in each source plant and target plant column with the different letter were significantly difference between ant treatments by *Kruskal-Wallis test* ($p \leq 0.05$) with *Tamhane's T2* ($p \leq 0.05$), meanabundance of ant were significantly difference between ant species treatments by *Mann-WhitneyU*-test at $p<0.05$)

Resemble to the source plants, mean aphid abundance on target plants was significantly different between ant treatments (*Kruskal–Wallis* test: $\chi 2 = 6.470$, df = 2, P=0.039) (Figure 5.4, Table 5.2).The mean abundance of aphid was significantly different only between *Camponotus rufoglaucus*-tended and *O. denticulata* tended colonies (*Tamhane*-T2 *test*, $p \leq 0.05$) (Table 5.2). The mean rank were greatest in *Camponotus rufoglaucus* treatment (mean rank=30.34), followed by non-tended ant (mean rank =25.31) and *Odontoponera denticulat*a treatment (mean rank = 17.84).

Focusing on tended-ants number in source plants, the number of *Camponotus rufoglaucus* tended to *A. gossypii* colonies increased during the study time while *O. denticulata* number remaining in low level along all study time.

The mean abundance of tended-ants on source plants between ant treatments was significantly different (*Mann-WhitneyU*-test, U=28.5, $p<0.05$) (Figure 5.5, Table 5.3). The higher mean number of *Camponotus rufoglaucus* (mean rank=22.72) over *Odontoponera denticulata* (mean rank=10.28) showed that *Camponotus rufoglaucus* and *Odontoponera denticulata* were both tended *A. gossypii*; however, *Camponotus rufoglaucus*-tended numbers of *A. gossypii* were approximately twice as high as those tended by *Odontoponera denticulata*.

Similarly, the mean number of tended-ants on target plants between ant treatments was significantly different (*Mann-Whitney U*-test, U=3.5, $p<0.05$) (Figure 5.6). The higher mean number of *Camponotus rufoglaucus* (mean rank=24.28) over *Odontoponera denticulata* (mean rank=8.72) showed that *Camponotus rufoglaucus* and *Odontoponera denticulata* were both tended *A. gossypii*; however, *Camponotus rufoglaucus*-tended numbers of *A. gossypii* were approximately triple as those tended by *Odontoponera denticulata*. The number of *O. denticulata* tended to aphid remaining in low level along all study time while *Camponotus rufoglaucus* number trend was unpredictable.

**Table 5.3** Mean number of tended-ants on each source and target plants, four experimental patterns, in three ant treatments (N= non-ant tended colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies)

| Day | Pattern CC | Number of tended-ants | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | cabbage | | | cabbage | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | - | 0.5 | 0.50 | - | 0.50 | 0.03 |
| 2 | | - | 0.75 | 0 | - | 0.75 | 0.03 |
| 3 | | - | 1 | 0 | - | 0.75 | 0.06 |
| 4 | | - | 0.25 | 0 | - | 0 | 0.06 |
| 5 | | - | 0.5 | 0.25 | - | 0 | 0.03 |
| Total | | - | 0.60 | 0.15 | - | 0.40 | 0.04 |

**Pattern CC** (inner/border plant: cabbage/cabbage)

| Day | Pattern SS | Number of tended-ants | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | Siam weed | | | Siam weed | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | - | 0.25 | 0 | - | 0.75 | 0 |
| 2 | | - | 0.50 | 0 | - | 1.00 | 0 |
| 3 | | - | 0.25 | 0 | - | 0.50 | 0 |
| 4 | | - | 1.00 | 0.25 | - | 1.00 | 0 |
| 5 | | - | 1.00 | 0 | - | 1.00 | 0 |
| Total | | - | 0.60 | 0.05 | - | 0.85 | 0 |

**Pattern SS** (inner/border: Siam weed/Siam weed)

| Day | Pattern CS | Number of tended-ants | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | cabbage | | | Siam weed | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | - | 0.25 | 0 | - | 1.00 | 0.09 |
| 2 | | - | 0.50 | 0.25 | - | 1.00 | 0.03 |
| 3 | | - | 0.50 | 0 | - | 0.50 | 0 |
| 4 | | - | 0.50 | 0 | - | 0.75 | 0.03 |
| 5 | | - | 0.50 | 0 | - | 0.75 | 0.06 |
| Total | | - | 0.45 | 0.05 | - | 0.80 | 0.04 |

**Pattern CS** (inner/border plant: cabbage/Siam weed)

| Day | Pattern SC | Number of tended-ants | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source plant | | | Target plants | | |
| | | Siam weed | | | cabbage | | |
| | Ant treatment | N | C | O | N | C | O |
| 1 | | - | 0.25 | 0.50 | - | 0.25 | 0.03 |
| 2 | | - | 0.50 | 0.50 | - | 0.25 | 0.03 |
| 3 | | - | 0.75 | 0 | - | 0.31 | 0.09 |
| 4 | | - | 1.75 | 0.25 | - | 0.31 | 0.13 |
| 5 | | - | 1.75 | 0.25 | - | 1.00 | 0.09 |
| Total | | - | 1.00 | 0.30 | - | 0.42 | 0.07 |

**Pattern SC** (inner/border plant: Siam weed/cabbage)

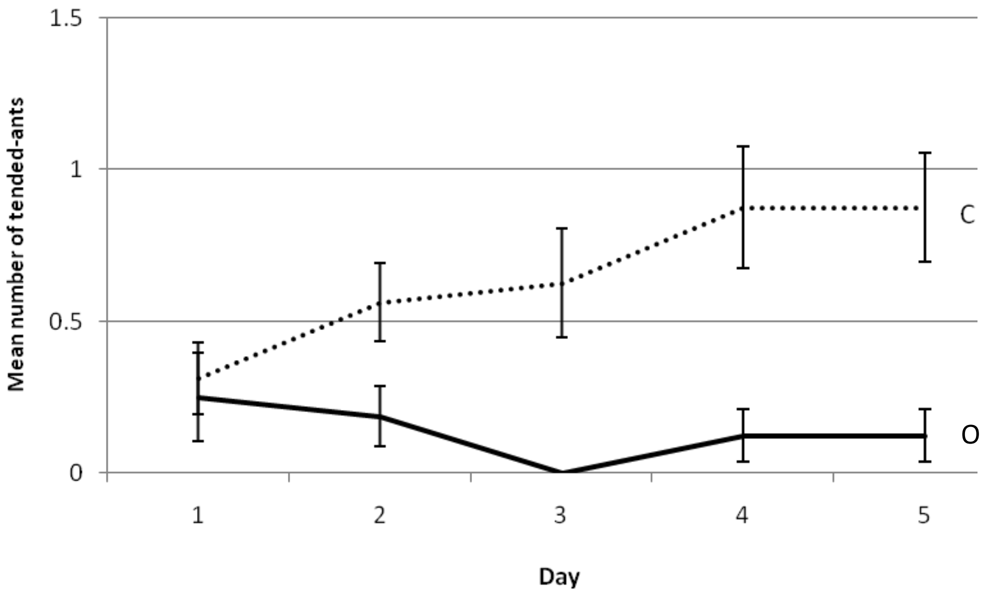



**Figure 5.5** Comparison of mean number of tended-ants of four experimental patterns on source plants between ant treatments, (C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies) (mean±SE)

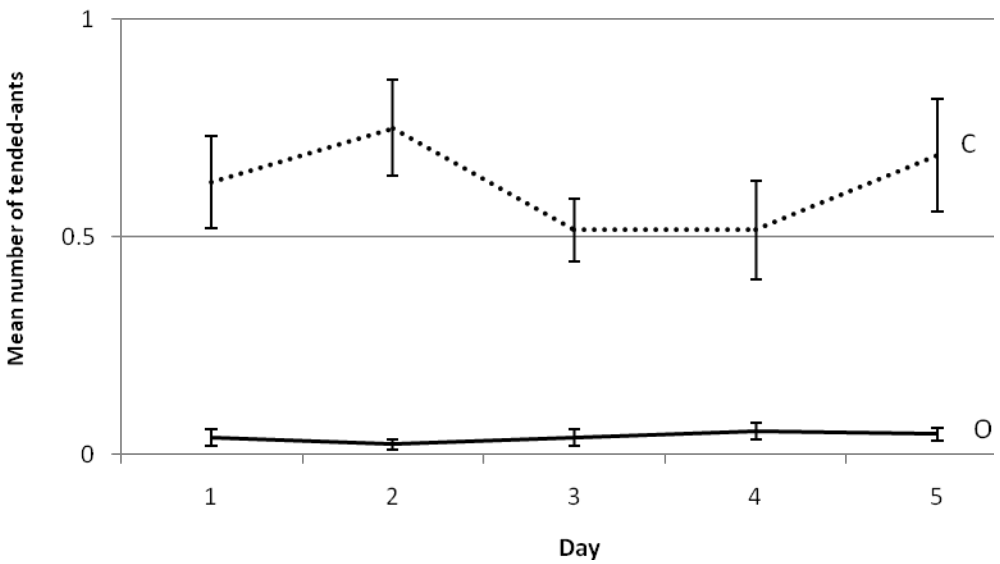



**Figure 5.6** Comparison of mean number of tended-ants of four experimental patterns on target plants between ant treatments, (C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies) (mean±SE)

In source plant, the abundance of aphids and ants were corresponded along study time and the number of *Camponotus rufoglaucus* tended-ant was in the same trend as aphid number along study time (Figure5.7).

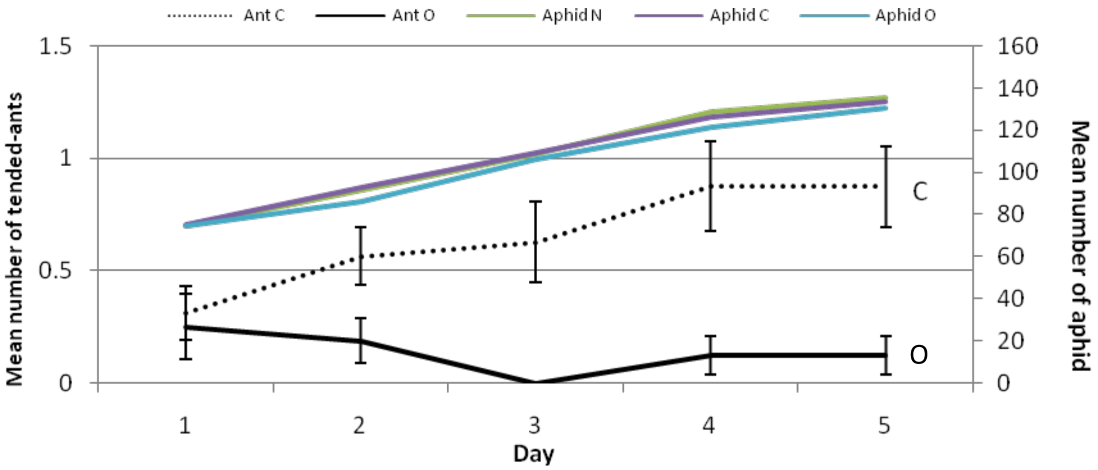



**Figure 5.7** Comparison of mean number of aphid and tended-ants of four experimental patterns on source plants between ant treatments, (C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies) (mean±SE)

While in source plant, the abundance of aphids and ants were not apparently correspond along study time in both ant treatments. (Figure5.8).

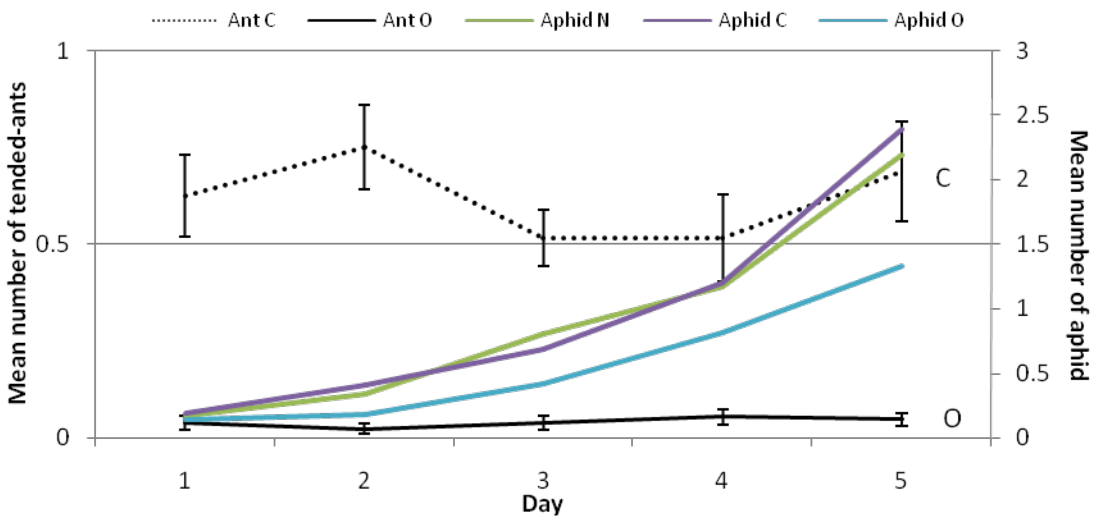



**Figure 5.8** Comparison of mean number of aphid and tended-ants of four experimental patterns on target plants between ant treatments, (C = *Camponotus*

*rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies) (mean±SE)

**Population growth**

The carrying capacity on this experiment for *A. gossypii* was 133.15 (Figure 5.3). The growth rates of aphid during study period on source plant were estimated and compared between experimental pattern and between ant treatments (Table 5.4).

Comparing aphid growth rate of three ant treatments, the significant differences of aphid growth rate between five day periods were found (*Kruskal–Wallis* test: $\chi2$ = 74.152, df = 3, $P<0.05$). The growth rate tended to decline along experiment date and was negatively valued on the fifth day (Figure 5.9). This showed that the population growth rate was lower and beyond the duration of dispersal to new host plant.

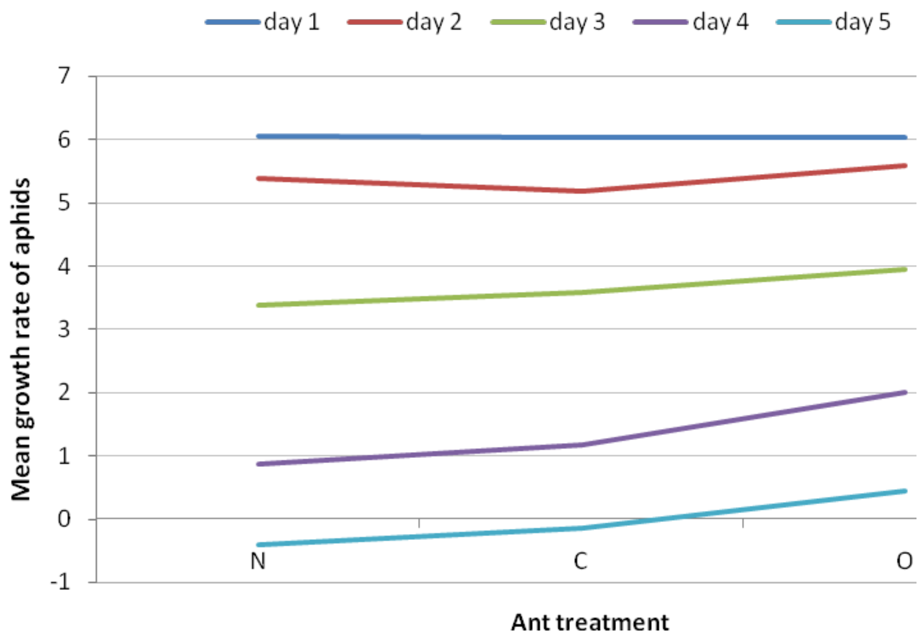



**Figure 5.9** Comparison of mean growth rate of aphids in three ant treatments between five day periods, (N= non ant tended-colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies)

**Table 5.4** Mean growth rate of aphid on source plants comparison on four experimental patterns, three ant treatments (N= non-ant tended colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies)

| Day | | Mean growth rate of aphid on source plant | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pattern | CC | | | CS | | | SS | | | SC | | |
| | Ant treatment | N | C | O | N | C | O | N | C | O | N | C | O |
| 1 | | 6.03 | 6.09 | 6.02 | 6.07 | 6.00 | 6.07 | 6.03 | 6.00 | 6.03 | 6.03 | 6.03 | 6.02 |
| 2 | | 5.20 | 5.02 | 5.71 | 5.03 | 5.23 | 5.60 | 5.31 | 5.23 | 5.48 | 5.42 | 5.24 | 5.52 |
| 3 | | 3.38 | 3.53 | 3.79 | 3.38 | 3.56 | 3.90 | 3.73 | 3.56 | 3.90 | 4.12 | 3.70 | 4.19 |
| 4 | | 0.73 | 1.40 | 2.54 | 0.73 | 0.95 | 1.95 | 0.77 | 0.95 | 1.39 | 1.06 | 1.44 | 2.11 |
| 5 | | -0.95 | -0.27 | 1.73 | 0.31 | 0.13 | -0.52 | -0.40 | -0.46 | -0.33 | -0.97 | 0.04 | 0.88 |
| Total | | 2.88 | 3.15 | 3.96 | 3.10 | 3.17 | 3.40 | 3.09 | 3.05 | 3.30 | 3.13 | 3.29 | 3.75 |

On the third day, the significant differences of aphid growth rate in non-tended ant colonies were found between experimental patterns (*Kruskal–Wallis* test: $\chi2$ = 10.576, df = 3, *P*=0.014). Moreover, on fifth day the significant differences of aphid growth rate in *O. denticulata* tended-colonies were found between experimental patterns (*Kruskal–Wallis* test: $\chi2$ = 9.345, df = 3, *P*=0.025). This showed the contrary results from the previous section (aphid and ant abundance comparison).

**Table 5.5** Mean growth rate of aphids between ant treatments in cabbage experiment on October 2011, Wiangsa district, Nan province**,** (N= non ant tended-colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies)

| Day | | Aphid growth rate (mean±SE) | | |
|---|---|---|---|---|
| | | Source plant | | |
| | Ant treatment | N | C | O |
| 1 | | 6.06±0.02 | 6.03±0.02 | 6.04±0.02 |
| 2* | | $5.37\pm0.06^{ab}$ | $5.18\pm0.06^{b}$ | $5.58\pm0.05^{a}$ |
| 3* | | $3.39\pm0.19^{b}$ | $3.59\pm0.11^{b}$ | $3.95\pm0.07^{a}$ |
| 4* | | $0.87\pm0.12^{b}$ | $1.18\pm0.12^{b}$ | $2.00\pm0.18^{a}$ |
| 5 | | -0.40±0.38 | -0.138±0.30 | 0.440±0.304 |

*The mean growth rate of aphid in each ant treatment column with the different letter were significantly Difference between ant treatments by *Kruskal-Wallis test* (p≤0.05) with *Tamhane's T2* (p≤0.05)

Comparing aphid growth rate between ant treatments, there was a significant difference of aphid growth rate found between ant treatments on the second, third, and fourth day (*Kruskal–Wallis* test: $\chi2$ = 19.912, df = 2, *P*<0.05; $\chi2$ =0.8435, df = 2, *P*<0.05; $\chi2$ = 18.087, df = 2, *P*<0.05), respectively (Table 5.5).

On the second day, the aphid growth rate of *O. denticulata*-tended was significantly higher than *Camponotus rufoglaucus*-tended colonies (*Tamhane*-T2 *test*, p ≤ 0.05). The third and fourth day, the aphid growth rate of *O. denticulata*-tended was significantly higher than *Camponotus rufoglaucus*-tended colonies (*Tamhane*-T2 *test*, p ≤ 0.05) and also non-ant-tended colonies (*Tamhane*-T2 *test*, p ≤ 0.05) (Figure 5.10, Table 5.5).

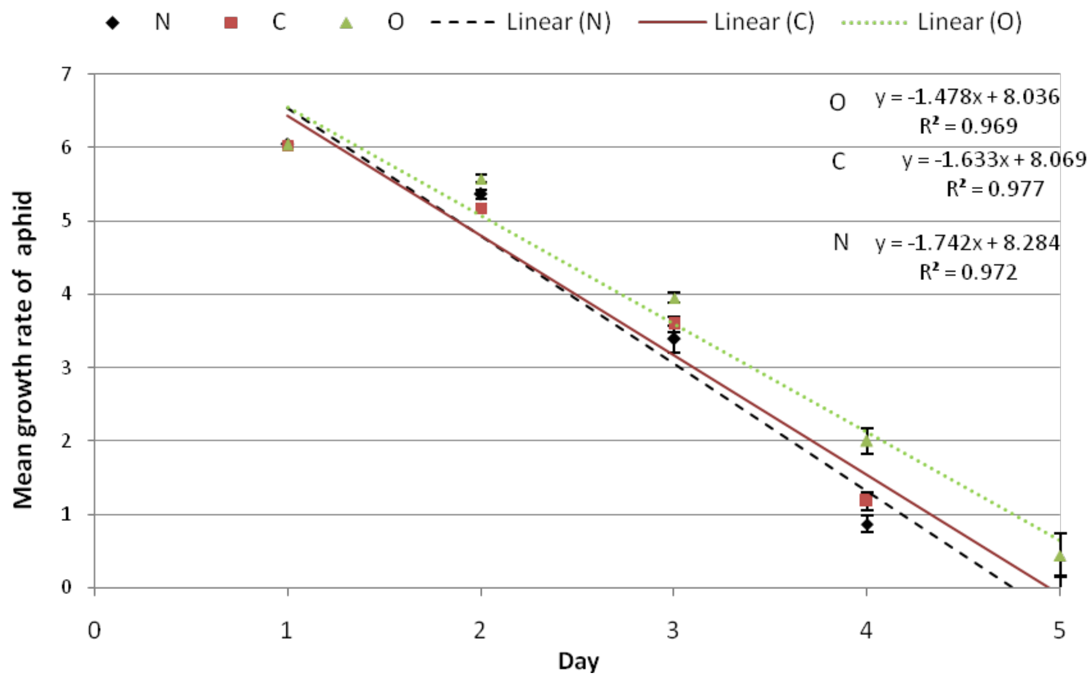



**Figure 5.10** Comparison of mean growth rate of aphids in five day periods between ant treatments, (C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata*tended-colonies) (mean±SE)

**Aphid dispersal**

The aphid dispersal rate was calculated by the equation adapted from the dispersal fromdispersal between leaf toleaf in one plantby Lombaert et al. (2006).

$$\text{Dispersal rate} = \frac{\text{No. aphids on target plant}}{\text{No. aphids on source plant}}$$

There was a significant difference of aphid dispersal rate in the 4th day. Aphids dispersedmore to cabbage in experimental pattern CC than SC which implied the greater preference of aphid on cabbage over Siam weed (*Kruskal–Wallis* test: $\chi 2 = 11.720$, df = 3, *P*=0.008, *Tamhane*-T2 *test*, $p \leq 0.05$) (Table 5.6, Figure 5.11). In the same day, the significant dispersal rate difference was also found to be greater in experimental pattern CS than SC which is contrary to the previous results(*Tamhane*-T2 *test*, $p \leq 0.05$). On the 5th day, aphid disperse was significant by higher in experimental CC than SC which agrees to the results from the previous day (*Kruskal–Wallis* test: $\chi2 = 10.126$, df = 3, *P*=0.018, *Tamhane*-T2 *test*, $p \leq 0.05$) (Table 5.6, Figure 5.11).

**Table 5.6** Mean dispersal rate of aphids between experimental patterns in cage experiment on October 2011, Wiangsa district, Nan province**,** (CC (inner-border plant: cabbage-cabbage), SS (inner-border plant: Siam weed-Siam weed), CS (inner-border plant: cabbage-Siam weed), SC (inner-border plant: Siam weed-cabbage))

| Day | Mean dispersal rate (mean±SE) | | | |
|---|---|---|---|---|
| | Source plant | | | |
| | CC | CS | SS | SC |
| 1 | 0.0020±0.0006 | 0.0018±0.0004 | 0.0034±0.0004 | 0.0020±0.0004 |
| 2 | 0.0040±0.0010 | 0.0034±0.0008 | 0.0041±0.0005 | 0.0018±0.0005 |
| 3 | 0.0081±0.0021 | 0.0056±0.0015 | 0.0069±0.0014 | 0.0030±0.0005 |
| 4* | 0.0119±0.0021 | 0.0087±0.0017 | 0.0103±0.0018 | 0.0039±0.0007 |
| 5* | 0.0203±0.0032 | 0.0130±0.0023 | 0.0124±0.0026 | 0.0082±0.0013 |

*The mean growth rate of aphid in each ant treatment column with the different letter were significantly difference between ant treatments by *Kruskal-Wallis test* ($p \leq 0.05$) with *Tamhane's T2* ($p \leq 0.05$)

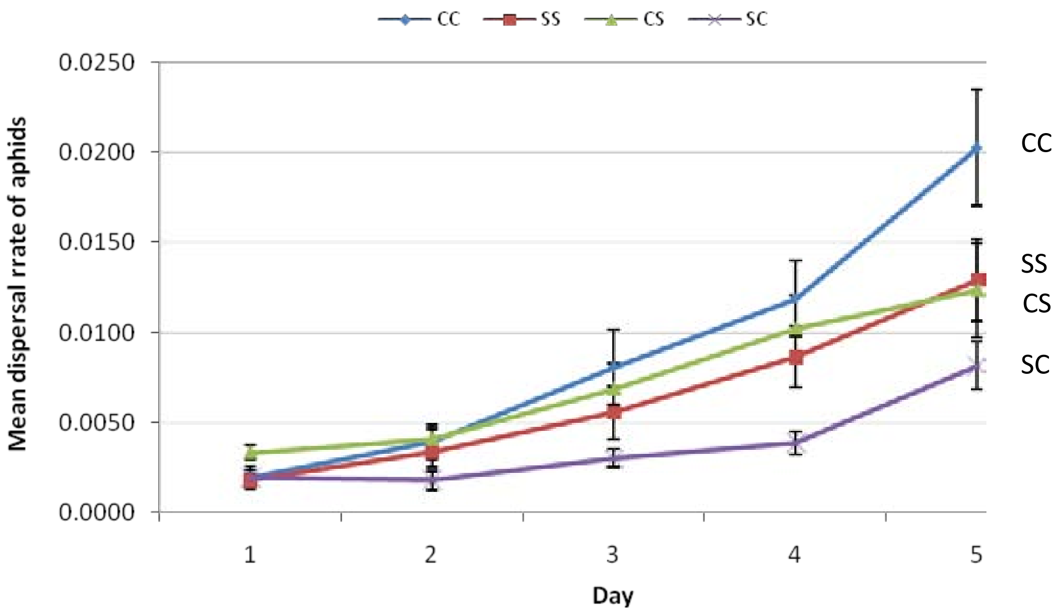



**Figure 5.11** Comparison of mean dispersal rate of aphids in five-day periods between experimental patterns, (CC (inner/border plant: cabbage/cabbage), SS (inner/border plant: Siam weed/Siam weed), CS (inner/border plant: cabbage/Siam weed), SC (inner/border plant: Siam weed/cabbage)) (mean±SE)

Comparing aphid dispersal rate between ant treatments,more aphids dispersed to target plants in the *Camponotus rufoglaucus*-tended colonies than in the *O. denticulata* tended-colonies significantly. This significant difference between two ant treatments of aphid dispersal rate only recovered on the 2nd day (*Kruskal–Wallis* test: $\chi2$ = 7.214, df = 2, *P*=0.027, *Tamhane*-T2 *test*, $p \leq 0.05$)(Table 5.7, Figure 5.12) and also on the 5th day (*Kruskal–Wallis* test: $\chi2$ = 7.168, df = 2, *P*=0.028, *Tamhane*-T2 *test*, $p \leq 0.05$) (Table 5.7, Figure 5.12).

**Table 5.7** Mean dispersal rate of aphids between ant treatments in cage experiment on October 2011, Wiangsa district, Nan province**,** (N= non ant tended-colonies, C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata* tended-colonies)

| Day | Mean dispersal rate (mean±SE) | | |
|---|---|---|---|
| | Ant treatment | | |
| | N | C | O |
| 1 | 0.0023±0.0004 [a] | 0.0027±0.0005 [a] | 0.0019±0.0004 [a] |
| 2* | 0.0036±0.0008[ab] | 0.0043±0.0005[b] | 0.0020±0.0005[a] |
| 3 | 0.0075±0.0018 [a] | 0.0064±0.0011 [a] | 0.0039±0.0007 [a] |
| 4 | 0.0094±0.0020 [a] | 0.0100±0.0012 [a] | 0.0067±0.0014 [a] |
| 5* | 0.0147±0.0028[ab] | 0.0167±0.0018[b] | 0.0090±0.0020[a] |

*The mean dispersal rate of aphid in each ant treatment column with the different letter were significantly difference between ant treatments by *Kruskal-Wallis test*($p \leq 0.05$) with *Tamhane's T2* ($p \leq 0.05$)

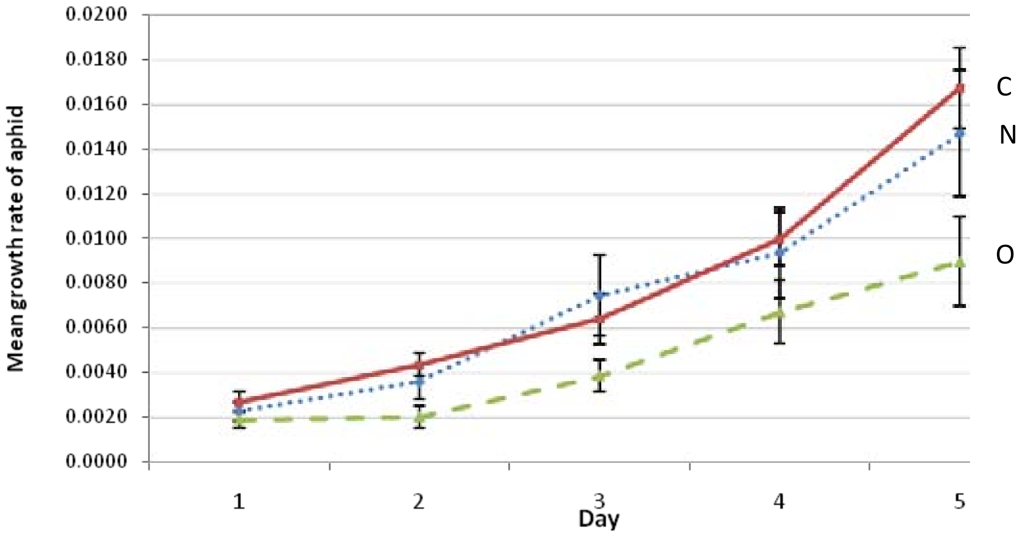



**Figure 5.12** Comparison of mean dispersal rate of aphids in five-day periods between ant treatments, (C = *Camponotus rufoglaucus* tended-colonies, 0= *Odontoponera denticulata*tended-colonies) (mean±SE)

## 5.4 Discussion

### Experimental pattern

The non significant difference among the four experimental patterns on the source plants shows that cabbage and Siam weed both have potential to be a good hosts plant of *A. gossypii*. In other words, the type of border plants or source plants regardless of cabbage or Siam wed did not play role on the aphid population density over the study period, indicating the similar aphid population growth pattern all experimental patterns.

### Ant treatments

The significant difference was found between mean aphid abundance on both source plant and target plants. The mean aphid abundance was highest with *Camponotus rufoglaucus*, followed by non-tended and lowest on *O. denticulata* tended-colonies on both plant patterns. The difference of aphid number on plants between the two ant species suggested that the nutritive assessment of *Camponotus rufoglaucus* and *O. denticulata* differed. The greatest mean number of aphid in *Camponotus rufoglaucus*-tended colonies correspond to the mean number of *Camponotus rufoglaucus* which were also found significantly greatest in the experiment. This has confirmed this ant preference in honeydew to protein as previously reported in Chapter III. The positive effects of this ant to aphid abundance and aphid population growth indicated that *Camponotus rufoglaucus* can influence the aphid population growth in colonies comparing to the other ant treatments. The results agree with the study which reported the higher aphid density as the result of *Camponotus rufoglaucus* attendance on *Aphis coreopsidis* (Thomas) on the plant *Biden spilosa* L. (Asteraceae)

In contrast, the lowest aphid abundance was observed in *O. denticulata*-tended colonies, indicating the negative effects of this ant species to aphid abundance or population growth. The role of *O. denticulata* serving as honeydew forager was rarely evident in this experiment. The preying behavior of tended-ants on lone, rapidly moving aphids was also reported (Way, 1963; Rosengren and Sundstrom, 1991). Some ant species may eat rather than tend aphid (Stadler and

Dixon, 1999). Therefore, the role of *O. denticulata* as predatory ants over honeydew harvested-ant is supported. In conclusion, the reduction of aphid population over the study periods in this treatment tended to be influenced by this *O. denticulata* predation.

The mean number of aphids on target plants represented the ability of aphid to establish on host target plant and also the potential of tended-ant on aphid dispersal. The nonsignificant difference between aphid number in both non- ant-tended colonies and *Camponotus rufoglaucus*-tended colonies shows that aphids in non-ant tended colonies have the same potential in dispersal to new host plants (target plants) as aphids in *Camponotus rufoglaucus*-tended colonies. However, the greater aphid number in previous ant treatment was higher than in *O. denticulata* tended-colonies indicating that *O. denticulata* not only suppresses aphid abundance in source plants but also have negative effects or suppress aphid dispersal ability in the target plants.

The mean ant abundance was corresponds to mean aphid abundance result, that is, *Camponotus rufoglaucus*-tended aphid number was significantly higher than *O. denticulata* number in both source plant and target plant. This confirmed the positive effect of *Camponotus rufoglaucus* on aphid abundance.

The low mean number of tended-ant on target plant during the first few days showed the non-apparent interaction of tended-ants on aphid dispersal. This may be due to the result of low number of dispersing aphid as well as the result from the low ability of ants to detect and evaluated the new target plant quality immediately. This is agreement with Collins and Leather (2002)who reported the late of tended-ant activity on the first time of aphid-ant-host plant contact, which was due to ant was trying to find the proper host plant quality for aphid and also great composition of honeydew for their ant feeding.

**Aphid growth rate**

The aphid population growth rate declined significantly along the study period and reached the carrying capacity at 133.15, assuming from the negative growth rate on the 5$^{th}$ day. This indicated that the host plant was beyond the aphid dispersal time.

Based on the experimental patterns, the mean aphid growth rate on the 3$^{rd}$ and 5$^{th}$ day significantly differed which was contrary to the previous result on the mean aphid abundance. This may be due to the established ability of *A. gossypii* on different morphological characteristics of source plant species. The significantly highest aphid growth rate on *O. denticulata* tended-colonies over *Camponotus rufoglaucus* and non-ant-tended colonies was found on the 2$^{nd}$ and 3$^{rd}$ day of the experiment. This may due to the non-effect of tended ants or even increased the probability of a population declining at high aphid densities which previously reported (Addicott, 1979; Breton and Addicott, 1992). This result confirmed that the ant-tended activity caused less effect at higher aphid densities. This may be because tended-ants are unable to respond to the increase in aphid population immediately or they might have limited needs for honeydew (Addicott 1979). Therefore, the mean growth rate between *Camponotus rufoglaucus* tended-colonies and non-ant-tended colonies were not significantly different. In the case of *O. denticulata*, aphid may induce a high rate of population growth for the persistence of the colonies by producing the more offspring strategies. In the absence of ants, tended-aphid colonies were reported to use more of their resources for preparing dispersal for searching new host plant to increase the chance of survival of their clones assuming from the reports on higher alate development rate in the non-ant tended colonies (Banks, 1958; El-Ziady, 1960). These could be the possible explanations for higher growth rate of *O. denticulata* tended-colonies. This is similar to the significant suppression on the aphid growth rate and establishment contributed from the presence of coccinellids (Meihls et al., 2010).

The significant reduction of population growth rate from ant attendance was found only in facultatively ant-attended aphid species (Stadler and Dixon 1998; Yao et al., 2000; Stadler et al., 2002). The non significant effect of *Camponotus rufoglaucus* on *A. gossypii* growth rate indicated that *A. gossypii* was facultative myrmecophiles.

**Aphid dispersal**

There was a significant difference of mean aphid dispersal rate on SC experimental pattern than CC on the 4$^{th}$ and 5$^{th}$ day. This confirmed the possible plant species and edge-location effect of both source plant and target plant on aphid preference which contribute to aphid dispersal and in population growth rate. The result indicates the preference of aphid on cabbages over Siam weed which may be due to the attracted volatile compounds emitted and the longer energy wave length reflected from cabbage plants (Pettersson, Tjallingii, and Hardie, 2007; Powell, Tosh, and Hardie, 2006).

The significant highest aphid dispersal rate of *Camponotus rufoglaucus* tended-colonies on the 2$^{nd}$ and 5$^{th}$ day of experiment confirmed the positive role of this species on aphid population abundance and also dispersal rate to target plant.

The results showed the contrary to reports found the reduction of dispersal in ant-tended colonies comparing to ant absence (Oliver et al., 2007). The explanation was focused on the timing of dispersal or host plant condition in each report. The reduction of dispersal which was influenced by ant presence may play a high-level effect on the high quality host plant or in the immediately tactile contact between them, but the result from this study gathered from the low quality host plant as demonstrated by the reaching point of carrying capacity. The experiment was done for five consecutive days which might provide enough time for ant to detect and evaluate whether they responded to host plant and aphid colonies. Consequently, the higher dispersal strategies to search for new high quality host plant may be the better choice evaluate from tended-ants.

The non significant difference of aphid dispersal rate between *Camponotus rufoglaucus* tended-colonies and non-tended-ant colonies also indicated that the relationship between *A. gossypii* and *Camponotus rufoglaucus* could play the low level effect on aphid abundance and dispersal rate colonies, and also confirmed that

*A. gossypii* was not the obligate myrmecophiles which totally depend on tended-ants.

# CHAPTER VI

# CONCLUSIONS AND RECOMMENDATIONS

*Aphis gossypii* and *A. spiraecola* were the only two aphid species found in the Siam weed sampling while only *A. gossypii* were found in commercial cabbage field (Chapter III), and *Lipaphis erysimi* was the dominant aphid species found on cabbage in the experimental plot together with *A. gossypii* which were the only aphid species found on both Siam weed and cabbage (Chapter IV). The higher number of *A. gossypii* over that of *A. spiraecola* during the study time was due to higher potential in reproduction and the wider range of host plant of *A. gossypii*. Therefore, *A. gossypii* had potential to become dominant pest and cause outbreak in Brassica plants in Wiangsa district Nan province. The common Brassica crops in Wiangsa Nan province were cultivated in early dry season which also coincided with the high aphid abundance observed in early dry season on both Siam weed and cabbage fields. *Camponotus rufoglaucus* was the most common tended-ants associated with *A. gossypii* and was also specific to the wet season. *Camponotus rufoglaucus* preferred to feed on honeydew while *Odontoponera denticulata* was the only predatory ants on aphids found in this study. Spiders show the highest potential as the predatory arthropods in suppressing aphid population.

The diversity and abundance of aphids and other arthropods in the experimental field was higher, but was still consistent to the sampling results (Chapter III). The aphid and other arthropod abundance on cabbage were greater in the second growing season than the first growing season due to higher temperature and low rainfall. On cabbage, *Lipaphis erysimi* was the dominant aphid species which were not found in the previous cabbage field sampling. *O. denticulata* and *Camponotus rufoglaucus* were the most abundant tended-ants on cabbage and both ants had the relationship to aphids, but *O. denticulata* mostly preyed on aphids rather than feed on honeydew. The dominance of these two species may be due to the large body size of both *Camponotus rufoglaucus* and *O. denticulata*. Adult and larval stages of lady beetles play an important role in suppressing aphid population on both cabbage and Siam weed in the first growing season, but their populations were not stable as they were not found in the last month of season. The greater abundance of arthropods suppressed the development of cabbages only 30 days after transplanting in the second growing season. On Siam weed, *A. gossypii* was the most abundant aphid which similar to the annual sampling result (Chapter III).The relative abundance of tended-ant still was *Camponotus rufoglaucus*, followed by *Anoplolepis gracilipes* and *Monomorium* sp. which confirmed the dominance of *Camponotus rufoglaucus* as the successful honeydew feeding ant. In contrast to the first growing season, Spiders were the most abundant other arthropods that may show the suppressive effect on the aphid population in the second growing season in this study site.

The edge-host plant effect was found on determining the population growth rate and dispersal rate of aphid (Chapter V). This showed the possible preference and different plant area usage of aphid and tended-ants on host plant species. *Camponotus rufoglaucus* had the positive effect on the mean aphid abundance and the dispersal rate to the tended-aphid colony. Ant presence in aphid colony resulted in higher mean aphid abundance and dispersal rate in this study which was consistent to the mean *Camponotus rufoglaucus* abundance tended on each colony. However, the low level of relationship assuming from the non significant difference of mean aphid abundance and dispersal rate between *Camponotus rufoglaucus* and non-ant-tended aphid colonies evidently showed that *A. gossypii* was the facultative myrmecophiles.

The lowest mean aphid abundance and dispersal rate in the aphid colony with *O. denticulata* confirmed the predatory role of *O. denticulata* in Siam weed and cabbage field sampling. Interestingly, the relationship form between aphids and *O. denticulata* resulted in the highest aphid growth rate comparing to other treatments. This showed the ecological adaptation to the unsuitable condition and responded in higher population growth rate to persist their colony; and *O. denticulata* also prevented aphids to reach the carrying capacity. There was no preference of aphid between cabbage and Siam weed in maintaining aphid colony. Therefore, the potential of Siam weed in being a reservoir plant for *A. gossypii* was confirmed and indicated the possible potential of Siam weed to serve as host plant to other aphid species which had related host plant range to cabbage, such as green peach aphid, *Myzus persicae*, and cabbage aphid, *Brevicoryne brassicae,* leading to more aphid outbreak. Consequently, more studies need to be done to determine the potential of this weed as plant reservoir in relation to other ant species. Further suitable management of Siam weed should be evaluated under concerning the relationship between both valuable crop and weed which also play an important role in other part of agricultural system.

To provide a sustainable outcome in Siam weed management, the ecological roles of pest, target plant, and also adjacent pest reservoir which play an important role in pest colonized and fluctuated should also be examined. Particularly in the Brassica production, the equal host plant potential between a Brassica plant (cabbage) and an aphid reservoir plant (cabbage) should also be considered in formulating the Siam weed and aphid management. The control of Siam weed should be accomplished before cultivating time, resulting in diminishing the colonized place and providing many profits in decreased insecticide usage. On the other hands, Siam weed could be served as a reservoir for natural enemies of aphids between the growing seasons, particularly spiders and lady beetles. Honeydew-tended ants such as *Camponotus rufoglaucus, Anoplolepis gracilipes,* and *Monomorium* sp. should be monitored and managed to reduce the dispersal of aphids from weed reservoir to crop plants. Moreover, ants and other arthropods in agricultural area should also be examined to evaluate whether they support or inhibit pest outbreak.

## REFERENCES


Addicott, J. F. 1979. A multispecies aphid ant association: density dependence and species specific effects. **Canadian Journal of Zoology** 57: 558 569.

Albajes, R., Lodovica, G. M., Van Lenteren, J. C., and Elad, Y. 2002. **Integrated Pest and Disease Management in Greenhouse Crops**. Netherlands: Kluwer Academic Publishers.

Ali, K., and Gebremedhin, T. 1990. Pea aphid: An important pest of field pea. **IAR Newsletter of Agricultural Research** 5: 1-2.

Alsina, A., Cerdá, X., Retana, J. & Bosch, J. 1988. Foraging ecology of the aphid-tending ant *Camponotus cruentatus* (Hymenoptera, Formicidae) in a savanna-like grassland. **Miscellania Zoologica** 12: 195-204.

Alvarez, J. M., and Srinivasan, R. 2005. Evaluation of hairy nightshade as an inoculum source for aphid-mediated transmission of potato leafroll virus. **Entomological Society of America** 4: 1101-1108.

Bale, J. S., Ponder, K. L., and Pritchard, J. 2007. Coping with stress in Emden, H. F. V., and Harrington, R. **Aphids as crop pests**. Wallingford UK: Cornwell press.

Banks, C. J. 1958. Effects of the ant, *Lasius niger* (L.), on the behaviour and reproduction of the black bean aphid, *Aphis fabae* Scop. **Bulletin of Entomological Research** 49: 701-714. Cited in Yao, I., Shibao, H., and Akimoto, S. 2000. Costs and Benefits of Ant Attendance to the Drepanosiphid Aphid Tuberculatus quercicola. **Nordic Society Oikos** 35: 30-38.

Beckerman, A. ., Uriarte, M., and Schmitz, O. J. 1997. Experimental evidence for a behavior-mediated trophic cascade in a terrestrial food chain. **Proceedings of the National Academy of Sciences of the United States of America**. 94: 10735–10738.

Bhatia, V., Uniyal, P.L., and Bhattacharya, R. 2011. Aphid resistance in Brassica crops: challenges, biotechnological progress and emerging possibilities. **Biotechnology Advances** 29: 879-88.

Billick I., Hammer S., Reithel J. S., and Abbot P. 2007. Ant–aphid interactions: are ants friends, enemies, or both? **Annals of the Entomological Society of America**. 100: 887–892.

Blackman, R. L. 1974. Life cycle variation of Myzus persicae (Sulz.) (Hom.,Aphididae) in different parts of the world, in relation to genotype and environment. **Bulletin of Entomological Research** 63: 595-607. Cited in Devonshire, A. L., Field, L.M., Foster, S. P., Moored, G. D., Williamson, M. S., and Blackman, R. L. 1998. The evolution of insecticide resistance in the peach-potato aphid, *Myzus presicae*. **The Royal Society** 353: 1677-1684.

Blackman, R. L., and Eastop, V. F. 1984. **Aphids on the World's Crops, An Identification Guide**. New York: John Wiley & Sons.

Blackman, R. L. 1998. The evolution of insecticide resistance in the peach-potato aphid, *Myzus presicae*. **The Royal Society** 353: 1677-1684.

Blackman, R. L., and Eastop, V. F. 2000. **Aphids on the World's Crops: An Identification and Information Guide**. England: John Wiley & Sons.

Blackman, R. L. and V. F. Eastop. 2007. Taxonomic Issues. In H. F. Van Emden and R. Harrington (eds.), **Aphids as Crop pests**, pp. 1-29. UK: CABI.

Bolton, B. 1994. **Identification Guide to the Ant Genera of the World**. Cambridge: Harvard University Press.

Borror, D. L., and De Long, D. M., and Tripelhorn, C. A. 1981. **An Introduction to the Study of Insect**. Fifth edition. Philadelphia: Saunders College Publishing.

Breton, L., and Addicott, J. F. 1992**. Density-dependent mutualism in an aphid-ant** interaction. **Ecology** 73: 2175-2180.

Brown, M.W., 1999b. Temporal changes in the aphid predator guild in eastern North America. Proc. integrated plant protection in orchards. **IOBC wprs Bull**. 23, 7–11.

Chandler, S. M., Wilkinson, T. L., and Douglas, A. E. 2008. Impact of plant nutrients on the relationship between a herbivorous insect and its symbiotic bacteria. **Proceedings of the Royal Society B - Biological Sciences** 275: 565-570.

Chapman, R.F., and de Boer, G. 1995. Regulatory Mechanisms in Insect Feeding. Chapman & Hall, New York, pp. 190–209.

Collins, C. M., and Leather, S. R. 2002. Ant-mediated dispersal of the black willow aphid *Pterocomma salicis* L.;does the ant *Lasius niger* L. judge aphid-host quality? **Ecological Entomology** 27: 238-241.

Dang K., Buffa, L. M., and Delfino, M. A. 2005. An aphid-ant interaction: Effects on different trophic levels. **Ecological Research** 20: 71–74.

Dang, Q. L., et al. 2010. Insecticidal activities of crude extracts and phospholipids from *Chenopodium ficifolium* against melon and cotton aphid, *Aphis gossypii.* **Crop Protection** 29*:* 1124–1129.

Delfino, M. A., and Buffa, L. M. 1996. Asociaciones hormigas-planta en la Argentina. **Revista Peruana De Entomologia** *39: 81-84.*

Devonshire, A. L., Field, L.M., Foster, S. P., Moored, G. D., Williamson, M. S., and Delfino, M. A., and Vuffa, L. M. 1996. Asociaciones hormigas-planta en la argentina**. Rev. Per. Ent.** 39: 81-84.

Dixon, A. F. G. 1973. **Biology of Aphids**. London: Edward Arnold.

Dixon, A. F. G. 1977. Aphid ecology: life cycles, polymorphism, and population regulation. **Annual Review of Ecology** 8: 329-353.

Dixon, A. F. G. 1985. Structure of aphid populations. **Annual Review of Entomology**. 30: 155-174.

Dixon, A. F. G. 1998. **Aphid ecology: an optimisation approach**. London: Chapman and Hall.

El-Ziady, S. 1960. Further effects of *Lasius niger* L. on *Aphis fabae* Scopoli. **Proceeding of the Royal Entomological Society of London**, Series A 35: 30-38. Cited in Yao, I., Shibao, H., and Akimoto, S. 2000. Costs and Benefits of Ant Attendance to the Drepanosiphid Aphid Tuberculatus quercicola**. Nordic Society Oikos** 35: 30-38.

Fischer, D. B., Wright, J. P., and Mittler, T. E. 1984. Osmoregulation by the aphid *Myzus persicae*: a physiological role for honeydew oligosaccharides. **Journal of Insect Physiology** 30: 387-393.

Fischer, M. K., Hoffman, K. H., and Volkl, W. 2001. Competition for mutualists in an ant-homopteran interaction mediated by hierarchies of ant attendance. **Oikos** 92: 531-541.

Fischer, M. K. and Shingleton, A. W. 2001. Host plant and ants influence the honeydew sugar composition of aphids. **Functional Ecology** 15: 544-550.

Fischer, M. K., Volkl, W., and Hoffmann, K. H. 2005. Honeydew production and honeydew sugar composition of polyphagous black bean aphid, *Aphis fabae* (Hemiptera: Aphididae) on various host plants and implications for ant-Attendance. **Eur. J. Entomol** 102:155-160.

Furk, C., and Hines, C. M. 1993. Aspects of insecticide resistance in the melon and cotton aphid, Aphis gossypii (Hemiptera: Aphididae). **Annual of Applied Biology** 123: 9-17.

Giordanengo, P., et al. 2010. Compatible plant-aphid interactions: how aphids manipulate plant responses. **Comptes Rendus Biologies** 333: 516-523.

Hagley, E. A. C. 1989. Release of *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae) for control of the green apple aphid, *Aphis pomi* DeGeer (Homoptera: Aphididae). **Canadian Entomologist** 121, 309-314.

Hall, J. B.., Kumar, R., and Enti, K. A. 1972. The obnoxious weed *Eupatorim odoratum* (Compositae) in Ghana. Ghana **Journal of Agricultural Sciences** 5: 75- 78.

Hardie, J., and Powell, G. 2002. Video analysis of aphid flight behavior. **Computers and Electronics in Agriculture** 35: 229-242.

Harrewijn, P., and Minks, A. K. 1989. Integrated aphid management: General Aspects. In P. Harrewijn and A. K. Minks (ed.), **Aphids: their biology, natural enemies and control**, pp. 267-271. New York: Elsevier.

Hennig, W. 1980. **Insect phylogeny**. New York: Wiley and Sons.

Hodgson, C. 1991. Dispersal of apterous aphids (Homoptera: Aphididae) from their host plant and its significance. **Bulletin of Entomological Research** 81: 417-427.

Holland N., De Angelis, D. L., Bronstein, J. L. 2002. Population dynamics and mutualism: functional responses of costs and benefits. **The American Naturalist** 159:231–244.

Idechiil, O., Miller, R. H., Pike, K. S., and Hansen, L. D. 2007. Aphids (Hemiptera: Aphididae), ants (Hymenoptera: Formicidae) and associated flora of Palau with comparisons to other Pacific Islands. **Micronesica** 39: 141-170.

Itô, K., and Iwao, S. 1977. Oviposition behavior of a syrphid, *Episyrphus balteatus*, in relation to aphid density on the plant. **Japanese Journal of Applied Entomology and Zoology** 21: 130-134.

Jankowska, B., Poniedzialek, M., and Jedrszczyk, E. 2009. Effect of intercropping white cabbage with French Marigold (*Tagetes patula nana* L.) and Pot Marigol (C*alendula officinalis* L.) on the colonization of plants by pest insects. **Folia Horticulturae**. 21: 95-103.

Junpong, P. 2008. **The chemical usage in Nan province agriculture**. Nan: Department of Agricultural Extension, (Mimeographed)

Kingsolver, J. G. and Daniel, T. L. 1995. Mechanics of Food Handling by Fluid-Feeding Insects. In Chapman, K. F. and Boer, G. De. **Regulatory mechanisms in insect feeding**. New York: Chapman & Hall.

Lambers, H. R. 1966. Polymorphism in Aphididae. **Annual Review of Entomology** 1: :47-78

Lang, A., Filser, J., and Henschel, J. R. 1999. Predation by ground beetles and wolf spiders on herbivorous insects in a maize crop. **Agricultural Ecosystem Environment** 72:189.199.

Lees, A. D. 1967. The production of the apterous and alate forms in the aphid *Megoura viciae* Buckton, with special reference to the role of crowding. **Journal of Insect Physiology** 3: 289-318.

Leroy, P.D., Sabri, A., Heuskin, S., Thonart, P., Lognay, G., Verheggen, F. J., Francis,F., Brostaux, Y., Felton, G. W., and Haubruge, E. 2011. Microorganisms from aphid honeydew attract and enhance the efficacy of natural enemies. **Nature Communications** 2: 348.

Le Trionnaire, G., Hardie, J., Jaubert-Possamai, S., Simon, J. C., and Tagu, D. 2008. Shifting from clonal to sexual reproduction in aphids: physiological and developmental aspects. **Biology of the cell** 100: 441–451.

Lombaert, E., Boll, R., and Lapchin, L. 2006. Dispersal strategies of phytophagous insects at a local scale: adaptive potential of aphids in an agricultural environment. **BMC Evolutionary Biology** 6: 75.

Matsuka, M . , Mittler, T. E. 1978. Enhancement of alata production by an aphid, *Myzus persicae*, in response to increases in daylength. **Bulletin of the Faculty of Agriculture of Tamagawa University Tokyo** 18: 1-7.

MacDonald, I.A.W. 1984. Infiltration of dreaded weed alarms experts. **Custos** 13: 33-35.

Mcdonald, S. A., Halbert, S. E., Tolin, S. A., and Nault, B. A. 2003. Seasonal Abundance and Diversity of Aphids (Homoptera: Aphididae) in a Pepper Production Region in Jamaica. **Environmental Entomology** 32: 499-509.

Miles, P. W. 1999. Aphid saliva. **Biological Reviews of the Cambridge Philosophical Society** 74: 41-85.

Ministry of public health. 2009. Nan new [Online]. Source: http://www.nancity.go.th/board/viewtopic.php?f=10&t=830 [2553, June 9].

Muller, C. B., Williams, I. S., and Hardie, J. 2001. The role of nutrition, crowding and interspecific interactions in the development of winged aphids. **Ecological Entomology** 26: 330-340.

Muniappan, R. and Marutani, M. 1988. Ecology and distribution of *Chromolaena odorata* in Asia and Pacific. In R. Muniappan (ed.), **Proceedings of the First International Workshop on Biological Control of *Chromolaena odorata*, February-March, Bangkok, Thailand, pp. 21-24**. **Guam: Agriculture Experiment Station, University of Guam.**

Napompeth, B., Hai, N. T., and Winotai, A. 1988. Attempts on biological control of Siam weed in Thailand. In R. Muniappan (ed.), **Proceedings of the First International Workshop on Biological Control of *Chromolaena odorata,* February-March, Bangkok, Thailand, pp. 57-62. Guam: Agriculture Experiment Station, University of Guam.**

Napompeth, B., Winotai, A. 1991. Progress on biological control of Siam Weed, *Chromolaena odorata* in Thailand. **Ecology and Management of *Chromolaena odorata*BIOTROP Special Publication** 44: 91-97.

Nault, B. A., Shah, D. A., Dillard, H. R., and McFaul, A. C. 2004. Seasonal and spatial dynamics of alate aphid dispersal in snap bean fields in proximity to alfalfa and implications for virus management. **Environmental Entomology**. 33:1593-1601.

Nentwig, W., Frank, T.,and Lethmayer, C. 1998. Sown weed strips: artificial ecological compensation area as an important tool in **conservation biological control**. In Barbosa, P. (ed.), Conservation biological control, pp. 142-144. USA: Academic Press.

Norgrove, L., Tueche, R., Dux, J., and Yonghachea, P. 2008. *Chromolaena odorata*: the benevolent dictator? ***Chromolaena odorata* Newsletter** 17: 1-8.

Office of Agricultural Economics, 2009, The annual crops 2007/2008 [Computer file]. **Office of Agricultural Economics**. Source: http://nan.doae.go.th/ [2009, May 9].

Oigicangbe, O. N., Uyi, O. H., Aisaghonhi, C. I., and Igbinosa, I. B. 2007. Ecological roles of insects on Siam weed *Chromolaena odorata* (L.). **Advance in Science and Technology** 1: 108-115.

Ollivier, M. and Rispe, C. 2010. Evolutionary dynamics in the aphid genome: search for genes under positive selection and detection of gene family expansions. **Evolutionary biology** 2: 133-142.

Oliver, T. H., Mashanova, A., Leather, S. R., Cook, J. M., and Jansen, V. A. A. 2007. Ant semiochemicals limit apterous aphid dispersal. **Proceedings of the Royal Society B** 274: 3127–3131.

Owen, D. F. 1978. Why do aphids synthesize melezitose? **Nordic Society Oikos** 31: 264-267.

Petelle, M. 1980. Aphids and melezitose: a test of Owen's 1978 hypothesis. **Nordic Society Oikos** 35: 127-128.

Perez, K., and Robert, Y. 1984. Observaciones sobre estacionalidad de vuelos de a´ *Myzus persicae* (Sulz.) en cultivo de patata. **Agronomie** 4: 161-169.

Pettersson, J., Tjallingii, W. F., and Hardie, J. 2007. Host-plant selection and feeding. In H. F. van Emden and R. Harrington (eds.), **Aphids as Crop pests**, pp. 87-113. UK: CABI.

Pike, K. S., Miller, R. H., and Stary, P. 2000. Aphid fauna (Hemiptera: Aphididae) and Associated flora of Guam. **Micronesica** 33: 179-207.

Pfeiffer, D. G., Brown, M. W., and Varn, M. W. 1989. Incidence of *spirea* aphid (Homoptera: Aphididae) in apple orchards in Virginia, West Virginia and Maryland. **Journal of Entomological Science** 24: 145-149.

Powell, G., Tosh, C. R., and Hardie, J. 2006. Host plant selection by aphids: behavioral, evolutionary, and applied perspectives. **Annual Review of Entomology** 51: 309–330.

Rabasse, J. M. and Steenis, M. J. V. 1999. Biological control of aphids. In Albajes, R., Lodovica, G. M., Van Lenteren, J. C., and Elad, Y (ed.), **Integrated Pest and Disease Management in Greenhouse Crops**. pp. 235-243. Netherlands: Kluwer Academic Publishers.

Rohitha, B. H., and Penman, D. R. 1986. Flight of the blue green aphid, *Acyrthosiphon kondoi* Shinji (Homoptera: Aphididae). III. Comparison of trapping methods for *A. kondoi* and natural enemies. **New Zealand Journal of Zoology** 13: 215-220.

Sanchez, M. C., Cermelio, M., Machado, W., Centeno, F., and Brown, E. 2000. Diversidad de áfidos (Homoptera: Aphididae) capturados con trampas amarillas en el cultivo de pimentón (*Capsicum annuum* L.) y su relación con los factores climáticos. **Boletin de Entomologia Venezolana** 15: 61-83.

Sarker, P. K., Rahman, M. M., and Das, B. C. 2007. Effect of intercropping of mustard with onion and garlic on aphid population and yield. **Journal of Biological Science** 15: 35-40.

Schalk, J.M., Kindler, S.D., and Manglitz, G.R. 1969. Temperature and the preference of the spotted alfalfa aphid for resistant and susceptible alfalfa plants**. Journal of Economic Entomology** 62, 1000–3.

Schoonhoven, L. M., Van Loon, J. J. A., and Dicke, M. 2005. **Insect-Plant Biology**, Ed 2. Oxford University Press, Oxford.

Shaposhnikov, G.C. 1987. Evolution of aphids in relation to evolution of plants. In A. K. Minks and P. Harrewijn (eds.), **Aphids, their biology, natural enemies and control**, pp. 409–414. Amsterdam: Elsevier.

Simon, J. C., Rispe, C., and Sunnucks, P. 2002. Ecology and evolution of sex in interspecific interactions in the developmemt of winged aphids. **Ecological Entomology** 26: 330-340.

Sirikajornjaru, W. 2002. **Taxonomic Study of Aphids (Homoptera : Aphididae) in Northern Thailand**. A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy (Biology), Mahidol University, Bangkok. 325 pp.

Smith, S.D., and Kentall, D. A., and Wright, M. A. 1984. Weed grasses as host of cereal aphids and effects of herbicides on aphid survival. In: **Proceedings British Crop protection conference-Pests and Disease,** pp. 19-24. Brighton.

Snyder, W. E., and IVES, A. R. 2003. Interactions between specialist and generalist natural enemies: parasitoids, predators, and pea aphid biocontrol. **Ecology** 84: 91–107.

Stadler, B. 2004. Wedged between bottom-up and top-down processes: aphids on tansy. **Ecological Entomology** 29:106–16.

Stadler, B., Dixon, A. F. G. 1998. Costs of ant attendance for aphids. **Journal of Animal Ecology** 67: 454–59.

Stadler, B., and Dixon, A.F.G. 1999**.** Ant attendance in aphids: why different degrees of myrmecophily? **Ecological Entomology**. 24: 363-369.

Stadler, B., and Dixon, A. F. G. 2005. Ecology and evolution of aphid-ant interactions. **Annual Review of Ecology, Evolution, and Systematics**. 36: 345-372.

Stadler, B., Dixon, A. F. G., Kindlmann, P. 2002. Relative fitness of aphids: effects of plant quality and ants. **Ecological Letter** 5:216–222.

Sunderland, K. D., and Samu, F. 2000. Effects of agricultural diversity on the abundance, distribution, and pest control potential of spiders: a review. **Entomologia Experimentalis et Applicata** 95, 1-13.

Symondson,W. O. C., Sunderland, K. D., and Greenstone, M.H. 2002. Can generalist predators be effective biocontrol agents? **Annual Review of Entomology** 47:561–594.

Tanaka, K., Endo, S., and Kazano, H. 2000. Toxicity of insecticides to predators of rice planthoppers: spiders, the mired bug, and the dryinid wasp. **Applied Entomology and Zoology** 35: 177-187.

The State of Queensland, Department of Employment, Economic Development and Innovation. 2009. **Siam weed, *Chrompolaena odorat***a [Online]. Available from:http://www.moretonbay.qld.gov.au/uploadedFiles/moretonbay/environment/vegetation/siam-weed.pdf [2012, May]

The World Conservation Union (IUCN). 2006. **Invasive Alien Species in the Lower Mekong Basin: Current State of (2006) Mekong Wetland Biodiversity Programme and Regional Species Conservation Programme** [Online]. Available from: http://cmsdata.iucn.org/downloads/mlb_ias_current_state_of_play.pdf, MWBP/RSCP Play, Asia. [2012, May]

Timbilla, J. A and Braimah, H. 2000. Establishment, Spread and Impact of *Pareuchaetes pseudoinsulata* (Lepidoptera: Arctiidae), an Exotic Predator of the Siam Weed, *Chromolaena odorata* (Asteraceae: Eupatoriae) in Ghana. In N. R. Spencer (ed), **Proceedings of the Tenth International Symposium on the Biological Control of Weeds, Montana, July, Montana State University, Bozeman, USA, pp. 105-111.**

Van Emden, H. F., and Hagen, K. S. 1976. Olfactory reactions of the green lacewing, *Chrysopa carnea*, to tryptophan and certain breakdown products. **Environmental Entomology** 5: 469–473.

Van Emden, H. F., and Harrington, R. 2007. **Aphids as Crop pests**. England: CABI.

Verghese, A., and Tandon, P. L. 1987. Interspecific association among *Aphis gossypii*, *Menochilus sexmaculatus* and *Camponotus compressus* Fab. In a guava ecosystems. **Phytoparasitica** 15: 289-297.

Verhulst, P. F. 1838. Notice sur la loi que la population pursuit dans son accroissement. **Journal of Mathematicl Physics** 10: 113-121.

Visser, J.H. (1986). Host odor perception in phytophagous insects**. Annual Review of Entomology**, 31, 121–44.

Volkl, W., Woodring, J., Fischer, M., Lorenz, M. W., and Hoffman K. H. 1998. Ant-aphid mutualism: the impact of honeydew production and honeydew sugar composition on ant preference. **Oecologia** 118:483-491.

Volkl, W., Woodring, J., Fischer, M., Lerenz, M. W., Hoffmann, K. H. 1999. Ant-aphid mutualisms: the impact of honeydew production and honeydew sugar composition on ant preferences. **Oecologia** 118: 483-491.

Wackers, F.L. 2000. Do oligosaccharides reduce the suitability of honeydew for predators and parasitoids? A further facet to the function of insect-synthesized honeydew sugars. **Nordic Society Oikos** 90: 197-201.

Way M.J. 1963. Mutualism between ants and honeydew producing Homoptera. **Annual Review of Entomology** 8**:** 307-343.

Whittaker J.B. 1991. Effects of ants on temperate woodland trees. In C. R. Huxley and D. F. Cutler. (ed.), **Ant-plant interactions**, pp. 67–79. New York: Oxford university Press.

Will, T., Tjallingii, W. F., Thonnessen, A., and van Bel, A. J. E. 2007**.** Molecular sabotage of plant defense by aphid saliva. **Proceedings of the National Academy of Sciences of the United States of America** 104: 10536-10541.

Winder, L., Perry, J. N., and Holland, J. M. 1999. The spatial and temporal distribution of the grain aphid *Sitobion avenae* in winter wheat. **Entomologia Experimentalis et Applicata.** 93: 277–290.

Wratten, S.D., Gurr, G.M., Tylianakis, J.M., and Robinson, K.A. 2007. Cultural control. Cite in: **Aphids as crop pests**. H.F. van Emden and R. Harrington (eds). CAB International, Wallingford, pp. 423-439.

Yao, I., Shibao, H., Akimoto, S. 2000. Costs and benefits of ant attendance to the drepanosiphid aphid *Tuberculatus quercicola*. **Oikos**. 89: 3–10.

# APPENDICES

# APPENDIX A

**Figure 1-A Study site (Chapter III)**

**Figure 2-A Study site (Chapter IV)**

# APPENDIX B

**Table 1-B** The abundance and percentage of relative abundance of ants found on *Chromolaena odorata*, August 2010-September 2011, Wiangsa district, Nan province

| **Species** | **Abundance (individual)** | **Relative abundance (%)** |
|---|---|---|
| *Camponotus rufoglaucus* | 361 | 39.80 |
| *Monomorium destructor* | 230 | 25.36 |
| *Tapinoma melanocephalum* | 98 | 10.80 |
| *Pheidologeton diversus* | 50 | 5.51 |
| *Anoplolepis gracilipes* | 40 | 4.41 |
| *Monomorium* sp. | 38 | 4.19 |
| *Crematogaster rogenhoferi* | 30 | 3.31 |
| *Oecophylla smaragdina* | 24 | 2.65 |
| *Monomorium pharaonis* | 20 | 2.21 |
| Crematogaster sp. | 11 | 1.21 |
| *Camponotus* sp. | 3 | 0.33 |
| *Paratrechina longicornis* | 1 | 0.11 |
| *Odontoponera denticulata* | 1 | 0.11 |
| total | 907 | 100.00 |

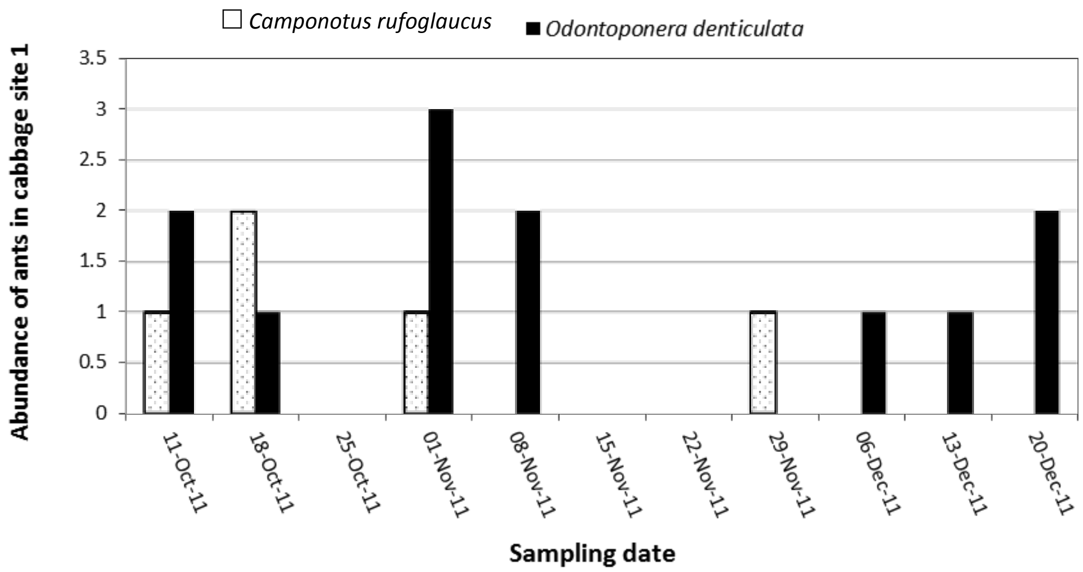



**Figure 1-B** Comparison of mean number of ants, *Camponotus rufoglaucus* and *Odontoponera denticulata*, caught per sampling time in cabbage cultivating sites 1, October-December 2011, Wiangsa district, Nan province

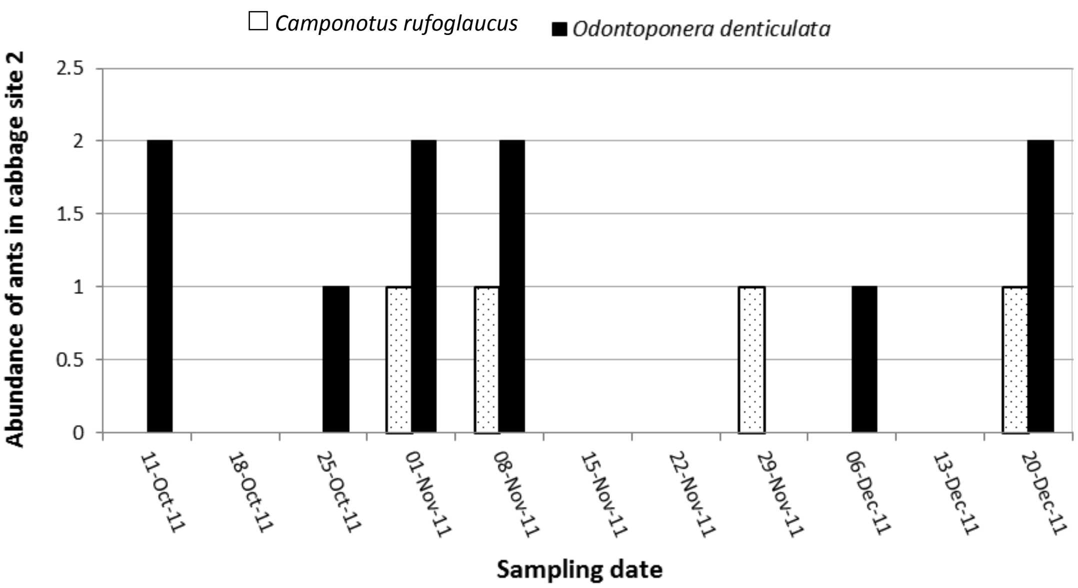



**Figure 2-B** Comparison of mean number of ants, *Camponotus rufoglaucus* and *Odontoponera denticulata*, caught per sampling time in cabbage cultivating sites 2, October-December 2011, Wiangsa district, Nan province

# BIOGRAPHY

Miss Puntharika Khongruang was born on the 29th of March 1987 in Songkhla province. She graduated her bachelor's degree of science in Zoology in 2008 from the Department of Biology, Faculty of Science, Chulalongkorn University. She continued her graduate study and graduated a master's degree of science in Zoology at the same institute in 2012.