Studies on the control of Dubas bug, *Ommatissus lybicus* DeBergevin (Homoptera: Tropiduchidae), a major pest of Date Palm in the Sultanate of Oman

AL SARAI AL ALAWI Mamoon

A thesis submitted for the Degree of Doctor of Philosophy

of Imperial College London and the Diploma of Imperial College London

Department of Life Sciences

Silwood Park Campus

Imperial College London

October 2015

Dedication

I lovingly dedicate this thesis to

my ***parents***

for their love, endless support and encouragement,

to

***my wife and my sons**,*

to

my brothers and sisters

who supported me on each step of the way.

Declaration

The work presented in this thesis is entirely my own and has not been submitted anywhere else.

Signed.. AL SARAI ALALAWI Mamoon

Certified...Professor Denis J. Wright

(Supervisor)

Certified ....Mr. Hans Dobson

(Supervisor)

Acknowledgments

"In the name of God, the Merciful, the Compassionate. Say (O Muhammad) He is God the One God, the Everlasting Refuge, who has not begotten, nor has been begotten, and equal to Him is not anyone." Allah! There is no god but He! To Him belong the Most Beautiful Names. To Prophet Muhammad (peace be upon him) the messenger, source of knowledge for the whole mankind.

I would like to convey my gratitude to my supervisors Professor Denis Wright and Mr Hans Dobson for their substantial guidance, continuous inspiration and individual support and assistance in bringing this thesis to its present form. I am indebted to them more than they know. Thank you for your encouragement, the unlimited opportunities you provided me and your undying support and confidence in my abilities.

I am also very grateful to Dr Simon Leather and Dr Roy Bateman for their constructive comments and encouragement during my upgrade exam.

I wish also to thank my internal supervisor Dr Murshed Kharusi and Dr Nizar Al-Anbaki who were more than generous with their expertise and precious time. A special thanks goes to my colleagues in Plant Protection Department and Desert Locust Centre for providing me all assistance requested and helping me to conduct my field research, especially Abdullah Al-Drmaki, Nassor Al-Harthy, Tariq Al-Manzari, Khalid Al-Harasi, Aziz Al-Owisi (R.I.P.), Ishaq Al-Blushi, Anwar Al-Hashli and Hani Al-Ajmi.

I am grateful to many friends who shared their memories and experiences and provided all assistance needed, especially Muhammed Tariq, Dr Munir Butrous, Asim Gulzar, Asad Ali, Muhammed Edress, Khalid Farooq, Jenan Al-Harbi, Muhammad Ahsan khan and Dr Mohammed El-Elami.

I am grateful too for the funding support by the Ministry of Agriculture and Fisheries who made this study possible and special thanks goes to Mr Khalfan Al-Nabai the Under Secretary and Khalid Al-Zadjali for their encouragement and emotional support, which always encouraged me to reach my goals. Special thanks go to the members of staff of the Ministry of Agriculture and Fisheries, Development and Human resources Centre for their continued support through all of my educational pursuits.

Words fail me to express my appreciation to my parents. “And we have enjoined upon man concerning his parents...his mother bore him in weakness upon weakness, and his weaning is in two years. Give thanks unto Me and unto your parents. Unto Me is the final destination (Quran 31:14), and say: "My Lord! Bestow on them your mercy as they did bring me up when I was young." (Quran 17:24).

A very special thanks to my brothers Ali, Farooq and Tariq and my sisters Tahya and Awatif, they have consistently helped me keep perspective on what is important in life and supported me from beginning to end. Most important thanks and gratitude go to my family, my lovely wife Afaf and my children’s (Yahya, Hoor and Mohammed) for their love and support and encouragement to pursue my interests and to reach my goal, and for believing in me and always being there for me.

Finally, I am grateful too for the support and advice from my faculty colleagues and library staff throughout the time it took me to complete this research and write the dissertation.

Thanks, Silwoodians.

Abstract

Date Palm (*Phoenix dactylifera* L. Family: Arecaceae; sub-family: Poaceae) is thought to be the oldest fruit tree grown in the Sultanate of Oman and is a major crop in terms of the number of trees and their distribution. Dates are widely considered to be a strategic source of food security as well as an important cash crop, and have always been looked upon as a key source of stability for oasis agro-ecosystems. Several insect and mite pests and plant pathogens attack Date Palm trees. The Dubas bug, *Ommatissus lybicus* DeBergevin (Homoptera: Tropiduchidae), has been considered the key pest of Date Palm plantations in Oman for 40 years due to the total area infested, the severity of infestations and the scale of the crop losses.

Current control programmes for Dubas bug are reliant on chemical pesticides, applied by air and from the ground over an area ranging from 12,000 – 20,000 ha annually. These pesticides are currently the only feasible control measure against this pest, although research is underway on bio-control technologies. The cropping environment resulting from traditional Date Palm cultivation - high planting density, high temperature and humidity, topography of the plantations, intercropping and variability in cultivars and plant height - has an influence on pest and disease incidence and also affects the control options available. The present research attempts to determine the effects of technical, environmental and biological factors on the control of Dubas Bug in order to develop a more integrated control strategy.

Data have emerged from this study on: 1) optimal spray droplet spectrum and application rates for improved coverage and placement of spray deposits, including under leaf deposition; 2) information on how Dubas bug daily movement can influence control efficacy; 3) on the selective use of insecticides against Dubas bug at economic threshold levels as a supplement to other IPM methods, including cultural practices such as thinning to maintain optimal distances between trees, irrigation management, the removal of old leaves including pruning cuts and surrounding tissues that may support and harbour Dubas bug.

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Chapter 1. **Introduction**

1.1. Background

Date Palm (*Phoenix dactylifera* L. Family: Arecaceae; sub-family: Poaceae) is thought to be the oldest fruit tree grown in the Sultanate of Oman and is a major crop grown in terms of the number of trees and their distribution. Dates are widely considered to be a strategic source of food security as well as an important cash crop (Al-Marshudi, 2002; Livingston, 2002; Tsai and Wang, 1996) and as a key source of stability, survival and evolution of the oasis agro-ecosystem, the Date crop constitutes the basic feature of the ecological pyramid in desert regions, and is major factors of social, environmental and economic stability and constitutes a source of income to owners/farmers (Ismail et al., 2006b; Rhouma, 2010; Rhouma et al., 2010) (Figure 1.1).

Figure 1.1 Diagrammatic construction of a Date Palm

Date Palm is a multipurpose tree, being highly regarded as a national heritage in many countries (Ismail et al., 2006a). It provides food, shelter and timber products, all parts of the

Date Palm plant being used (Agoudjil et al., 2010; Mahmoudi et al., 2008). The religious and socially deep-rooted heritage in the Middle East and North Africa has enhanced its economic, nutritional and environmental value. Date fruits are a good source of low cost food and are an integral part of Arabian and most Muslim's daily diet. For Muslims all over the world dates are of religious importance and are mentioned in many places in the Quran (Baliga et al., 2011; Miller et al., 2003). Among the 29 references to dates is advice to Mariam (Mary), during the birth of Jesus, to eat dates for her labour pains: 'shake towards thyself the trunk of the palm-tree: it will let fall fresh ripe dates upon thee' (Ali, 1983). They are customarily used to break the day long fast during the holy month of Ramadan (Al-Farsi et al., 2005a; Al-Farsi and Lee, 2008; Al-shahib and Marshall, 2003; Dowson, 1982).

The Date's fruits are considered as a nutritious fruit (Lambiote, 1982). Dates are rich in nutrients and provide a good source of rapid energy due to their high carbohydrate content (70-80%), in the form of fructose and glucose, which are easily absorbed by the human body (Al-Farsi et al., 2005a). Dates are also rich in phenolic compounds possessing antioxidant activity (Al-Farsi et al., 2005a; Allaith, 2008). The high nutritional value of dates is also based on their dietary fibre content, which makes them suitable for the preparation of fibre-based foods and dietary supplements. In addition to being good sources of vitamins 'A' and 'B' and 'C' and minerals (Anwar et al., 2005) and micro-elements include aluminum, cadmium, chloride, lead and sulphur (Al-shahib and Marshall, 2003; Habib and Ibrahim, 2011), they are a good substitute for refined sugar (Gad et al., 2010; Miller et al., 2003). Dates have been identified as having antioxidant and anti-mutagenic properties (Vayalil, 2002), and were also found to reduce heart disease (Lambiote, 1982). Dates also contain elemental fluorine that is useful in protecting teeth against decay (Al-Farsi et al., 2005a). Recently, a formulated 'coffee' has been produced from date seeds (Alzadjali, 2011).

When nutrients missing in dates are supplied by other available foods, such as milk products and fish, the resulting uniquely simple diet becomes sustaining (Ismail et al., 2006b), and that was the main source of food in Gulf region (Ahmed et al., 1995).

The origin of the Date Palm (*P. dactylifera* L.) is still uncertain even if there are several claims that it originated from Babel in Iraq, from Dareen or Hofuf in Saudi Arabia or Harqan and also from an island on the Arabian Gulf in Bahrain. The oldest radiocarbon discovery of date seeds was on Dalma Island, part of the Abu Dhabi Islands group. Two seeds were found in 1998, the oldest was from 5110 BC (Hadrami and Hadrami, 2009).

Agriculturists believe that the Date Palm is one of mankind's oldest cultivated plants, (Habib and Ibrahim, 2011), with at least 6,000 years of cultivation, and it was certainly domesticated by 900 B.C (Porter, 1993) or may be as early as 3000 B.C in Mesopotamia (Iraq now) (Nixon, 1951). Its exact native distribution is unknown but Date Palm probably travelled remarkably well with human migration out of the Middle East, around the Mediterranean and into Africa (Al-shahib and Marshall, 2003).

The Date Palm tree starts to produce fruits at an average age of 5 years, and continues production for up to 60-100 years (Jahromi et al., 2007), with an average yield from 100-200 Kg of fruit per year (Jaradat and Zaid, 2004; MAF, 2009c), and with yields as high as 400-600 kg per year (Amer, 1994). The yield of dates depends on many conditions. The fruits are arranged on spikelets bearing 20-60 individual dates, and a number of such spikelets are attached to a central stalk to form a bunch (5-30 bunches per tree).

Some fruits ripen early in the season, some ripen mid-season and some ripen late season. Many fresh varieties are available throughout 8 months of the year. Packed, dry dates keep well without the addition of preservatives for at least 8 months, the high sugar content acting as an effective preservative (Al-shahib and Marshall, 2003). The average per capita consumption is about 25 kg per year in Bahrain, 41kg in Emirates and 60 kg in Oman (Allaith, 2008; Ismail et al., 2006b; MAF, 2010a). There are more than 120 million Date Palm trees worldwide and between 1,500-2,000 different varieties of fresh dates, over two-thirds are in Arab countries (Amer, 1994; FAO, 1982).

In Oman, farmers and governmental organizations have given special attention to Date Palm. The Ministry of Agriculture and Fisheries (MAF) reports a total cultivated area of Date Palm in Oman of about 35,500 ha, which is more than 83% of the total fruit area and about 49% of the total agricultural land, with date production representing 81% of the total fruit production (Al-Farsi et al., 2005b; MAF, 2005c; MAF, 2010a; Siebert et al., 2007) (Figure 1.2).

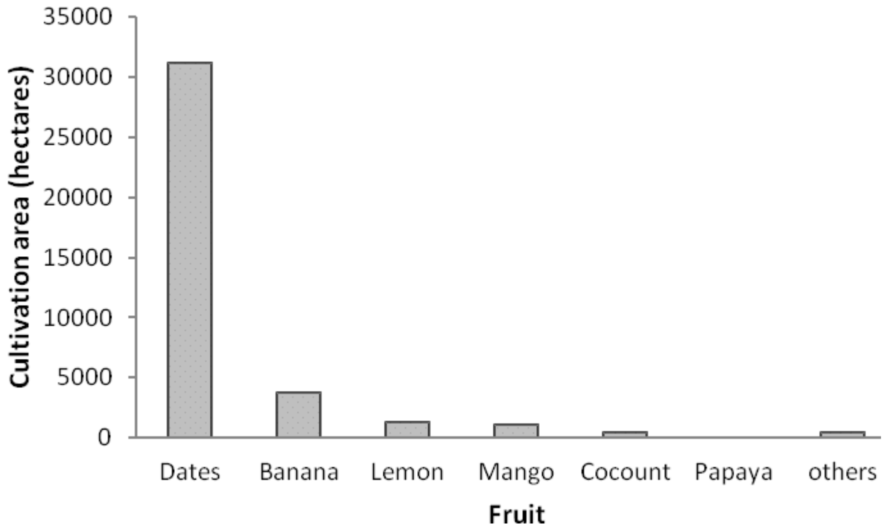


Figure 1.2 Average of total fruits cultivation areas per hectare (MAF, 2010), based on agriculture census in 2007.

The number of Date Palms in Oman was recorded at over 7,859,400 palms in 2009, of which 83% were productive (MAF, 2009c). Among productive Date Palms, 64% are for fresh consumption and 36% are for industrial use. Date Palm production in 2008 increased by 6% compared with 2005 (MAF, 2008a) but due to the lack of rain and other factors, production usually fluctuates from year to year (MAF, 2009c; MAF, 2010a) (Table 1.1).

Table 1.1 Annual production of Date Palm fruit in Oman (thousand tonnes)

Year	2005	2006	2007	2008	2009	2010
Total production	251,538	258,738	260.810	266,893	258,572	276,400
Value in US$ (million)	196,19	201,81	204,34	208,17	201,66	215,60

Source: Ministry of Agriculture and Fisheries, Sultanate of Oman, Production of Dates Report 2009 and 2010.

The majority of dates are consumed locally or used by local date processing plants. The total amount of Date Palm fruit exported differs from one year to another but averages about 7,000 tonnes) (Table 1.2), with Oman contributing around 3.5% to the total global production (FAOSTAT, 2009).

Table 1.2 Annual quantities of Date palm fruit exported (thousand tonnes).

Type of Date	2007	2008	2009	2010
Dates, wet and fresh	123	93	95	333
Dates, dried	7,913	6,062	6,668	4,239
Stored dates	185	842	544	2,121
Total (tons)	8,221	6,997	7,307	6,693

Source: Ministry of Agriculture and Fisheries, Sultanate of Oman. Production of Date Reports, 2009 and 2010.

Date Palm plantations act as reservoirs for many local plants, which support the biodiversity that helps to create suitable growing conditions for other crops, including tree fruits, such as lemon, fig and banana. Date Palm plantation also plays an important social role in the stability of rural communities by reinforcing the subsistence base of a large population group and helping them to remain in rural areas rather than migrating to urban centers (El Juhany, 2010). The Date Palm industry also provides employment opportunities for a large number of citizens and expatriates in Oman.

1.2. Rationale of the study

Date Palm trees are affected by several insect pests, mites and plant pathogens, These can attack roots, trunk, leaves and its fresh and dried fruits (MAF, 2008b). Worldwide, ten families of moths and butterflies are significantly represented among palm defoliators. Larvae of some moth and butterfly species consume entire portions of the leaf blade tissue, while other species remove only the superficial tissue of the abaxial (lower) leaf surface, leaving the tough leaf veins intact. Other species, of the order Hemiptera, pierce into the tissues of foliage or fruits of palm to feed on the sap. These include the 'true bugs' plant hoppers, aphids, mealy bugs and scale insects (Howard, 2001; Howard et al., 2001).

Buxton (1920) observed at least 24 pest species attacking Dates palm during his mission in Iraq to carry out an investigation upon the failure of the Date crop. Martin (1972) and (El-Haidari, 1980) mentioned 20 species attacking Date Palm in the Arabian Peninsula. The MAF in the Sultanate of Oman (1994) recorded more than 45 arthropod species (insect and mites) attacking Date Palm plantations, while (Kinawi, 2005) indicated 27 economic pests infesting Date Palm and dates in Oman. Although each Date Palm growing country has its list of pests and diseases, many of these are common across a number of countries (El Juhany, 2010; Talhouk, 1991) (Table1.3).

In addition, Date palms are afflicted with many diseases, with one of the most serious fungal diseases in North Africa being Bayoud disease caused by *Fusarium oxysporum*. This disease has caused large losses of Date Palms. Other important diseases are Black scorch *Ceratocystis paradoxa*, Brown leaf spot *Mycosphaerella tassiana*, Diplodia *Diplodia phoenicum* and Graphiola leaf spot *Graphiola phoenicis* (Chao and Krueger, 2007; El-Juhany, 2010).

Table 1.3 Main insects recorded on Date Palm in different Arab countries

Common name	Casual insect	Country
Dubas Bug	*Ommatissus lybicus* DeBergevin	Morocco, Algeria, Tunisia, Libya, Egypt, Sudan, Iraq, Saudi, Oman, UAE
Red palm weevil	*Rhynchophorus ferrugineus* Olivier	Egypt, GCC[1] countries, Iraq, Syria
Lesser date moth	*Batrachedra amydraula* Meyrick	Libya, Egypt, Palestine Territories, Kuwait, Iraq, UAE, Bahrain, Saudi
Rhinoceros beetle	*Oryctes rhinoceros* L.	Tunisia, Egypt, Yemen, Iraq, Qatar, Oman, Bahrain, UAE
Carob moth	*Ectomyelois ceratoniae* Zeller	Morocco, Algeria, Tunisia, Libya, Egypt, Iraq, Saudi

[1] Gulf Cooperation Council (GCC)

Red scale	*Phoenicococcus marlatti* Cockerell	Morocco, Algeria, Tunisia, Egypt, Palestine, Jordan, GCC countries
White scale	*Parlatoria blanchardi* Targ.	Mauritania, Morocco, Algeria, Tunisia, Libya, Egypt, Sudan Kuwait, Iraq, Oman, Saudi Arabia
Boufaroua	*Oligonychus afrasiaticus* McGregor, O. pratensis Banks.	Iraq, Tunisia, Algeria, Morocco, Egypt, GCC countries

Source; El Juhany, L. I. 2010. Degradation of Date Palm trees and date production in Arab countries: causes and potential rehabilitation. Australian Journal of Basic and Applied Sciences, 4, 3998.

Region wide, the major arthropod pests on Date Palm are the Dubas bug *Ommatissus lybicus* DeBergevin (Hemiptera, Suborder Homoptera: Tropiduchidae), Red Palm Weevil *Rhyncchophorus ferrugieneus* Olivier (Coleoptera: Rhynchophoridae), Lesser Date Moth *Batrachedra amydraula* Meyer (Lepidopptra: Batrachedridae), Old Date Mite *Oligonychus afrasiaticus* McGregor (Acari: Tetranychidae) and the Oriental Hornet *Vespa orientalis* L., (Hymenoptera, Vespidae) (Hussain, 1974; Kinawi, 2005; MAF, 1981; MAF, 2008b; Talhouk, 1991).

Dubas bug is considered to be the key pest for Date Palm plantations in Oman, Iraq, Iran and United Arab Emirates (UAE) for more than 40 years, based on the total area infested as well as the severity of the infestation and economic damage caused (Alalawi, 2010; El-Haidari, 1980; Hussain, 1974; Payandeh et al., 2010).

Previous attempts by MAF in Oman to develop alternative control measures have been hindered by a lack of human resources, budget constraints and lack of research, which eventually forced the MAF to introduce a control programme totally reliant on pesticides, applied mainly by aerial spraying and to a lesser extent by ground sprayers (MAF, 2008b).

Date Palm is the only host of this pest (Gassouma, 2004). Dubas bug causes two kinds of damage on Date Palm. Firstly, due to the direct feeding of nymphs and adults on the sap in the leaves and to some extent on fruit bunches, the severity of damage being proportional to the level of infestation and density of palms in the cultivated area (MAF, 1981). Excessive damage for a number of years can weaken palm trees and reduce their production quantitatively and qualitatively. Secondly, there is indirect damage caused by excessive accumulation of honeydew on leaves and fruits excreted by the insects, particularly during their nymphal development stages, which interfere with vital biological processes such as photosynthesis and transpiration. Honeydew is an excellent medium for the growth of sooty mould fungi. The fungal growth covers the fronds with a dark coating that interferes with photosynthesis and causes considerable debilitation (Al Deeb, 2012). Damage due to honeydew also affects inter crops within Date Palm plantations. Other indirect damage includes leaf tissue damage during egg laying. MAF (1983) has estimated that productivity for some Omani Date Palm varieties has decreased by 28% due to Dubas bug damage.

Aerial spraying has been used in Oman to control Dubas bug since 1976, usually with one insecticide spray application per year. Aerial spraying is used predominantly where large areas are to be treated in a short period and ultra low volume (ULV) application of insecticides offers substantial logistical advantages as well as reducing the weight carried by aircraft, compared with conventional high volume spraying. ULV insecticides are applied as small droplets, and are formulated to be used undiluted at 5 l/ha or less (Lavers, 1993b). The total area sprayed in Oman, which includes some ground spraying, ranges from 12,000 – 20,000 ha annually (Figure 1.3).

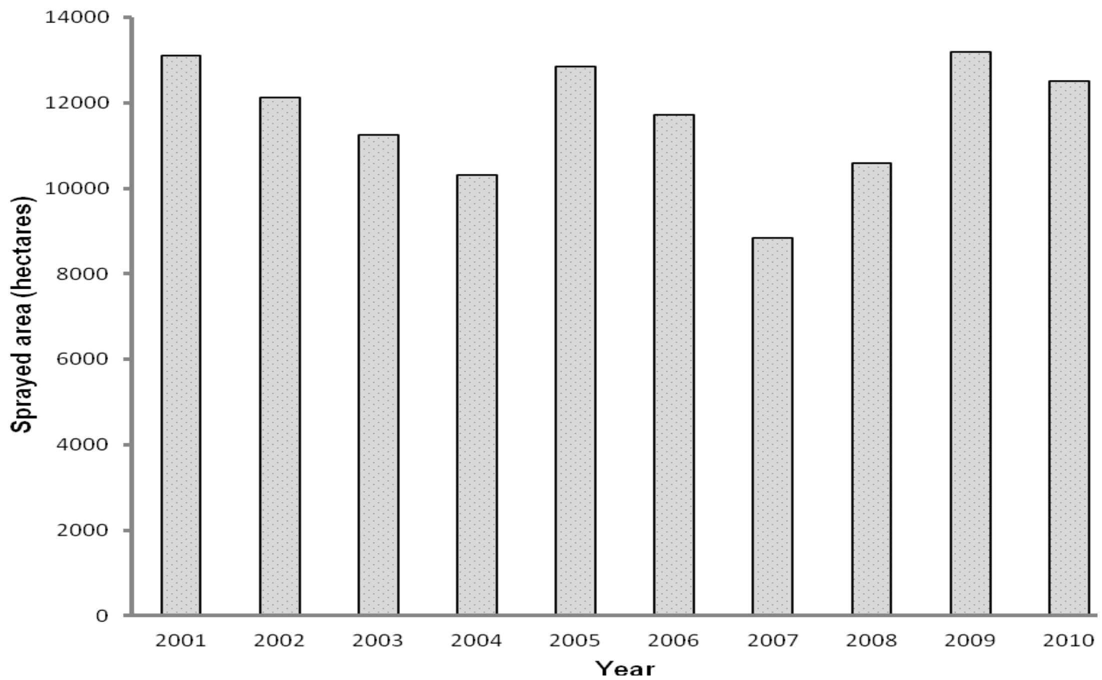


Figure 1.3 Average Date Palm treated area with pesticides from 2001 to 2010 (MAF, 2010).

The chemical control of Dubas bug has been facing several problems, such as decreasing efficacy, increasing costs and predicted environmental impacts. The nature of the traditional agricultural system for Date Palm plantations in Oman: high density/unit area, environmental conditions (temperature and wind), topography of plantations, variability in crop height and cultivar types, and intercropping, together with the possible development of insecticide resistance are all potential factors affecting the efficacy and efficiency of chemical control programmes. Chemical control (aerial and ground spray application) remains the sole control measure against Dubas bug in all date-growing countries affected by this insect including Oman. Organophosphate (OP) and pyrethroid (PYr) insecticides have been widely used in Dubas bug control programmes for the last 35 years (Appendix 1).

One of the major constraints to successful application of insecticides in Oman are the weather conditions, particularly wind velocity & temperature. In order for aerial ULV spraying to be successful, there needs to be a consistent wind of at least 1 m/s. Unfortunately, in the early morning when spraying usually takes place, there is often no wind or light wind of variable direction. Later in the day as the wind velocity increases and temperatures increase, aircraft safety may be jeopardized (Aston, 2005). In addition, the topography of plantations is another important factor in reducing control efficacy with Date Palm trees in mountainous areas and on the edges of the valleys. Plantations nestled in steep-sided valleys is a particular issue, making spraying extremely difficult and some areas clearly cannot be sprayed to an acceptable standard due to the nature of the terrain. Date Palm trees within plantations can also be of unequal heights, due to differences in age, growing conditions and varieties.

1.3. Aims and objectives of the present study

Application technology has already played a major role in improving the efficiency of pesticide usage, and in protecting the operator and the environment by minimizing the off-target contamination through spray drift or during filling, mixing and cleaning operations (Landers, 2004). Since chemical control, particularly aerial and ground application has been and still is the sole available method to control Dubas bug in Oman, it is important for the MAF to optimize the major factors affecting its efficacy. This study will focus on determination of the effects of technical, environmental and biological factors on the control of Dubas bug in order to identify and implement the best methods of control.

Specific objectives

This study, based in the Sultanate of Oman, compared different pesticide application methods, including specialized aircraft and ground-based methods to control Dubas bug. The influence of temperature and relative humidity on the daily movement of Dubas bug and its distribution within orchards during the day and night were also investigated, together with a study on the relative susceptibility of Dubas bug populations to insecticides. The following specific objectives were addressed:

1. To develop an evaluation system to assess the efficacy of aerial spraying operations. Measurements were made of spray coverage and deposition on foliage using oil and water papers attached to different locations in the tree canopy.

2. To clarify the optimum parameters for aerial spraying in terms of flow rate from nozzles, mean spray droplet size and spectrum, and foliar deposition (density/cm^2).

3. To investigate improved ground spray application techniques by evaluating the high volume sprayers used currently and the efficiency of ground-based medium volume spray application as an alternative method for Dubas bug control.

4. Examine the movement of Dubas bug within and between Date Palm trees and its influence on spray application and control efficacy.

5. Evaluate the different types of pesticides used against Dubas bug over the past 10 years to provide a preliminary indication of whether insecticide resistance has developed or is likely to develop.

6. To develop improved pesticide application guidelines for Dubas bug on Date Palm in Oman.

Chapter 2. **Literature review**

2.1. Current situation of Date Palm in Oman

Due to the economic, environmental and social importance of date palm trees, MAF has given priority to this crop in terms of applied research, extension and investment plans. The agricultural census in 2005 (MAF, 2005a) stated that the average density of Date Palm trees was 300 palm trees in one hectare. However, there are often far more than 300 palm trees per hectare, especially in mountainous and valley area, and other fruit trees (e.g. banana, mango, citrus, lemon and other seasonal fruit or perennial forage) are cultivated within palm plantations. Most of this land is irrigated in a traditional way, from wells and Al-flaj (surface irrigation system), so that the land is flooded, which causes high humidity in the plantation microclimate. Based on actual crop water requirements, irrigation demand/supply ratios among monitored farms suggests relatively high water wastage in Date Palm farms (Norman et al., 1997) which leads to a high relative humidity in the farms and creates conditions favourable to Dubas bug (Alalawi, 2010).

Although Date Palms are known to withstand extreme environmental conditions there are a number of problems and constraints that have reduced their numbers and caused low productivity namely:

1. Drought and salinity. Oman is characterized by an arid and semi-arid climate. Rainfall is highly erratic in space and time, annual precipitation ranges from less than 50mm to 250mm (Al-Marshudi, 2002; William et al., 2004) and water is one of many factors that have contributed to a reduction of date production (Al-Yahyai, 2007), but poor water management, such as the overuse of limited groundwater, can also have a negative impact. Also soil salinity and nutrient deficiencies are major factors in limiting fruit yield and quality from Date Palm trees cultivated in Oman (Cookson, 1999; MAF, 1993). Although the solution may be to rehabilitate old plantations and to employ more appropriate and efficient technologies and management practices, no improved management scheme has been developed. On the other hand, since the majority of Date Palm plantations are irrigated by the Al-flaj system, and all they need to do to reduce salinity is to manage water resources in each area (Anon, 1978).

2. Pests and Diseases. The Dubas bug *(Ommatissus lybicus)* is the most destructive pest

in Date Palm production in Oman. Other pests that threatens Date Palm production include *Rhynchophoru ferrugineus*, *Oligonychus afrasiaticus, Batrachedra amydraula*, *Orytctes spp.* and *Oryctes rhinoceros* (El Juhany, 2010; MAF, 2004b; MAF, 2008b).

3. The prevailing pattern of agriculture and lack of good agricultural practices. Date Palm requires several labour-intensive management practices, typical management of Date Palm farms includes hand pollination of palms, removal of dead fronds, pruning, regular irrigation at between 3 and 5 day intervals, hand weeding of the irrigation basin, etc. Many factors may have contributed to the reduction of Dates production, including the limited availability of skilled labour to carry out field operations, pests and diseases, degradation of soil and water quality, and pre- harvest and post-harvest losses (Al-Yahyai, 2007; Cookson, 1999).

4. Low economic returns compared to other crops. Al-Yahyai (2007) stated that Omani Date Palm growers face numerous challenges in date production and marketing which have affected the economic revenue from date production and its quality. Determining these problems and proposing feasible solutions will alleviate the extent of these problems and enhance date production quality and quantity in the country. Also improving date quality and income depends on access to improved cultivars adapted to local climatological conditions, and on the skill and dedication of the date producer (Mahmoudi et al., 2008).

5. Immigration of farmers from the countryside to cities for improvement in their living standards. This socio-economic change may play an important role in reduced focus on and care for Date Palm plantations. This situation has caused huge damage to Date Palm plantations due to the neglect in basic agriculture practices as well as over reliance on foreign inexperienced labour (expatriates).

Other contributory factors are lack of adequate pest and disease research studies, the small range of good quality varieties, poor harvesting, processing and packing techniques and poor water management. El Juhany (2010), also reported further factors that lead to the deterioration of Date Palm groves in Arab countries such as technical and socio-economic factors. Rehabilitation of Date Palm trees in the Arab countries is crucial and needs collaborative efforts and a dedicated budget.

2.2. Dubas bug: history and nomenclature

The Date Palm is the main host of Dubas bug, which is also known as the Palm bug. Lepsme (1947) has reported that the first description of Dubas bug was made by Fieber in Spain in 1875, after he collected samples from ornamental trees (*Chamaerops humilis)*. Fieber named this bug *Ommatissus binotatus* (Homoptera: Tropiduchidae). Some other publications have used this name as well, such as Rao and Dutt (1922) and Hussain (1963) in Iraq, Dowson (1936) in Turkey, Linnavuori (1973) in Sudan and Klein and Venezian (1985) in Palestine.

DeBergevin (1930) re-described this bug, demonstrating that Dubas bug was different from the bug described by Fieber and named it *Ommatissus binotatus lybicus* DeBergevin. Although Asche and Wilson (1989) revised this genus and re-described Typetimorphini family and *Ommatissus* species. The most notable outcome of this study being that the Dubas bug was named *Ommatissus lybicus* DeBergevin.

Asche and Wilson (1989 and (1987a) pointed out that Dubas bug is an important pest of Date Palm and widely distributed in the Middle East. According to available sources, the first record of Dubas bug in the Middle East was in 1922 (Rao and Dutt, 1922). In Oman, the Ministry of Agriculture records Dubas bug for the first time in the Rustaq area in 1962 (MAF, 1981; MAF, 1997). El-Haidari (1981) reported that Dubas bug had been found on Date Palm in Bahrain in 1979, and it was recorded for the first time in north Sudan in 1981. However, the bug had been recorded by a number of researchers in Algeria, Egypt, Kuwait, Iraq, Iran, Oman, Saudi Arabia, Spain, Sudan and United Arab Emirates (where it is reported almost everywhere that Date Palm trees are grown). Venezian and Klein (1985) stated that Dubas bug was one of the most important insect pests on Date Palm in Palestine in the 1980s. Dubas bug has also been reported from Libya (Lal and Naji, 1979), Qatar (Al-Azawi, 1986) and Yemen (Anonymous, 2005; Hubaishan et al., 2005).

2.3. Biology of the Dubas bug

2.3.1. Life stages

The adult is yellowish green (Figure 2.1). The female is usually longer than the male - 4.0-4.8 mm with an average of 4.38 mm for the female compared with 4.0-4.4 mm for the males with an average of 4.1mm. There are no black spots on the back of the male and female which is different from what Hussain described in 1963 (MAF, 1997). The male and female can be distinguished by the presence of an orange spot on the dorsal surface of abdomen of the male. There is a dark brown line at the end of the abdomen of the female at the time of egg laying.

The eggs are rectangular and about 0.5 to 0.8 mm in length (Figure 2.2). The egg is bright green when first laid then changes to yellowish white and then to shining yellow before hatching. There are five nymphal instars, each of which is yellow to greenish yellow, distinguished by a bundle of waxy caudal filaments and a number of dorsal grey lines along their bodies. Number of dorsal grey lines assists in differentiation of nymphal instars. Other nymphal characters such as body length, width, and wing buds length are variable characters for differentiation of nymphal instars (Al-Abbasi, 1988b). The number of caudal filaments is consistent in each nymphal instars and increases after each moult. Their number for the 1st, 2nd, 3rd, 4th, and 5th nymphal instars is 6, 10, 16, 20, and 24 respectively. The filaments grow to reach a maximum length of 5mm, which exceeds the length of the fully-grown 5th instars. Another important diagnostic character is the dorsal grey marking of the thorax in the nymph. In the 1st and 2nd instar the gray spot is not differentiated into lines, in the 3rd instar there are 2 lines on each side of the thorax, in the 4th and 5th instar there are 3 lines on each side of the thorax, but the outer two lines are connected posteriorly to form a closed cell in the 5th instar (Figure 2.3).

Figure 2.1 Dubas bug adult (female).

Figure 2.2 Dubas bug eggs on dates palm leaves.

Figure 2.3 Dubas bug nymphs.

2.3.2. Life cycle

Hussain (1963) made the first detailed study on life cycle of Dubas bug in Babel Province in Iraq. He reported that the insect has two generations/year (Autumn and Spring). The Autumn generation is also called 'the dormant generation" which lays eggs in the second week of November and hatches around the first week of April. The egg period for this generation is 140 days and the nymphal stage lasts 45-50 days. The longevity of the adult male is about 15 days compared to 45 days for the female. The spring generation lays eggs in the second half of June and hatches in the first week of August. The egg laying period for this generation is 50 days and the nymph stage lasts 54 to 60 days. The male lives 13 days compared with 40 days for the female.

Al-Abbassi (1988) conducted a study on the life span of Dubas bug under different temperatures, at 22 to 32°C and fixed at 27°C, 12 hr photophase and 50-70% R.H. the number of eggs deposited by the female was 83 eggs and the maximum number obtained from one female was 130 eggs in its lifetime. The female longevity was 26 days and ranged from 16-43 days. Development time from egg to adult was 82 days for males and 84 days for females at 22-32°C, 12 h photophase and 50-70% R.H. The nymphs had a similar growth rate under both temperature regimes. One of the major conclusions of this study was that it was possible to rear Dubas bug successfully on date palm leaves under laboratory conditions (Al-Shamsi, 2003).

Hasson (1988) also studied the life cycle of this bug under controlled conditions. She highlighted the impact of heat and relative humidity on the bug life cycle. The study shows that temperature influences the eggs' incubation period and the optimum temperatures were 25 and 30°C at which the incubation periods were 42.5 and 42.15 days respectively, the eggs did not hatch at 15 or at 40°C. The growth rate increased with increased temperature up to 30°C, there was a positive correlation between the temperature and pre-ovipostion period, oviposition period and the adult age. The relative humidity had no effect on the egg incubation period but it affected percentage of hatching. The highest percentage (97%) was at 80-90% R.H., and the lowest (56%) was at 30% R.H. The optimum relative humidity level for nymphal growth was 50-70%, and the highest mortality rate (43%) was at 30-40% and the lowest (17.33%) was at 50-70%. This result was in line with studies on the impact of high temperature and low humidity on egg production and increased mortality of *Bemisia argentifolii* (Tsai and Wang, 1996).

Hasson (1988) also studied the reproduction of sexual and nonsexual Dubas females (parthenogenesis) by conducting a study on longevity and egg production of pregnant females. She found an absence of the phenomenon of parthenogenesis in Dubas bug, also she found that, the lower thermal threshold for nymph development was 14°C and average of thermal units required 515.5 degree days, while the thermal threshold for egg development was 13°C and thermal units 641 degree days.

For the Arab Peninsula El-Haidari and Al-Tijani (1977) found that Dubas bug egg laying in Oman and the UAE was earlier by 30 days or more compared to Iraq. The difference for newly hatched nymphs due to variance among province and governorates in Iraq and other countries (Al-Izzi et al., 1989). This suggests that the date of emergence of each generation and its development phase will vary from one country to another and from region to another depending on the climatic condition in the area.

In Oman, the data in Table 2.1 are consistent with Abd-Allah et al., (1995) who stated that, the longevity of the nymph in the spring generation ranges between 45 to 52 days with an average of 48.4 days. The average development time for the five nymphal stages was 12.4, 10.1, 7.9, 8.8 and 8.8 days, respectively. The female starts laying eggs from the second week of April. It continues egg lying till the last week of June. It was found that the full longevity of the bug is about 82 days for the male and 72 for the female, which lays about 143 eggs - see Figure 2.4.

In the spring generation, females tend to lay eggs on the fifth frond row to provide maximum protection for eggs against heat during the summer seasons (Mokhtar et al., 2001a) while during the autumn generation it tends to lay its eggs on the third row of the frond. The eggs are laid on all the green parts of the Date Palm except the fruits, the majority on the leaf, particularly the upper and lower surface of the midrib. They are distributed evenly on the four aspects of the Date Palms, but unevenly on the frond rows (Hussain, 1963). Dubas bug nymphs emerge in small numbers at the beginning of hatching for both the spring and autumn generation, then their numbers increase gradually; 75% of the nymphs come out over the month following first egg hatch in the field. It was found that the upper surface of fronds contains 76% of the laid eggs compared to 24% for the lower surface (El-Haidari, 1980).

Table 2.1 Average duration (days) of Dubas bug nymphal stages

Nymph phase	Average nymphal stage duration in autumn generation	Average nymphal stage duration in spring generation
First	6	9
Second	10	9
Third	7	8
Fourth	9	10
Fifth	12	12
Total	44	48

*Reference, MAF (1997) Dubas bug insect *Ommatissus lybicus* pamphlet

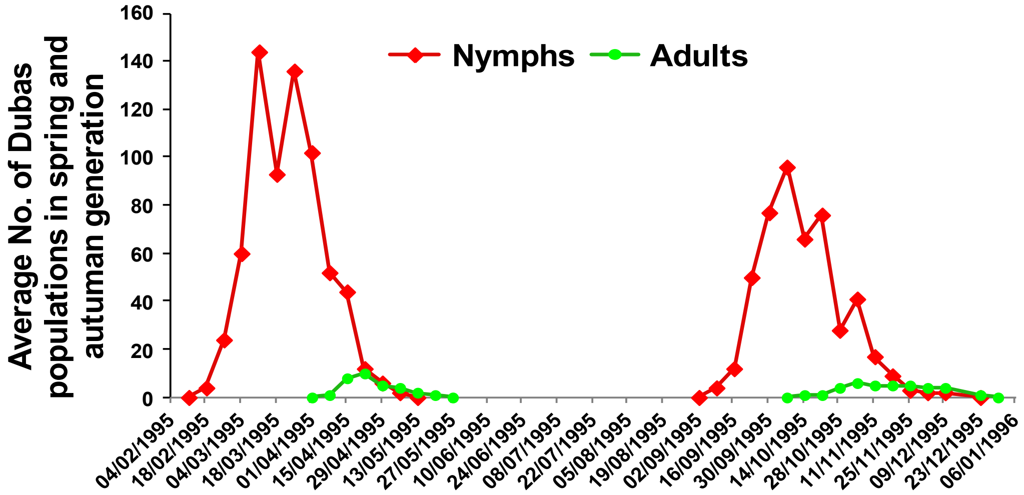


Figure 2.4. Population density of Dubas bug from February 1995 to January 1996, and the sample size was around 10 hectares (source; MAF, 1997).

2.4. Damage by Dubas bug and its economic importance

Cameron (1921) affirmed that Dubas bug makes the Date Palm tree lose its vitality therefore leading to a decline in its productivity. Alfieri (1934) studied this bug in Egypt and came to the conclusion that Dubas bug causes great damage to the Date Palm tree as they suck the sap from the trees and make it feeble. Repeated heavy infestations cause the weakening of the tree, the leaves may be exposed to fungi due to sooty moulds growing on the honeydew droplets excreted by the nymphs. Dowson (1936) expanded his study on the damage caused by this serious bug in Al-Basra Province in Iraq where almost 7 million Date Palm trees were planted on about 28,000 ha. The damage was very high in an area of about 8,000 hectares, causing an estimated $0.4 million financial loss due to this bug in 1935. In the same context, (Kranz et al., 1978), reported that up to 50% economic loss recorded on Date palms in Iraq was due to the infestation by this insect.

Abdul-Hussein (1974) prepared the first comprehensive expanded study on this bug in Iraq. In his study titled “Date Palm Trees, Fruits and their Pests” he described the damage caused by this bug in detail, stating that the nymphs and the adult bugs suck the sap from the Date Palm leaves and fruits and then exude a sticky liquid (honeydew) that makes the fruits small, bad and not edible. The bug excretes droplets of honeydew on the different parts of the tree therefore providing a medium for the growth of sooty moulds. The accumulation of honeydew collects dust and causes disruption of the metabolic activity of the fronds (Al-Izzi et al., 1989). This makes the trees lose vitality. When the infestation is heavy, the honeydew falls on the other fruit trees or on the field crops or the vegetables under them. Fruits from infested trees are small and covered with honeydew, dust and dirt, which makes the fruits inedible and the price of the infested fruits is low compared to healthy fruits (MAF, 1981) (Figure 2.5 and 2.6).

Wilson (1987b) and Howard et al., (2001) explained that, honey dew supports the growth of micro-fungi, especially dark-coloured Ascomycetes of the order Dothideales. This substance known as sooty mould is detrimental to plant growth, because it interferes with photosynthetic process. Heavy and recurrent infestation leads to remarkable weakness in the growth of the Date Palm tree. It also makes the fronds yellow and the production low, and heavy and recurrent infestation for years sometimes kills the trees.

Carpenter and Elmer (1978), Btaw and Ben Saad (1990) in Libya, Abd-Allah et al., (1995) in Oman, Al-Garabi (2006), Abdul-Sattar and A-Haq (2009) in Yemen and Shah et al., (2012) in Baluchistan, Pakistan, pointed out that Dubas bug was one of the major pests that affected Date Palm, and was the most serious pest of date production, causing high levels of damage to the date crop (Aminaee et al., 2010; Wilson, 1987a). In a study about the economic damage caused by Dubas bugs in the productivity of palm trees in Oman, MAF (1983) confirmed that the average percentage of loss in yield was 28% of the total yield in the absence of control, and in Yemen (Ba Angood, 2009) reported that USD 860,000 was the total cost of controlling Dubas bug infestation in Wadi Hadramout province during 2006-2007. MAF Oman (2010) stated in their reports that, the total cost of Dubas bug campaign during 2008, 2009 and 2010 was USD million; 1.7, 1.8 and 1.4 respectively (MAF, 2010b). There is a lack of detailed studies assessing the cost effectiveness of controlling Dubas bug on palm trees. However, Agricultural and Fisheries Development Fund (AFDF) in Oman in 2009, estimated the profits from controlling Dubas bug in the autumn generation to be US$ 15 million which represents the value of crops saved. Whereas the overall majority of costs for MAF are incurred by flight operations and expenses for pesticides at US$. 4.6 million (AFDF, 2009).

Figure 2.5 Indirect damage, the the growth of micro-fungi on honey dew on the Date Palm fruits (Photo by Al Katri, 2008).

Figure 2.6 Indirect damage, heavy honeydew excretion on banana leaf (inter crops).

2.5. Control of Dubas bug

In Iraq (Hussain, 1985) estimated the economic threshold for Dubas bug infestation through the number of eggs on each frond. He reported that when there are up to five eggs on each frond, the infestation is low, when there are between 5 to 10 eggs on each frond, the infestation is medium and when there are more than 10 eggs on each frond, the infestation will be high. In Oman, (MAF, 1997) it was estimated that the economic threshold of infestation to be the presence of more than five nymphs on leaves after using the following formula;

Average number of nymph =

$$\frac{\text{total number of nymphs in (20 leaflet) from (3 leaves) from (5 offshoots)}}{300}$$

Mokhtar et al. (2001d) estimated the economic threshold of Dubas bug by calculating the density of honeydew droplets excreted by the insect. This was considered the economic threshold, based on that, the number of bugs that are expected to excrete honeydew that cover 10% of the frond surface in a week was calculated (Table 2.2). The results show that, 10.9 first nymph instars per one leaflet is the economic threshold when inspection is done at the beginning of the season or where the first nymph instar is the dominant stage of the population, while 0.6 of fifth instar nymphs per leaflet is the critical level of infestation when this instar is dominant.

Table 2.2 The area of honeydew droplets on water sensitive papers (WSP) calculated for each stage of Dubas bug and the number of insects needed to cover the upper surface of a Date Palm leaf.

Stage	No. of produced droplets per h	Droplet diameter in microns	No. of insects needed to cover 10% of leaf area in 7 days*
N1	6.5	156	10.9
N2	6.4	256	4.2
N3	7.4	481	1.0
N4	7.6	545	0.8

N5	7.6	622	0.6

N=nymph Instars: 1= first; 2= second; 3= third; 4= forth and 5= fifth.

**Area of the upper surface of leaflet average 40cm^2, so10% is equivalent 4cm^2*

* *Mokhtar et al., (2001) - using the production of honeydew as indication to estimate the population of Dubas bug Ommatissua Lybicus* DeBergevin.

2.5.1. Cultural control

2.5.1.1. Tree stands density (Date Palm spacing)

The area of land owned by individual farmers and available for growing Date Palm has reduced over time as populations have increased, with the result that farmers have planted too many trees per unit area in an effort to maximise yield. Plants are densely spaced making the density to reach 470 palms per ha instead of the recommended 165 per ha (ICARDA, 2004) and 120 in the Coachella Valley of California (Akyurt et al., 2002b). Field observations indicate that infestations of Dubas bug are always higher in dense Date Palm orchards. Askari and Bagheri (2005) pointed out that this was because densely planted Date Palm groves induce low ventilation and high relative humidity, that tends to increase the population of the pest. Changes in Date Palm density could be the most important factor in helping to reduce Dubas bug infestation (Al-Alawi, 2010).

MAF recommends that the best distance between trees should be 8 x 8 m. This distance improves ventilation and allows more sunlight to penetrate the tree canopy thus reducing humidity and creates a less suitable environment for Dubas bugs (Ali et al., 2009). These changes in agronomic practices are necessary measures that help to mitigate the severity of Dubas bug ;(Alalawi, 2010; MAF, 1997; MAF, 2008b). However this planting density advice is often not followed.

Traditional Date Palm plantations are still common in “Al-flaj” areas in Oman system (ground water flow from underground galleries or surface spring on neighbouring mountain slopes), where most of the trees are old, low yielding and have lost their vigour and productivity (MAF, 2008b).

2.5.1.2. Irrigation management

Oman has a hot climate and very little rainfall. Drought and limited rainfall contribute to shortages in the water supply, so maintaining an adequate supply of water for agricultural and domestic use is one of Oman's most pressing environmental problems, with limited renewable water resources, 94% of available water is used in farming, with the majority sourced from fossil water in the desert areas and spring water in hills and mountains. The mountain areas receive more plentiful precipitation, with annual rainfall between 50 mm to 200 mm, but these areas are not suitable for farming However, virtually all crop production is therefore dependent on irrigation (Al-Marshudi, 2002; Norman et al., 1997).

In general, Date Palm trees are usually irrigated by Al-falaj, basin or gravity irrigation system that uses an excessive amount of water, with the quantity usually determined by the farmer's experience (Anon, 1978). Abd Rahman and Omezzine (1996) believed about half of the cultivated area 76,000 ha in Oman is irrigated from wells, while the remaining half is irrigated by the traditional Al-falaj system. Albaker (1972) reported that the water requirement for mature Date Palms ranges between 115 and 306 m^3 per ha. In general Date Palm are drought resistant and can also withstand salinity up to 4dS[2] per m without any reduction in yield (Ayers and Wescot, 1985). Although the root zone depth range between 1.5 to 2.5 m (Doorenbos and Pruitt, 1997) and the tree can take up to 65 to 80% of water within a root zone depth not exceeding 1.2 m (Yaacoob, 1996).

Ahmed (1996) pointed out that in many places the assumption is often made that high water losses are inherent in all forms of surface irrigation, with efficiencies often estimated at 50% or less. Abdurrahman and Al-Nabulsi (1996) reported in controlled system (drip system) the average water used by Date Palm trees in California is between 200 and 250 m^3/year per tree, while in open canal (flooding method) has been found to vary between 27,000 m^3 to 38,000 m^3 per ha/year. However, due to the high humidity microclimate in Date Palm plantations which is suitable for Dubas bug development and high water losses, it is vital to manage water resources carefully and use controlled irrigation systems such as a drip system (Anon, 1978).

Al-Amoud (2010) reported that the drip system has proven its superiority over other irrigation system in increasing yield and reducing the cost of labour and other activities. In

[2] DeciSiemens per metre (dS/m)

addition, it improves efficiency and reduces water losses due to evaporation and deep percolation, also the drip system prevents the growth of weeds around the tree and less accumulation of salts compared to other systems (Ayers et al., 1995; Nimah, 1985). Barth (1995) compared the drip system with surface system (surface runoff); results show that the overall water use is reduced by 30 to 50% compared to the surface system. It was also noted that production was increased by a percentage ranging between 30 to 70% compared to surface system. Results have also indicated that Date Palm irrigated with drip system show a clear increase in leaves, flower and fruits. Abdul-Star (2009) maintained that the modern irrigation system applied in the demonstration were a major factor which controlled humidity in Date Palms fields. In this context, modern irrigation methods may be able to play a significant role in achieving higher crop productivity, water use efficiency, and sustainability in agriculture (Khan and Prathapar, 2011).

2.5.1.3. Pruning and Thinning of Date Palm trees

The Date Palm tree commonly grows 20 to 30 m tall and consists of a slender bare trunk of 0.3m to 0.8m in diameter with a tuft of leaves at the crown (Al-Suhaibani et al., 1988). The dates grow in bunches in a ring about 1.2 m in diameter around the base of the leaves at the top. Bankhar and Akyurt (1995) pointed out that many operations take place at various times during the growing season; Pollination needs to be carried out in the spring, whereby the pollen is brought into the proximity of the flowers; pruning involves the selective removal of some fruit strands; thinning is the selective removal of fruit from the tree with the objective to obtain a uniform crop comprising large, properly grown dates and promote uniformly spaced bunches (Akyurt et al., 2002a). Also, the old leaves are cut off at the base of the leaf stem and the removal of premature strands in order to promote uniformly spaced bunches, the objective being to facilitate the moving about of a person during subsequent operations. The leaf base will remain attached to the trunk and where palms are still climbed, are used as steps for the climber's feet (Figure 2.7).

Figure 2.7 Traditional pruning, thinning and harvesting required the farmer to climb the tree and work at consideration height above the ground using a belt and a rope.

Improvements occur in the fruit yield and quality as a result of these farm operations, e.g. pollination, thinning, pruning and fertilizing. Consequently, as Dubas females lay eggs on the leaves and midribs, the resulting distribution of Dubas bug eggs shows that 64.3% and 64.4% laid on 1^{st} and 2^{nd} fronds rows respectively compared with 18.8% and 15.8% on 4^{th} and 5^{th} fronds (Jasim and Al-Zubaidy, 2010b; MAF, 2008b). This farming practice and the selective removal of old branches from the trees can help to get rid of the eggs that were laid in these branches at an early stage.

Al-Izai (2000) concluded that pruning is one of the essential processes helping to reduce Dubas bug population and other pathogens in Date Palm plantation. Also, (MAF, 1997) reported that pruning and removal of old dead fruits bunches and fronds are necessary to reduce Dubas bug infestation in the next generation. In Iran, Askari and Bagheri (2005) also report large trees with dense canopies are responsible for restricting aeration in orchards which consequently causes highly humid environments which favour Dubas bug population increases. Al-Anbaky in Iraq (Personal communication, 2010) and (Shah et al., 2012) in Pakistan believe that, removal of (2-4) fronds row from the lower- middle portion before egg hatching will reduce Dubas bug infestations by 30 to 40% and thus be part of an IPM approach for Dubas management.

Pruning is also important in other large trees such as Avocado trees, where it is important to prune branches selectively to increase yields and to redistribute fruit production within the available canopy (Thorp and Stowell, 2001). Snijder and Stassen (1999) believe pruning to reduce the number and length of branches increases fruit yield on the remaining scaffolds without reducing fruit size. Compared with other tree fruit crops, relatively few Date Palm tree pruning and thinning studies have been reported in the scientific literature.

2.5.2. Biological control

Understanding the role of natural enemies is crucial to any pest management programme and for strengthening the economic justifications for conserving the remaining natural habitats and biodiversity in agricultural landscapes as well (Daily, 2000; Matson, 1997). However, apart from a few notable exceptions, studies on how predator removal indirectly affects herbivory rates in agricultural systems are lacking, particularly from tropical regions (Koh, 2008).

In Oman several surveys were conducted in different Dubas bug-infested regions and several biological control agents, such as *Aprostocetus sp*., *Cheilomenes sexmaculata*, *Chrysoperla canara* and *Runcina sp,* were recorded on different stages of Dubas bug life cycle (Beg et al., 1994). Among the egg parasitoids, *Oligosita* sp. has been commonly reported in different Date Palm growing areas (MAF, 2004a). *Oligosita* sp, make two appearances, the first in March and April and the second in October and November. The parasitoid *Oligosita* sp. has shown more than 50% parasitism in several locations and can be considered as a potential biological control agent of Dubas bug. Al-Shamsi (2003) recorded 22% of parasitism in the spring generation and 17% in the autumn generation on Dubas bug eggs.

Abdul-Hussein (1974) in Iraq and Yemen reported a number of predators in Date Palm orchards, including *Chrysopa carnea*, *Chrysoperla mutata*, *Chrysoperla stephens* (Neuroptera: Chryopidae), and *Coccinella septempunctata*, *C. undicimpuncat*, *Chilocoris bipustulatus* (Coleoptera: Coccinellidae). Al-Shamsi et al. (2003) recorded a new egg parasitoid species, *Pseudoliogista babylonica*, (Trichogrammatidae: Pseudoligosita).

Shahab (2005) determined the effectiveness of the predator *C. mutata* (MacLachlan) for controlling Dubas bug nymphs under controlled condition. He reported that the average number of nymphs consumed by each predator was 291, with 9%, 29% and 61% for the first, second and third nymph, respectively.

Sfih et al. (2009) investigated fungi isolated from nymphs and adults of Dubas bug. A spore suspension of *Trichoderma harzianum* and *T. viride* on nymphal instars showed rates of mortality of 68.5 and 65.8%, respectively after 72 h. Aminaee et al. (2010) investigated biological control agents in Kerman province in Iran during 2005–2007; 178 fungal isolates were collected from naturally infected Dubas bugs, and *Beauveria bassiana* was identified as a potential biological control agent.

2.5.3. Chemical control

In some situations, insecticides offer the only practical, cost-effective method of pest management. Conventional insecticides are among the most popular chemical control agents because they are readily available, rapid acting and highly reliable. A single application may control several different pest species and may form a persistent residue that continues to kill insects for hours or even days after application. Because of their convenience and effectiveness, insecticides quickly became standard practice for pest control during the 1960's and 1970's.

Matthews (1972) reported that insect control is essential if economic yields of crops are to be obtained. Also in his books on pesticide application methods (1979, 1982 and 1992) he described a variety of equipment and methods used for applying insecticides to palms and tree crops. For instance on small farms, hand-held or backpack sprayers with long booms are used for foliar application. Aerial application is used on African oil palm, other palm plantations, forestry spraying and control of migrant pests.

In Oman many Date Palm growers, particularly small holders, have difficulty in obtaining sufficient control by using conventional ground-based sprayers. A pesticide needs to be applied to the particular areas occupied by the pest. When spraying the whole area of a field crop, timing of insecticide's spray and application methods are considered as a key factor for the success of the operation. Spraying to ‘run-off’ has been recommended on many occasions to ensure complete wetting of Date Palm foliage. In general a tree crop with dense foliage retains more spray (Matthews, 1982). Dubas bug insecticide application are initiated when more than 75% of eggs have hatched and/or fourth nymphs are dominant in the population (Mokhtar et al., 2001d). In contrast, Smith and Van den Bosch (1967) argued that economic thresholds should be based on damage rather than pest numbers. This strategy is often employed in a therapeutic manner when populations reach the economic threshold or in a preventive manner based on historical problems (Michael et al., 2009).

The Ministry of Agriculture in Oman and Iraq conducts most of its chemical control campaign against Dubas bug by aerial spraying. In large scale operations (8,000-12,000 ha) for Oman and (68,000-77,000 ha) for Iraq, the cost of conventional high volume application operations can be reduced substantially by reducing volume application rate, and thus increasing work rate (Bateman, 2004). Therefore Ultra Low Volume (ULV) spraying is used, which has been defined as the minimum amount of liquid per unit area compatible with the economic requirement of achieving control. Date Palms have tall woody trunks, and at maturity can reach a height of 20 or 30 m, far beyond the reach by ground sprayers to adequately cover the canopy and control Dubas bug. Thus aerial spraying was considered to be the only suitable way for controlling Dubas bug especially in rough terrain such as mountainous sites and narrow valleys (Figure 2.8 (a) (b)). The challenge therefore is to select the aircraft that can fly safely, perform economically, and apply the spray uniformly over the treatment area.

(a)

(b)

Figure 2.8 ULV aerial spraying (a) in mountainous terrain for non-uniform plantations;

(b) in open areas and oases.

Since recording Dubas bug in Oman in 1962, MAF have evaluated a number of insecticides for controlling Dubas bug by aerial and ground spray. The recommended insecticides were DDT in 1976, followed by malathion 96% ULV at 2.4 l/ha, then dichlorvos 50% EC (not diluted) at 3.6 l/ha, fenitrothion 50% ULV at 2.4 l/ha, and mixture of fenitrothion and esfenvalerate (Sumi Combi Alpha®) 50% ULV at 2.4 l/ha (Appendix1). Both second and third generation organophosphate and pyrethroid insecticides have been widely used in Dubas bug control programmes mainly one aerial spraying per year for several decades (MAF, 2008a).

2.6. Implementation of an integrated pest management (IPM) programme

An integrated pest management strategy is a comprehensive approach to eliminate or reduce a pest problem using all appropriate cultural, biological, physical and chemical technologies. The development of a particular strategy will be greatly influenced by the biology and ecology of the pest and its interaction with its host and environment. Strategy development will also be influenced by the economics of production and the pest management interventions (Michael et al., 2009).

Abdul-Sattar (2009) in his study about implementing an IPM package for controlling Dubas bug in Yemen reported that cultural practices, such as proper plant spacing, removal of weeds, pruning, removal of offshoots and the use of drip irrigation reduced the incidence of Dubas bug. The proper inter and intra row spacing's (8 m) permitted the penetration of sunlight and air and reduced humidity; the use of drip irrigation system also helped to reduce humidity. After implementation of IPM treatments there was a further decline in the population of Dubas bugs (0.17% Dubas bug population on tree), and the population level of Dubas bug in the control field was 9-10 fold higher than the demonstration field. Also during sampling and examination of leaflets the eggs of the lacewing *Chrysoperla stephens* and the parasitoid *Pseudoliogista babylonica* parasitoid were observed in the fields and around Dubas bug eggs.

One of the most important outcome of the implementation of an IPM programme was minimize use of pesticides and improve pest management practices. IPM is the aim for the control of Dubas bug. Substantial efforts to rehabilitate Date Palm cultivation are made by the Government through the implementation of projects that aim to rehabilitate the cultivated areas of Date Palm and increase productivity, but that there are constraints on its implementation; technical, social, and financial. Lack of research on appropriate biological control methods. Inability to afford drip irrigation systems and unwillingness to plant at recommended spacings. Therefore need to develop a national integrated system against Dubas bug and facilitate the implementation difficulties of the project.

Chapter 3. **General Materials and Methods**

3.1. Pesticide application techniques

Two methods of application were used for spray applications.

3.1.1. Aerial application

A Bell 206B Jet Ranger III with 420shp turbo shaft was used to carry out aerial applications. The helicopter was leased by the Ministry of Agriculture in Oman and equipped with electrically driven atomizers, model Micronair AU6539. Operational equipment such as navigational guidance equipment (DGPS) and flow meter were used during application (Chapter 4).

3.1.2. Ground application

Two types of ground sprayers were used; power spray (PS) and knapsack motorized mistblower (MM). Honda model GX 160 used in the power spray treatment consists of an integrated spray tank, a petrol engine connected to a high-pressure pump and atomization was carried out using a hydraulic cone nozzle (Figure.5.2).

The MM sprayer had a tank with 15 l capacity, and was carried on the operators' back. The sprayer uses a small two-stroke engine to force the liquid to the nozzle (AU8000), and has a fan and a flexible discharge hose. The sprayer runs at full throttle (Chapter 5 and Chapter 6).

3.2. Evaluation of spray coverage, Dubas bug population and efficiency

In the present studies different methods for assessment of spray coverage, deposition and efficiency were used. Some methods provided more reliable results than other, but all had some limitation under certain conditions. However, none of the existing assessment techniques is suitable for all spray applications, therefore each technique was used for a particular application.

3.2.1. Water and Oil sensitive papers

Both Water- and Oil- sensitive papers (WSP and OSP) have been used for qualitative or quantitative assessment of spray coverage (Kilpatrick et al., 1970; Salyani and Fox, 1999). WSP was used to estimate Dubas bug population by counting the number of honeydew droplets falling on the WSP, and OSP was used for qualitative and quantitative assessment of spray coverage. Captured droplet stains on WSP and OSP targets were examined under a binocular microscope to measure droplets from aerial and ground applications. Also spray density and the percent area coverage and distribution of deposits were determined (Chapter 5 and 6).

3.2.2. Visual counting

Visual counts were used to monitor Dubas bug populations in the field. Visual counting was used as an alternative method in comparison with WSP counts of honeydew droplets. Visual counts and WSP, attested to the overall reliability of the evaluating the population level and dispersal methods (Chapter 5 and Chapter 6).

3.2.3. Yellow sticky traps

Yellow sticky traps were used in field experiments to determine how Date Palm height affected insect movement, to monitor insect population and to assess the effect of movement on development and re-establishment of the next generation of Dubas bug (Chapter 7).

3.3. Insect culture

A field strain of Dubas bug were collected in the 2011 spring season from Date Palm fields in Samail and Al-Rustaq governorates. Lab strain insects were reared on Date Palm seedlings planted in plastic pots (20 cm dia.) inside transparent cages (50 cm×50 cm×70 cm) in the laboratory at room temperature, which ranged between 25 and 27°C (Chapter 8).

3.4. Pesticides

Four formulated insecticide products, were applied at Ultra Low Volume (ULV) for aerial application. Emulsifiable concentrates (EC) were used for ground application and assessed during this study. Deltamethrin (Decis 12.5 ULV®, Bayer, Germany) was applied in the aerial spray trial (Chapter 4). In the ground spraying experiment esfenvalerate (Sumi Alpha® 5% EC, Sumitomo, Japan) was used (Chapter 5), while deltamethrin (Decis 2.5% EC®, Bayer, Germany) (Chapter 6 and Chapter 8), fenitrothion (Sumithion 50% EC®, Sumitomo, Japan) and etofenprox (Etofenprox 20% EC®, LOD's, France) (Chapter 8) were applied in other experiments.

3.5. Data analysis

All data from these trials have been statistically analyzed using SPSS statistic. Data obtained were submitted to an analysis of variance and the significant of differences between treatment means was determined using parametric statistics (ANOVA) after log or square root transformation if necessary, and classification of homogenous groups was performed with the test of Tukey HSD and Kruskal–Wallis at the level of 5%.

3.5.1. Statistical analyses of bioassay tests

The LC_{50} values were calculated using the procedure PROBIT of SAS (2002). LC_{50} values were determined by specifying a generalised linear model with binomial errors to estimate the slope and its standard error, with significance tested at the 5 % level.

Chapter 4. **Introduction Determine an effective droplet spectrum for controlling Dubas bug on Date Palm when applying an aerial spray.**

4.1. Introduction

Aerial spraying of pesticides began in the 1920s in the United States, but the idea of using aircraft was first announced in 1911 when Alfraid Zimmermann, a German forester was granted a patent by the Imperial Patent Office, Berlin, German (Barry, 2004). The State Experiment Station of Ohio (USA) demonstrated the first actual use of aircraft to apply pesticides in August 1921. After effective insecticides and fungicides were developed in the 1940s, then it became widely used worldwide. Aerial application, involves spraying crops with fertilizers or pesticides, from an agricultural aircraft. Busby et al. (1983) indicated that since 1945 there has been an increase in the use of chemical pesticides in food and fiber protection and in vector control in most parts of the world, and aerial spraying is used wherever there is a need for rapid application of pesticides to large or remote land areas (Gordon and Richter, 1991). In his explanation of application techniques, Matthews (1999) pointed out that, aircraft ranging from micro light to multi-engine transport planes have been used for aerial application. Multi-engine aircraft are preferred over forests, but in arable agriculture a single-engine, low-wing aircraft specially designed for field spraying is normally used. Helicopters are also used as they have greater maneuverability, can land anywhere without the need for an airstrip and are able to operate at lower flying speed.

The first use of aircraft to apply insecticides for controlling Dubas bug was in Iraq in May 1964 on an about 10 million Palm trees, while the first use of ULV insecticide was in 1965 (AlJubouri, 2000). In Oman the first use of aircraft for controlling Dubas bug on Date Palm was in September 1976 (Al-watan, 1976; Mohammed, 2010).

In 1976 outbreak Dubas-infested an area reached nearly 12,500 ha spread over most provinces in the country. MAF used two fixed-wing aircraft, to cover the infested areas in oasis and villages where plantations were in open country, while a helicopter was used in mountains and valley areas. An ultra- low volume (ULV) technique was the method of choice because of the economic benefits, operational efficiency, the efficiency of penetration of small droplets into tree canopies and speed that allows spraying large area in a short time

(Pimentel, 1995). Also rotary atomization can produce droplets that are relatively uniform in size (80um – 150um), in contrast with conventional spray nozzles, which produce droplets that vary widely from small droplets that may drift or evaporate before reaching the target to large droplets that produce a wastefully large deposit of pesticide in one spot.

Dubas bug have two generations autumn and spring generation (Chapter 2). In autumn generation where the area infested is relatively limited, MAF recommended ground application using Power and Hydraulic Sprayers, while in the spring generation and due to the heavy infestation dispersed over 12,500 hectare in various province/regions in Oman, aerial application was the method of choice to control this pest. Aircraft are used predominantly in countries where large areas are to be treated in a short time, or targets are high and inaccessible. For Dubas bug, the aerial operations had to be completed within one month before crops ripened.

MAF have developed specifications for aircraft used for aerial control against Dubas bug, including the use of controlled droplet application (CDA) technology, and Micron® AU6539 atomizer with electric pump. The Micronair AU6539 Direct Drive Electric Atomizer is specifically designed for use on helicopters, and specialised installations on fixed wing agricultural aircraft (Micron, 2007). The atomizer with a rotating woven wire gauze cylinder used to produce spray droplets within a narrow spectrum of sizes over a wide range of flow rates from a few milliliters/minute to 3 l/min. The spray droplet size is determined by the atomizer rotational speed, thus the speed controller can be adjusted to give the correct rotational speed for the optimum droplet size for a wide range of applications. The narrow droplet spectrum ensures that the maximum amount of liquid is sprayed as droplets of the optimum size and minimizes wastage or contamination from excessively small or large droplets. Also MAF requisite is to use Global Position System (GPS), that allows pilots to determine the position and record the flight path (Matthews, 1999). In addition to that, MAF has also required Differential Global Position System (DGPS) as a new technology in the aircraft. DGPS allows tracking more accurately, the treatment and recording exactly where spray was applied from aircraft (FAO, 1998; MAF, 2004c; Matthews, 2006) with much smaller margins of error than with conventional GPS.

The basis of CDA is that ULV pesticides will have the greatest effect in a particular situation if they are applied in droplets within a particular narrow size range (Symmons et al., 1991). ULV was developed in eastern Africa in the control of Desert Locust, shortly after the World

War II. Initially it developed in the 1950s for the use against Desert Locust (Dobson, 2001). Development of ULV for crop spraying started much later in the 1960s (Hill 1975). The technique consists essentially of production of very small droplets carried in light oil and blown by fan in drift spraying. The use of ULV spraying requires fine droplets to ensure adequate cover but not so fine to avoid loss due to drift and evaporation. The development of rotary atomizer enables the production of narrow spectrum of droplet size. This small quantity of concentrated insecticide is usually supplied ready to spray; it's not mixed with water or any other solvent. This formulation is known as ULV formulation. It is defined as applying between 0.5- 5.0 l of spray liquid per ha.

Woods (2001) believed that the ULV technique of applying insecticides has proven to be a very useful and economical method for controlling many species of insects. The most effective size range of droplets for adult flying mosquitoes as ground aerosols is thought to be about 15 µm, and for aerial sprays from 10 to 50 µm (Brooks, 1970; Hill 1975; Rose, 2001; Sugiura et al., 2011). For fogging application (Matthews, 2000) reported less persistent insecticides are to be used in fog (droplet size <25 µm) at low dosages as the aim to treat an area with droplets that remain airborne as long as possible, but for controlling insects in foliage a larger droplet size is required to be effective. The more numerous very small droplets of a finer spray might produce a more uniform dose and, because of the greater number of contact points, one which might have a greater effect.

Fritz et al. (2008) pointed out numerous studies on optimizing of aerial application practices for pest control in cotton, corn and weed control, noting that optimum spray droplet size combinations are pest specific and vary from one pest or target to another. The degree of effectiveness of sprays against pests is correlated with the size of the insecticide droplets. Based on literature review, a droplet size between 80 to 100 µm is most efficient for controlling agricultural pests.

Matthews (1992a) believed that, insect control of mobile pests such as jassids can be readily achieved without complete cover, but that the deposited droplets of 100µm diameter should be sufficiently close to give a high probability of a direct hit on the small insects. Alm et al., (1987) reported that 120 µm droplets of bifenthrin were more efficient than 200 µm droplets. Hall and Thacker (1994) indicated the topical toxicity of permethrin 2EC and lambda-cyhalothrin 1EC would vary with the droplet diameters of 100, 200, 500 and 1000 µm when applied to the dorsal surface of third instars larvae cabbage looper *Trichoplusia ni.* The topical toxicity of both compounds was highest for the smallest droplet size.

(Dobson, 2001; Symmons, 1992; Symmons et al., 1991) reported the ideal droplet diameter for locust control is thought to be between 50 and 100 µm, and the best performance was considered to be when 80% or more of spray volume fell within that range (FAO, 2002). On the other hand, a study in the Sudan showed that, the recovery on cotton leaves increased from approximately 30 to 80%, when the volume median diameter (VMD) of the spray was increased from 80 to 130µm (Anon, 1981). Such an increase in droplet size causes a reduction in droplet density on the crop, accompanied by an uneven deposit of pesticide. For a given volume application rate, an increase in droplet size above a certain limit will therefore adversely affect pest control, particularly if pest movement is limited and/or the treatment relies on contact action to effect control (Lavers, 1993a). Subsequent studies confirm the greater efficiency of penetration of small droplets into tree canopies and their impaction on foliage. Also, results indicate that recovery of spray is influenced by application rate, droplet size, tree species, and density of foliage (Barry, 1984).

In general, selection of the droplet size for application needs to take into account many factors such as meteorology, formulation type, crop morphology and pest habitat and mobility. Also aerial applications from aircraft should be correlated with weather conditions so that insecticide does not drift out of the area to be treated (Lofgren, 1972; Maccollom et al., 1986; Woods et al., 2001). For example, volume of spray and the droplet spectrum used in aerial spraying of forests have varied as indicated (Table 4.1).

Table 4.1 Volume of spray and droplet spectrum used in aerial spraying (from Barry, 1994).

Volume	VMD	l/ha
High volume (HV)	> 500 µ	>50
Low volume (LV)	150-500 µ	5-50
Ultra low volume (ULV)	80-150 µ	<5

In Oman, there is no technical recommendation based on the field trial results about the droplet size that can be used for controlling Dubas bug on Date Palm plantation. However, MAF (2000), as the local authority, provide instructions for aerial spray operators. The application requirements for the Micronair atomizer AU6539 include a VMD of the droplet spectrum ranging from 80 to 100 µm. This study aimed to test this recommendation to see if larger or smaller droplets give more effective control of Dubas bug.

4.2. Materials and Methods

Field experiments were conducted during spring generation of 2010. Trials were conducted on selected infested villages in four locations. Each location was divided into five plots. Each plot was a village in the same valley, covering about 10 ha. There is a normal boundary of up to one kilometer separating the villages. Insecticide was applied by contractor-owned helicopters (Bell 206 Jet Ranger III), leased by the Omani Ministry of Agriculture (MAF) for Dubas bug control campaign. A deltamethrin (Decis 12.5 ULV®) formulation as recommended by MAF was used with two dose rates; 450 g a.i /ha recommended dose rate by MAF and half dose rate 225 g a.i /ha. This is equivalent to 3.6 and 1.8 l product per ha. Thus for the second treatment the dose and volume rates were both halved.

4.2.1. Evaluation of population and the efficacy

4.2.1.1. Water sensitive papers

Dubas bug populations were estimated by counting the number of honeydew droplets on water sensitive papers (WSP). The evaluation for the efficacy of insecticide was based on the reduction in the number of Dubas bug honeydew droplets as described by (Mokhtar and Al-Mjeni, 1999; Salyani and Fox, 1999). Ten Date Palm trees were selected randomly from each of the five plots. Under each tree, four Petri dishes (90 mm diameter) containing water sensitive papers (76 x 26 mm) were supported 20 cm above the ground beneath the Date Palm canopy in four directions (East, West, North and South) about 1.5 to 2 m from the trunk base (Figure 4.1). The WSP were left for two hours starting from eight o'clock in the morning. After 2 hours, the papers were collected and the number of fallen honeydew droplets counted (Figure 4.2).

Figure 4.1 Distribution of WSP, 1.5 meter around Date Palm trunk in different directions (East, West, South and North).

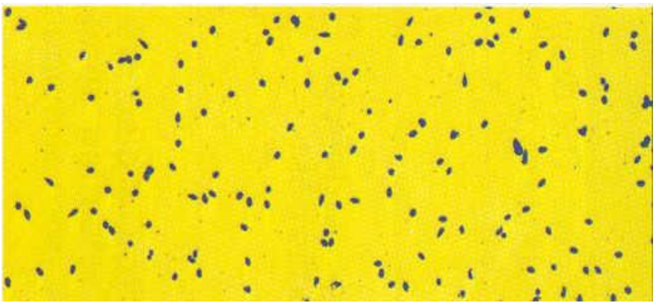


Figure 4.2 Honeydew droplets on water sensitive paper prior to a spray

Dubas bug population was also estimated by visual counting of different instars and adults from ten small Date Palms trees randomly selected from each plot. Three fronds per tree were randomly selected for data collection. From each leaf, one sampling portion (either, from the lower part, middle part or at the tip) was marked for data collection, and counting of Dubas bug instars and adults was done from 60 leaflets (20 leaflets/frond) as describe by (MAF, 2006a; MAF, 2006b). Therefore, the total number of leaflets used for data collection per tree was 60 and 600 in total. Data were collected, 2 days before spraying, and then at 7, 14, 21 and 28 days post insecticide application (Askari and Bagheri, 2005; ICARDA, 2009).

4.2.1.2. Oil sensitive papers

Spray deposits were sampled at ten site/trees per plot along various parts of the tree (attached to palm leaves in the top, middle and lower part) also on inter crops like Banana or lemon and on the ground. They were placed perpendicular to swath orientation and located at adequate distance from the margins of plot as describe by Payne et al., (1997). All drops deposited on the OSP samples (76 x 52 mm) were visually counted using a binocular (X 10 magnification), and deposit densities (number/ cm^2) on ground cards were counted in four 1-cm^2 areas per card. Droplets, that were well distributed on these samples with 20 droplets per cm^2 at least, indicated a good spray treatment.

4.2.2. Calibration

Calibration is the process of adjusting sprayer components to deliver the desired volume (rate) per area when applying chemical products, to ensure that the correct volume is being delivered per unit of area. Accurate calibration of the aircraft is vital for effective spraying. The successful aerial applicator recognize the importance of uniform distribution, proper aircraft setup, spray droplet size, drift control and weather condition. Each of these factors has a significant effect on the degree of efficacy with pesticides (Gardisser and Kulhman, 1993).

4.2.2.1. Droplet Size

Droplet size is a key factor in the success of ULV application. The size of the spray droplets produced by electric driven AU6539 depends upon the rotational speed of the atomizer and the properties of the liquid being sprayed. Micronair AU6539 atomizer Droplet Size Prediction Model was used to calibrate the volume median diameter (VMD) as described by Micronair. The required VMD of droplets were 75, 100, 150, 200 and > 200 μm respectively. The spray droplet size is determined by the atomizer rotational speed, and the speed controller was adjusted to give the correct rotational speed for the specific droplet spectra used in the trial. Using the speed controller, the atomizer speed was varied from 500 rpm to12,000 rpm, the maximum possible at the aircraft supply voltage (Table 4.2). Calibrating the system was made when the aircraft engine was running and charging the battery, and the speed of an atomizer checked with a digital tachometer on a regular basis (Figure 4.3).

Table 4.2 Droplet size (VMD) data as set by Droplet Size Prediction Model for the rotary atomizer used.

Atomizer speed (rpm /1,000)	Droplet diameter size (µm)
5,100	75
4,500	100
2,800	150
2,100	200
1800	> 200

Figure 4.3 Adjusted RPM speed by digital tachometer.

4.2.2.2. Spray application equipment

The helicopter was equipped with four Micronair AU6539 atomizer, flow meter, DGPS differential spraying device in addition to other accessories to meet the department's requirements and conditions (Figure 4.4). Therefore all required parameters such as liquid flow rate, together with the swath width and ground speed of the aircraft, and all other vital parameters of the spray operation will be computed all the vital parameters of the spray operation.

Figure 4.4 Bell 206, Jet Ranger III equipped with specialized equipment.

4.2.2.3. Determination of swath width

In order to ensure that the spraying system is functioning correctly, it is advisable to undertake a swath pattern analysis before spray operations commence. The aircraft is flown over a target site and the droplets collected downwind on OSP cards positioned vertically on sampling support. The best swath is determined at the flight lane separation, which gives an acceptable level of recovery of the volume applied. The graphs below display the number of droplets per cm^2 captured on the cards corrected to a single pass (

Figure 4.5). Based on the results from these trials, swath width was 15 m at forward speed of 100 km/h.

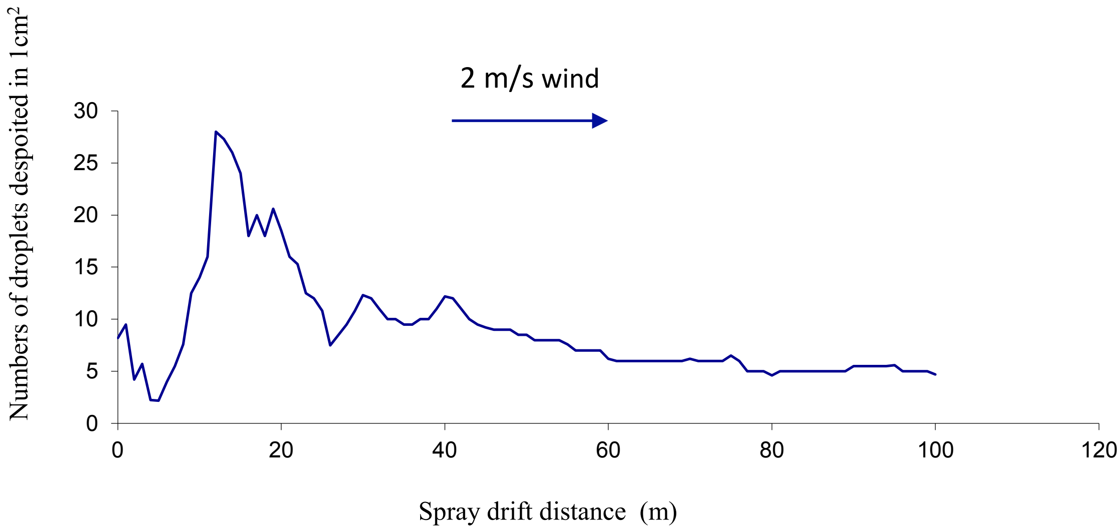


Figure 4.5 Downwind dispersal of spray at 2 m/s wind speed.

4.2.2.4. Flow rate

The flow rate is related to the required volume rate, the aircraft ground speed and the effective swath width, a relationship that can be expressed as the equation:

$$\text{Flow rate (l/min)} = \frac{\text{Speed (km/h) X Swath width (m) X Application rate (l/ha)}}{600}$$

Flow rate was checked and adjusted to achieve the required two flow rates of 9 and 4.5 l/min from 4 atomizers, 2.25 l/min and 1.125 l/min for each atomizer respectively. Calibration was carried out on the ground with the engine aircraft running were satisfactorily calibrated to apply the correct volume.

4.2.3. Ecological condition

The prevailing meteorological conditions during and after the insecticide spray application influence its efficiency. To comply with operational practice, spray application was made under typical meteorological conditions for Date Palm insecticide application in Oman, specifically in light wind, moderate temperature 25-30ºĊ and low turbulence condition.

Traditionally aerial insecticide application for forests are made early in the morning to take the advantage of the stable layer, low wind speed, often found at that time of the day (Payne, 2000), and it is the same for Date Palm spray application. They are also favourable conditions for pilot safety because of the low turbulence levels and light wind. Sprays were applied between 6 and 9 a.m., and each application took about 10-15 min to complete. Meteorological conditions during the application are measured at a site near the treated areas. Relative humidity, temperature and wind speed are recorded at the time of application using a portable weather station. In addition, a handheld pocket Weather Meter (Kestral, 3500 DeltaT) was used to maintain a record of temperature, relative humidity and wind velocity.

4.2.4. Efficiency assessment

The ± population reduction was evaluated after 7, 14, 21 and 28 days of application on the same Date Palm trees and at the same time as described above by calculating the difference in honeydew droplets/number pre and post application in comparison with the control as described by Henderson and Tilton (Henderson and Tilton, 1955) by the following equation :

$$\text{Efficiency \%} = \frac{\text{Insect number before spraying} - \text{Insect number after spraying}}{\text{Insect number before spraying}} \times 100$$

4.3. Results

The data from this trial have been statistically analyzed using the SPSS program. Data obtained were subjected to an analysis of variance and the significance of differences between treatments means were determined with F-test and a classification of homogenous group, and performed with the test of Tukey HSD and Kruskal–Wallis at the level of 5%. Also SPSS performs canonical linear discriminant analysis. The discriminant analysis performs a multivariate test of differences between groups.

4.3.1. Sprays applied at ULV rates

The results of five treatments (75, 100, 150, 200 and > 200 microns), either by reduction of

Dubas honeydew or reduction of insect numbers, showed the highest number of Dubas bugs before applications were recorded at the site, treated with droplet 150 µm. These data were collected two days pre insecticide application and, on 7 days, 14 days, 21 days and 28 days after application respectively (Figure 4.6).

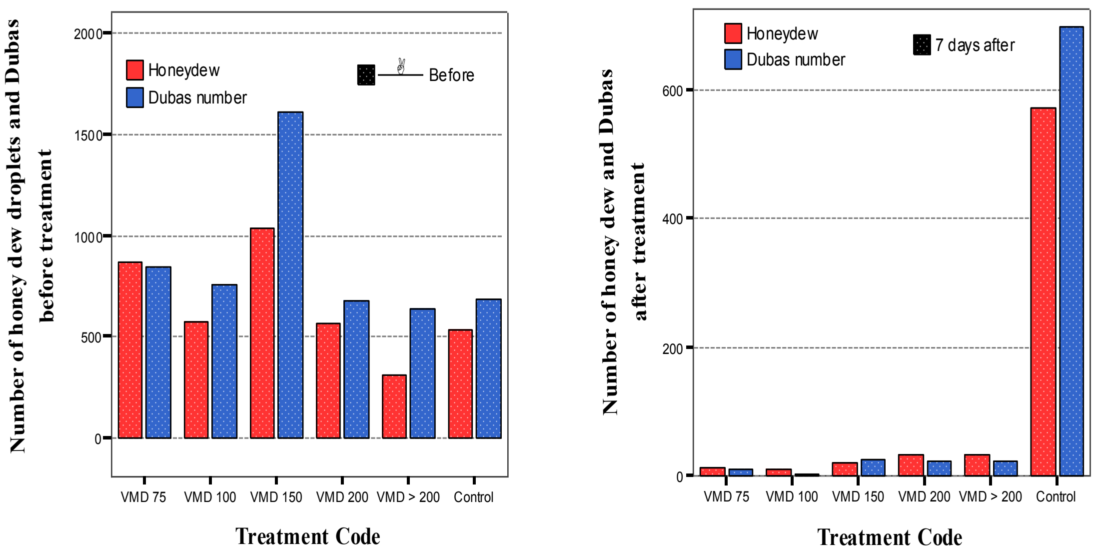


Figure 4.6 Average numbers of honeydew droplets and Dubas bugs before treatments at the trial sites (left); and average numbers of Dubas bug honey dew droplets, nymphs and adults 7 days after application (right).

The analysis of variances on the number of Dubas bugs honeydew droplets and numbers of adult and nymph at different times (after 7, 14, 21 and 28 days of pesticide application), showed the best result obtained after 7, and 14 days respectively but no significant difference with other periods. The data was analysis also to determine better distinction between droplet sizes. The result showed no significant difference between droplets sizes smaller than 150 µm that achieved maximum pest mortality percentage in the field (98%), but droplets bigger than 150 µm shows less efficient and pest mortality percentage ranged between 93 - 88 % (Figure. 4.7).

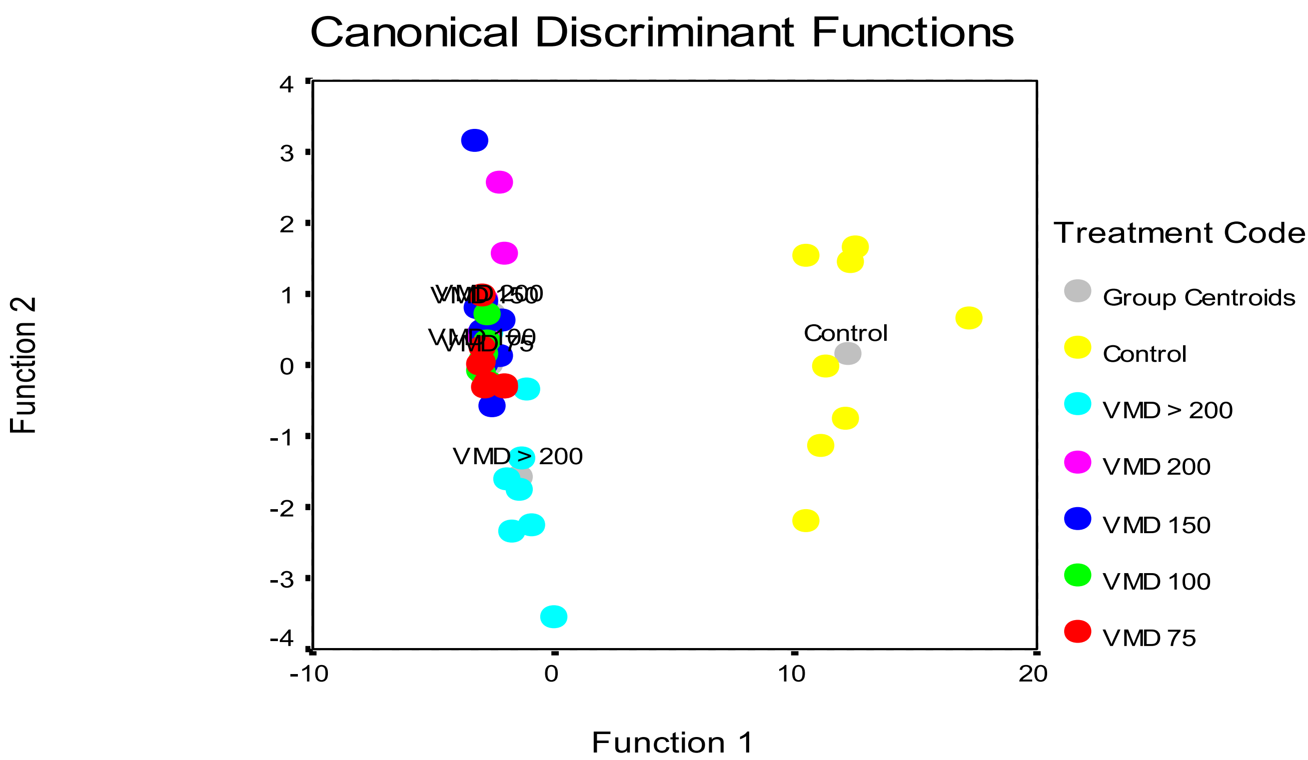


Figure 4.7 Result of five treatments of VMD 75, 100, 150, 200 and > 200µm applying full dose and differences between treatments as showed by Canonical discriminate functions. Function 1 shows difference between control and spray treatments, while Function 2 shows the variation between spray treatments. The discriminate functions were honey dew droplets and efficacy. Droplets from 75 – 150µm, were more effective on Dubas bug, with less secreted honeydew on plants treated with the smaller droplets. Larger droplets - 200µm were less effective, with greater variation with droplets > 200µm and in the control plots.

Similar results were obtained in the evaluation of visual account of Dubas bug numbers, with no significant difference between droplet diameters (75, 100 and 150 µm). There was no significant difference between the two methods used to evaluate spray effectiveness after 7, 14 or 21 days after application.

4.3.2. Spray at half volume and half dose,

The percentage of efficiency was calculated by Henderson-Tilton's formula. The best results appeared to be obtained with a droplet size of 100 µm, which gave 65%, 65.4%, 65.7% and

64.4% reduction of honeydew droplets after 7, 14, 21 and 28 days, respectively. However, droplets ranging from 75 µm to 150 µm diameter were not statistically significant in terms of Dubas bug honey dew or insect numbers (P>0.05) but there was a significant difference between 100 and 200 µm diameter (P=0.001). In addition, similar results were obtained using visual counts of nymphs and adults to estimate reductions in Dubas bug (Figure 4.9).

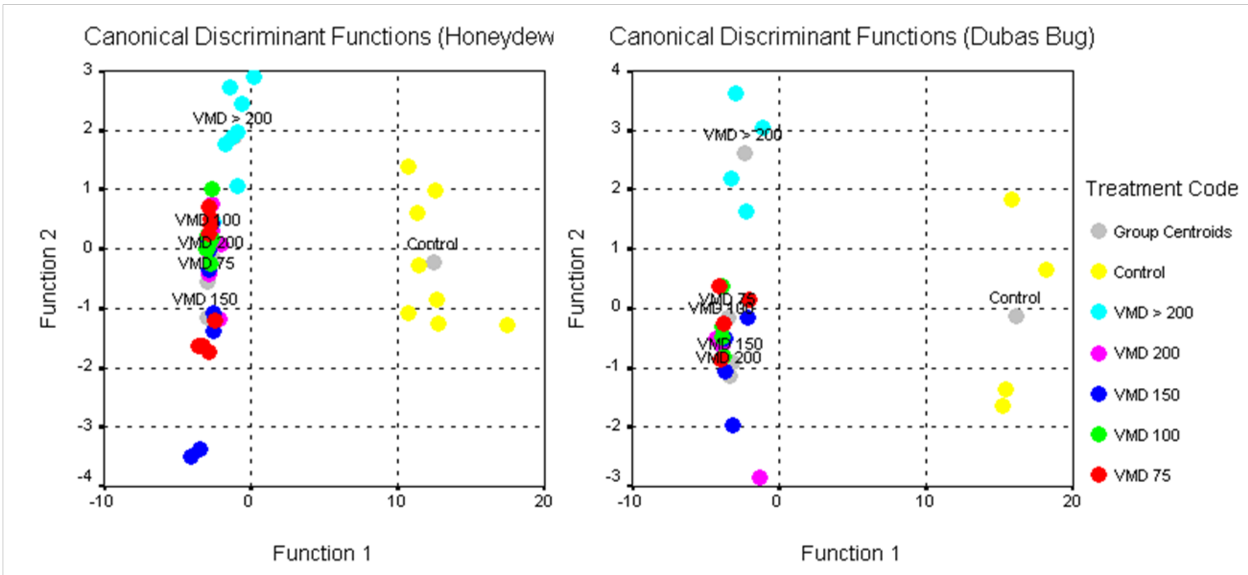


Figure 4.9 Results on honeydew (left) and Dubas bug numbers (right) when applying half dose and half volume treatments of VMD 75, 100, 150, 200 and > 200µm with differences between treatments as shown by Canonical discriminate functions. There were no differences between VMD from 75 – 200µm, which were more effective on both honey dew droplets and Dubas numbers. Droplets > 200µm were less effective.

4.4. Discussion

The results obtained from this trial show that, the droplet diameter plays a major role in determining the efficiency of controlling Dubas bug, particularly droplets of a diameter between 75-150 µm. The mortality percentage of insects has reached to 98% when using spray droplets diameter in this range. Larger spray droplets of 200 µm diameter were less effective. That is probably due to excellent coverage achieved with more numerous small droplets. The rotary atomization gave a fine spray with more uniform droplets, that are most effective for the control of relatively mobile insects like Dubas bug. The penetration of small droplets 75-150 µm into tree canopies and their impaction on foliage was better (Barry, 1984), because of the greater number of contact points, which might have a greater effect especially if most deposited droplets contain a lethal dose (Bateman, 1993; Symmons et al., 1991).

Although, the nature of the Date Palm trees plantation in the traditional areas in Oman resembles largely forest, the choice of droplet size spectrum is important because it also affects droplet coverage. For a given volume application rate, too large droplet spectrum will yield in too few droplets for adequate coverage, and the pest insect may not receive the required dose. The droplet size spectrum also affects spray deposition, too fine a spectrum will result in a droplet size that impact at very low efficiencies, because droplet size tends to decrease with distance. Droplet size spectra between100-200 µm has been successfully employed in broadleaf forest canopies (Glare et al., 2003; Payne, 2000).

This trial has indicated that the efficiency of an insecticide can be determined from either of the designated post treatment periods from 7 - 28 days after treatment, because results on different sampling dates were not statistically significant. MAF recommendation was to evaluation pesticide efficiency after seven and fourteen days of treatment application. Another important finding is that biological efficiency of insecticide application on Date Palm plantation (particularly insecticides with similar mode of action) for aerial applications can be assessed easily by either WSP or visual count of Dubas density on the shorter offshoots because of non-significant differences (<0.05) between these samples and elsewhere on the date palms. This is consistent with the assessment mentioned by (Mokhtar and AlMujni, 1999). Therefore, actual counts of Dubas on offshoots trees can be considered as an indicator of control efficiency for aerial application. The distribution of spray droplets must be used as an assessment parameter to ensure that adequate deposition over the whole spray swath is achieved but it is not necessary that every card must have the required average number of droplets/cm^2. Therefore results from WSP/OSP should both be used and with caution (Salyani and Fox, 1999).

A positive relationship was found between the amount of active ingredient and droplet diameter in respect of Dubas bug mortality. Higher doses were shown to be more effective against Dubas. Droplets in the size range from 75- 150 µm were more effective for mortality at the full dose than at the lower dose, which had 60% mortality only compared to 98% at the full dose.This variants maybe due to deposit recovery was less in half dose droplets in contrast with full dose droplets. The relationship between dose and mortality is complicated.

Therefore, choice of dose is not simply a function of increasing the density of droplets on the foliage, but a balancing act between droplets and dose in the droplets (Glare et al., 2003).

Hence, spray droplets and the quality of spray deposits can have a significant effect on the biological impact of given insecticides dose (Hislop, 1987). The biological implication is that good coverage increases the probability that a pest will encounter a pesticide; this is primarily based on what is known from application of pesticides. Because of the relationship between the diameter of droplets and volume, there will theoretically be a cubic increase in numbers of droplets produced for every halving of their diameter (Bateman, 2008).

Chapter 5. **Evaluation of ground application control of Dubas bug – efficacy and impact on re-infestation**

5.1. Introduction

Ground application plays an important role in Dubas control operations and complements aerial applications, particularly in newly and mildly infested areas and in areas that cannot easily be accessed by aircraft. Ground application has been widely used in many countries to control Dubas bug infestations in conjunction with aerial application. Both Abdul-Hussein (1974) and (AlJubouri, 2000) reported that ground application was widely used in Iraq for controlling Dubas bug in the 1960s before moving to using aerial application in 1965, when the infested area increased dramatically. The United Arab Emirates, Iran, Pakistan and Saudi Arabia have also used high volume sprays for ground application to control Dubas bug (Mahmoudi et al., 2014). Yemen has used ground application through power sprayers to control Dubas infestation in Hadramout and Al Mahara provinces since 2006.

To obtain efficient chemical control, it is necessary not only to apply an appropriate insecticide at the correct dose but also to select the correct formulation, volume application rate, time of application, and the type of application equipment (Lever, 1969). A sound understanding of the biology of the pests, the climatic conditions and the farm management system are also essential for effective crop protection (Hall, 1994).

A major spray application problem in Date Palm is that trees are often very tall (up to 20 m) and grown on undulating terrain, making it very difficult to treat trees uniformly from the ground. Power sprayers have been used but these are rarely powerful enough to deliver spray to the upper canopy. Spray nozzles are an important part of sprayers and should ensure safe and efficient application; hydraulic nozzles being the most common. They determine output, spray pattern and droplet size – all important factors for spraying with minimum drift and off-target contamination (Friedrich, 1998).

To characterise spray quality there are many references in the literature to the use of water sensitive paper (WSP) to assess droplet size, coverage, deposition, and/or drift. Kromekote card can also be used if a dye is put into the spray tank, and oil sensitive paper can be used for oil-based spray formulations.

For most applications, the utility of a particular spray sampling method depends on the availability of human and capital resources, the physical and biological characteristics of the crop, and the desired degree of accuracy (Salyani and Fox, 1999). WSP are the most popular artificial targets for evaluation of water-based spray coverage and deposits (Hołownicki et al., 2002). Since water in spray stains the WSP and the spot size can thus be observed or measured, WSP can be used to evaluate the number of stains per unit area and to measure the percent area covered (Syngenta, 2008). WSP have been used extensively by the Ministry of Agriculture in Oman (MAF) to quantify spray quality from various spray applications, particularly to evaluate the efficiency of treatments in reducing the population of Dubas bug as a result of fewer honey dew droplets numbers being secreted by the Dubas bugs. These measurements were possible by simply counting the number of spots on sample WSP as no spread factor was required.

The hypothesis for the present study is that, ground application cannot obtain good control of Dubas in Oman. This is supported by observations at many sites where ground application has been used and Dubas bug reappeared in large numbers in the next generation (MAF, 2008b). This lack of sustained control could be due to various factors which make it difficult to conduct ground control operations, including the high density of Date Palm stands, the irregularity of palm plantations within the agricultural units, the difficulty of movement between trees and varying height of the palms, especially in mountainous areas. Untrained farmers also rank low price and durability of technologies higher than operator safety, comfort and efficiency when choosing their equipment, especially if it will be operated by hired or casual labour.

The objectives of this element of the research were: (1) to evaluate the efficiency of ground application to control Dubas bugs (2) testing the two methods of assessing Dubas bug populations and (3) to determine the reasons that can lead to re-infestation at the next generation. All tests were conducted under field conditions.

5.2. Material and methods

The trials were conducted during the autumn generation of Dubas bugs in October 2010, in the Samail of Al-Dakhiliya province. Trees under similar growing conditions at highly infested sites were selected randomly and divided into three blocks (see section 5.2.2 for more detail of application techniques). Each block was divided into three plots of about 0.5

ha each; two plots for the ground application treatments and one (untreated) as control. All blocks had been marked as having a high density of palms per unit area, at a rate of more than 300 palm trees per ha (MAF, 2005a). The three treatments (one application, two applications and untreated control) were allocated to plots randomly and there was a natural break (buffer zone) of 10 m between blocks. The casual labourers were divided into two teams with three person in each, the first team treated plot no.1 and the second team treated blot no.2.

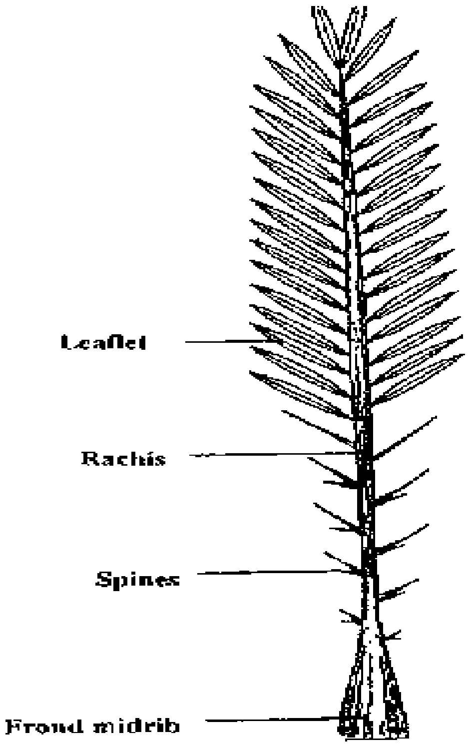
5.2.1. Dubas population assessment

To assess the level of Dubas bug infestation on the experimental sites, 10 Date Palm trees were chosen at random, and numbered in each plot and used for the duration of the experiment in order to allow for the natural variation of pest populations on different trees.

A pre-treatment assessment was made of Dubas bug populations on the 10 palms by measuring the number of honey dew droplets secreted by Dubas bugs (Section 4.2.1.1). The assessment of the efficacy of population control was based on the reduction in the number of honeydew droplets. Four WSP (76 x 26 mm) were placed in polystyrene Petri dishes (90 mm dia.) and placed on the ground in four directions (North, South, East and West) beneath each Date Palm canopy about 1.5 m from the trunk for 2 h starting at 0800 h (Chapter 4, Figure 4.1). The WSP were then collected and the droplets of honeydew counted. Efficacy of the insecticide was evaluated at 7, 14 and 21 days after each spray application. The percentage of insecticide efficacy was estimated by calculating the difference in honeydew droplets before and after application using Henderson and Tilton's formula (Henderson and Tilton, 1955) and data analysed statistically in SPSS (Section 4.2.4).

In addition, 10 offshoots (less than 3 m high) were identified randomly in each plot at the same sites, and from each offshoot, three fronds were allocated to count Dubas bug (nymphs and adults) on 20 leaflets from each frond (Figure 5.1). Thus, in total, 600 leaflets were assessed. The number of nymphs and adults were counted before application in the three treatments. Blocks with one treatment, treated once then followed up result during an intervals of 7, 14, 21 days. The blocks with two treatments, treated at the same time with one treatment block for first treatment, and then followed up at intervals of 7 and 14 days. A second treatment (for blocks with two treatment) was applied on day 15 (i.e. 2weeks after the 1st spray) then it was followed up at intervals of 7, 14, 21 days. Assessment being made at the same time as the WSP assessments.

(a)



(b)

Figure 5.1 (a) View of 20 leaflets (marked between two red tapes) of a Date Palm leaves used to determine Dubas bug infestation on offshoots; (b) diagram of a Date Palm leave (source Date Palm Cultivation book, FAO, 2002).

5.2.2. Insecticide and application equipment

The ground application trial was carried out using the pyrethroid esfenvalerate (Sumi Alpha®) at 1.0 ml 5% EC per litre of water, the recommended local mixing rate for Dubas bug control (MAF, 2006a). This spray mix was applied at 2,400 l per ha (120 g a.i. per ha). The most commonly used sprayer for applying insecticide to Date Palm tree is the power sprayer. Here, mobile power sprayers (Honda 6GX) with a 10 hp engine were used for all spray applications. The sprayer was connected to an external spray tank with a capacity of 200 l. The spray pump was connected via a pressure-regulating valve to a 50 m hose fitted with a spray gun (Nagata pistol injection mouth nozzle, Nagata Seisakusho Company, Japan) and adjustable hollow cone nozzle. Hollow cone spray nozzles produce a fine, atomized liquid flow, displaying spray patterns characterized by a ring-shaped impact area where liquid is concentrated on the outer edge of the spray patternation. They give good target coverage and are used with contact acting agrochemicals such as fungicides and insecticides and for penetrating dense canopies. The flow rate was 12.5 l per minute at a pressure of 35 bar (35.687 kg/cm^2). The sprayer was operated from an open area, projecting the spray upwards, trying to reach the highest point of the canopy possible. Spraying was done to 'run-off' i.e. when spray liquid is dripping off the branches, fronds and trunks. All blocks were sprayed on the same day starting at 0700 h and finishing by 1200 h, and temperature was between 23 to 25 °C (Figure 5.2).

Figure 5.2 Implementation of ground treatment of Dubas bug by casual labourers

5.3. Results

5.3.1. Efficacy of Ground Spray

The results of the trial are presented in Table 5.1 and Figure 5.3. There were no differences in infestation between blocks before treatments. After the first treatment, there was a reduction in honeydew droplets and number of Dubas bugs in the spray treatments compared with the control. Effect of esfenvalerate insecticide on honeydew production and Dubas bug number on day 7 and 14 after treatment were significantly different from the control.

Table 5.1 Results of insecticide applications at different intervals on Dubas bug reduction of honey dew droplets and Dubas numbers.

Block No.	First treatment	First treatment results of control (%)		Second treatment	Second treatment results of control (%)	
block 1	Honeydew	37.6	61.6			
	Dubas umbers	39.3	68.6			
block 2	Honeydew	40.3	86.3		94	95
	Dubas umbers	39.6	83		87.6	95.3
Treatment date	12-Oct-10	19-Oct-10	26-Oct-10	27-Oct-10	03-Nov-10	10-Nov-10

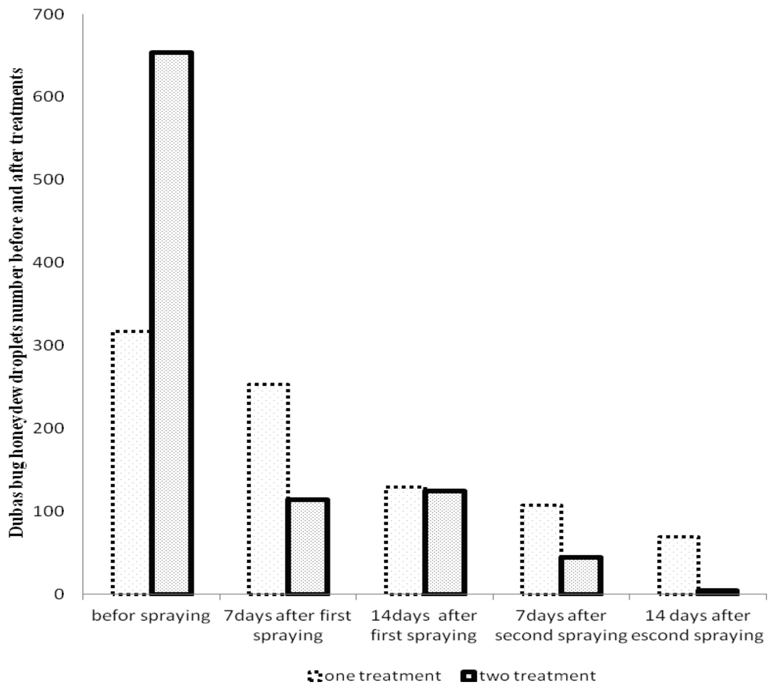


Figure 5.3 Effect of esfenvalerate insecticide on Dubas bug at different intervals after treatments.

Result indicate that 7 days after first spraying there were no differences existed between two blocks where results ranged between 37 to 40% in different blocks, but there was a difference after 14 days in reduction of honey dew droplets and Dubas numbers ranging between 61 to 86 % but the differences observed were not significant (p>0.05).

The best results were obtained with esfenvalerate in the second treatment 14 days after spraying, which gave 95% reduction of honey dew and Dubas numbers. Reduction of honeydew droplets and Dubas numbers is significantly different between first and second spraying (P<0.000), and better results were obtained with the two treatments. Honeydew droplets declined after the second treatment by up to 95% after 14 days and by 99% after 21 days. No-significant differences was found on the mean reduction of honey dew droplets (F=4.28, P<0.001) or Dubas number (F=4.50, P<0.001) by 7 and 14 days after the second spraying.

Figure 5.4 shows the results of the spray assessment methods - visual counts of Dubas adults and nymphs and Dubas honeydew on WSP. There was no significant difference between these methods (P >0.05). This result confirmed that Dubas bug numbers are a good method of determining Dubas bug populations. However the reduction percentage of Dubas number and honeydew droplets increased to 95% for both after 14 days of the second treatment.

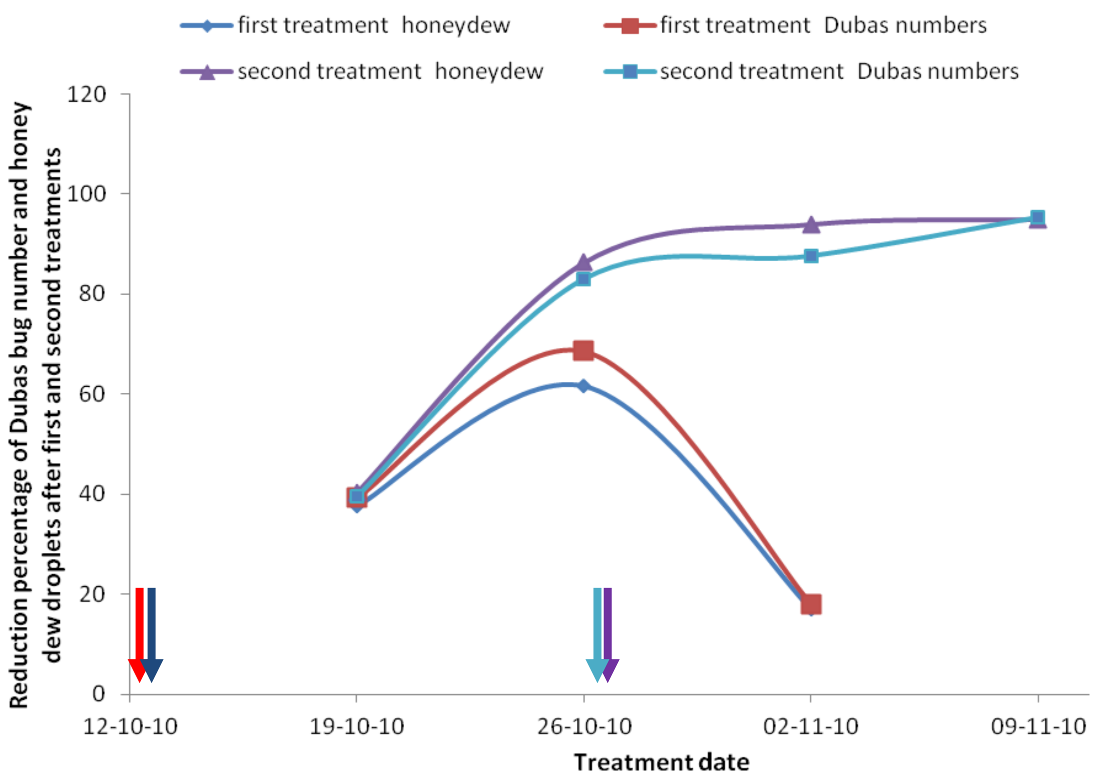


Figure 5.4 Decline percentage of Dubas bug; honey dew droplets and number at different intervals after treatment (differences between assessment methods). The red dark blue and purple aqua colours arrows indicate time of first and second sprays.

5.4. Discussion

Knowledge of the fate of pesticides applied for crop protection is clearly essential to understand the efficiency and likely effectiveness of any application technique (Cook and Hislop, 1993). The trend for larger trees to receive lower deposits is entirely consistent with the concept that a spray has to be distributed over an increasing canopy area (Manktelow et al., 2004). This is only true if the same volume of spray is applied to a big tree as to a small tree. In this experiment, the laborers made spray volume adjustments between tree canopies by adjusting spray nozzle (vertical type mode) to reach top of the trees canopies. However, from the beginnings of spray research, it was understood that the quantity of pesticide reaching the canopy of arable crops could be influenced by density and application method (Zande et al., 2003).

In order to make a general evaluation of the experiment results, we need to understand that ground-based insecticide applications to Date Palm trees in Oman are largely effective from the point of view of managing damage caused by Dubas bug (less than 5 insect per leave), particularly on small and medium height trees, but not suitable on tall trees above 10 metres. In this case study, the assumptions were that the equipment was good and new, the insecticide used is effective and that previous control operation results were effective (MAF, 2008c). Since stability is expressed in relation to each axis; stability in treated time, pesticides, sprayer and area. These results reveal the different effectiveness between the control teams for instance reduction of honeydew droplets after the first treatment was between 62-64% after 14 days in some plots and up to 90 % in other plots, in contrast the efficacy was 94 % and 95% after 7 and 14 days respectively for second treatment (Figure 5.4).

These results are not consistent with trained application labourers, who have reached 95% to 99% after 7 and 14 days respectively from one treatment (Alkhatri, 2005; MAF, 2008c; MAF, 2009b). It's clear that using untrained casual labourers for ground application gives different results, the distribution of the spray will depend on the skill of the operator, some areas got overspread while other parts of the crop, especially the undersurface of leaves, may remain untreated (Matthews, 1999), so second treatment might be required. However, incorrect implementation of the process by grower/ labourers can negatively affect the result of ground control of Dubas bug. These data are therefore consistent with received wisdom about ground application in Date Palm in Oman – that it is less effective for Dubas control than aerial spraying (Thacker et al., 2003).

Since all sites over the country were targeted by ground application in the same manner and technique, the efficacy of spraying insecticide to reduce Dubas bug populations was not sufficient to stop significant egg-laying and resulting significant Dubas bug populations from the following. On other hand, whereas if we are only getting 95% control with ground spraying, then possibly it is re-infestation that is causing next seasons population, because the surviving 5% that are breeding to produce large numbers again in the next season.

Follow-up of trial sites in the next generation field survey showed occurrence of Dubas bug on these sites. These results strengthen the assumption of the surviving 5% of Dubas that are breeding to produce large numbers again in the next season. Particularly if we know that Dubas bugs female lays more than 100 eggs and survive several weeks before dying (MAF, 1981; MAF, 1997), so potentially even 99% control could lead to the remaining 1% breeding up to the original numbers in one generation. Of course natural enemies and other natural mortality of Dubas will mean that is not likely, but the percentage control required to prevent the next generation being significant is not known.

We should distinguish between the inevitable deposit variability between the inner and outer canopy and the unacceptable/avoidable variability introduced by the method of application. Because the Date Palms in the grove were very closely planted due to the scarcity of land as well as being non-uniform in rows or level and age (Talhouk, 1979), means that they are planted at different times depending on the environmental conditions and availability of land and water. This uniformity of target in even one crop made movements of spray teams between trees difficult, negatively affecting spray and control efficiency (Alalawi, 2010).

Spray application requires faith on the part of the sprayer operator, who receives insufficient feedback on how the spray was distributed on the target canopy or what dose was achieved. So the distribution of the spray will depend on the skill of the operator. In order to optimise pesticide application, knowledge of its performance is required. This high volume spraying results in washing the most exposed surface of the Date Palm with considerable wastage of pesticide that drips to the ground. Therefore the quantity of pesticide reaching the canopy of Date Palm with higher volume rates applied at the time, runoff spraying was very common and losses to the ground underneath the crop were very high. Only about 20% of the pesticide was deposited on the crop, particularly when the volume of spray liquid applied > 500l/ha (Matthews, 2006).

The comparison of efficacy assessment methods i.e. by WSP and visual counts of Dubas bugs, showed that they gave fairly similar results. These results confirm previous findings in chapter four. Although they may give similar results, but Dubas bug visual counts are impractical for tall palms, which is just where ground spraying is likely to give poor spray deposits. Nevertheless, ground application on offshoot and performance of power sprayer visual counts method of Dubas bug can be used in line with assessment methods by WSP.

However, the control results are influenced by multiple variables of which application; spray deposition and volume rate are just a part. Date Palms trees require particular consideration due to their height, and specialized equipment needs to be developed. An increased awareness is required amongst growers of the effect of tree density and tree height.

Finally, operator safety is of paramount importance during the spraying process. During conventional field crop applications, the sprayer operator is at risk from direct chemical exposure, particularly during mixing and loading. Ground-based Date Palm spraying is a special case and in addition to these usual risks, there is a large risk that spray liquid directed upwards into the canopy will not be retained by the leaves and will drop off or simply fall back down onto the operator below. Folding of the hose of a high pressure spraying also carries exposure risks if any pesticide is spilled on your skin. It is best to avoid direct contact with pesticides by wearing the proper protective clothing. A more rigorous approach to application techniques is required to comply with the Labourers Protection Standard for Agricultural Pesticides in the Sultanate of Oman.

Chapter 6. **Evaluate the potential efficiency of an air assisted sprayer as an alternative to conventional method for Dubas bug control**

6.1. Introduction

Water based spraying is common in conventional agricultural crop protection. Usually tree-spraying involves applying hundreds of litres per hectare of spray mix (insecticide diluted with water). The insecticide formulation, i.e. the mixture supplied by the manufacture, is often an emulsifiable concentrate (ECs), but there are also other types of formulation such as suspension concentrate (SCs), water dispersible granules (WGs) and wettable powder (WPs). Emulsifiable concentrates are normally diluted with water to form 1 to 5% sprays which are applied at medium or high-volume application rates.

The spray needs to be atomized or broken into small droplets, often by passing through a small orifice under pressure – known as a hydraulic nozzle. Hydraulic nozzles are so designed that when liquid is forced under pressure through the nozzle, a very thin sheet of liquid is formed which breaks up to give droplets of different sizes. Number of terms have been used, namely high, medium, low, very low and ultra low volume. These terms have acquired different meaning for field and tree crops separately (Table 6.1). The trend has been to decrease the total volume of application, and thus reduce the coast of carting diluents and the time required for application (Matthews, 1992b).

Initially high volume spraying technique was used for pesticide application but with the advent of new pesticides the trend is to use least amount of carrier or diluent's liquid. The droplet spectrum from hydraulic nozzles produce a wider range of droplet sizes than other types of nozzles. The British Crop Protection Council (BCPC) has classified these range of droplet size >450µm. In general terms (Matthews, 1992; Woods, 2003) divided drop sizes into five main classes; Ultra low volume size (<5 µm VMD) and very low volume (<50µm VMD) tend to be used for flying insect spraying. Small droplets (<150µm VMD) are used for (ULV) insecticide spraying of foliage, and medium and large droplets (200–400µm), are used for the application of insecticides, fungicides and herbicides to a range of cropping systems. Note that VMD is the diameter at which half the spray volume is in drops of larger diameter, and half the volume is in drops of smaller diameter, which gives a useful measure of spray drop size spectrum.

Table 6.1 Volume application rates (VAR) of liquid formulation (l/ha) for field and tree/ bushes crops.

Designation	Field crops	Trees and bushes
High volume (HV)	> 600	> 1000
Medium volume (MV)	200-600	500-1000
Low volume (LV)	50-200	200-500
Very low volume (VLV)	5-50	50-200
Ultra low volume (ULV)	< 5	< 50

Hydraulic nozzles are common because of their simple construction and low price, and are most often found on tractor booms, on lever-operated knapsack and power sprayers. One important feature of hydraulic nozzles is that they impart a velocity to spray droplets that can assist their transport and deposition.

Cone nozzles are a type of hydraulic nozzle that produces a multi-directional spray, which gives better coverage of a complex target, such as foliage, than a fan nozzle (another type of hydraulic nozzle that produces a sheet of spray which is mostly two-dimensional). Cone nozzles are rarely used for spraying 'flat' surfaces, since their deposit is greatest at the edges and overlapping of deposits cannot be used as a means of achieving a more uniform deposit. Generally, cone-pattern nozzles produce finer particles than most flat fans used in horticulture because they operate at high pressure, encounter shear from air assistance (air assistance is provided by equipment in which drops are released into a jet of moving air, carrying them greater distances). Once released, water-based spray droplet size decreases rapidly through evaporation and/or volatilization. As the release height above the target or crop canopy increases, the potential for spray drift also increases.

Effective and economic use of a product requires the active ingredient to reach the target; if the dose does not reach the target it will not perform the required function. Effective application is influenced by two parameters; appropriate equipment and formulation (Juste et al., 1990). These two parameters are interrelated. Equipment will not perform at an optimum if the characteristics of the product and the application equipment are not suitable. The formulator of commercial pesticides aims to provide the product in the most suitable form for optimal performance of the application equipment. Likewise, application equipment is designed to maximize the effectiveness of a product through accurate and safe delivery within the constraints of practicality and cost. Equipment for application of spray liquid (the formulation diluted with water in most cases), ranges from small hand-held apparatus to large machinery capable of treating large areas in a short time.

Spray volumes vary greatly (Table 6.1). Low volumes are preferred in areas where water is scarce because there is reduced volume and weight to be transported, and sometimes less time needed for application. Higher volumes are aimed at providing complete wetting of a target surface, although this also risks high run off of spray from the target. Reduction of volumes increases the need to optimize spray droplet size to maximize coverage of the target. Coverage is influenced by droplet viscosity, impaction and retention and depends on several factors. Impaction is influenced by complex interaction between droplet size and velocity as well as obstacles in its path (Johnstone et al., 1977; Matthews, 1992b; Reardon, 1991).

Amongst Date Palm producers there is often a debate as to the most appropriate and effective spraying equipment for use in Date Palm and their crops. The inability of smallholder farmers to afford the capital costs of power sprayers (PS) has been documented frequently. Even if they can be afforded, mistblower (MB) air assisted sprayers are evidently doubt of capability of treating the tops of high trees. Also they have substantially lower work rates than aerial spraying or use of powerful vehicle-mounted spraying machinery, and are thus less suitable for large-scale control operations. Ministry of Agriculture (MAF), Oman have been trying to quantify where the “break even” point may occur for use of mistblower sprayers and illustrate the way data have been gathered, using best available current equipment.

In Date Palm, where the aerial application of insecticides is limited to only one generation of the pests, (usually spring generation) and is only suitable for treating large areas, the use of ground based spray equipment may have to be used frequently at other times in the season. With the small agricultural holdings, natural and artificial barriers often prevent vehicle entry to carry out Dubas bug control. Where aerial spraying is not available and power sprayers at high volume application are not appropriate due to limited access, required abundant water, small size of orchards and unacceptable levels of operator exposure, in this case air-assisted knapsack mistblowers may be a viable option particularly in small and medium-height trees. Molto et al. (2002) pointed out that pesticide treatments make up between 30 and 42% of the production costs in orchard tree in Western Europe. One reason for the high cost of these treatments is due to the high percentage loss of pesticide due to drift when treating tall trees, due to the shape and height of their canopies. Juste et al. (1990) reported up to 20.8 % loss of pesticide with hydraulic nozzles at high volume application (5000l/ha), and it should be noted that the current application volumes used by Date Palm farmers are generally greater, which must produce losses that are even higher. This wastage raises an important environmental issue. The problem is similar in other crops, and has lead to various attempts to solve it elsewhere in the world.

The major objective of this study was to investigate the potential efficiency of a motorized mistblower sprayer (MM) application using sprays applied at low volume as an alternative application method to a power sprayer (PS). The PS has an engine driving a pump, and is generally used to apply sprays at high volume application rates as commonly used on Date Palm in Oman. The aim was to determine the efficiency of control achieved by the different equipment when tested applying insecticide against Dubas bug.

Difficulties can arise, particularly with larger droplets, as a given volume produces less large drops, so the insect may not encounter a drop of insecticide. Polles and Vinson (1969) reported that higher mortality of tobacco budworm larvae with 100µm droplets of ULV pesticide than with larger droplets. Larvae were able to detect and avoid more widely spaced droplets (300-700 µm). Conventional mistblowers produce droplets of widely varying sizes. Some droplets may be too small, and hence very liable to drift and evaporation. Other droplets may be too large and will waste a substantial amount of pesticide by sedimentating quickly or running off leaves and falling on to the ground. For any spray application there is an ideal range of droplet sizes which gives the best coverage and penetration of the spray target while minimizing potential risks to the environment and to operators. Research may be needed to determine this most effective spray performance for different crops.

Reduction in the volume of spray has necessitated controlled droplet application (CDA) in which the range of droplet sizes is smaller than those produced by hydraulic nozzles and the VMD is often less than conventional water-based high volume spraying. Control of mobile pests using insecticide sprays can be achieved without complete coverage, but relatively uniform coverage is needed to control pests such as leaf miners which are more static (Matthews, 1979).

Spinning disc and rotary cage atomizers operated with and without air-assistance, produce a narrower spectrum of spray droplets compared with conventional air shear mistblower nozzles. In one retro-fit type of rotary nozzle that can be fitted to mistblowers, air from the mistblower rotates an atomizer and is then carries the spray safely away from the operator. The Micronair AU8000 motorized mistblower uses a rotating cylindrical woven wire mesh gauze atomizer to produce droplets of a more controlled size range compared to a hydraulic nozzle. The droplet size produced depends upon the rotational speed of the atomizer, which is controlled by the fan blade angle and the speed of the air driving it. This allows the atomizer to be set to produce the optimum droplet size range for the application of the product being used, ensuring good coverage at low spray volumes) Figure 6. 1).

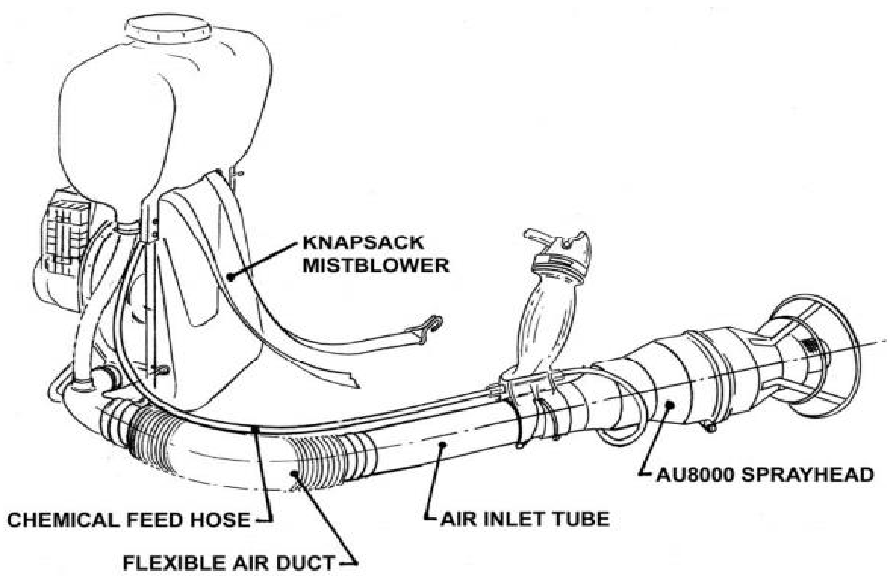


Figure 6. 1 Diagram AU8000 Micronair

One piece of information required was how far up in the canopy would the MM deliver the spray. The MM was compared with the PS at present being used by Ministry of Agriculture in Oman. In that country, farmers are normally using routine spraying, capable of applying insecticides at varying heights of Date Palm trees, to attempt to achieve adequate control of the Dubas bug. As stated previously, mistblowers fitted with rotary atomizers give good control over droplet size, allowing the minimum amount of water and pesticide to be used for spraying, whilst ensuring that the maximum amount is deposited where it is needed. This eliminates the problem of run-off in agricultural spraying, and the powerful air-blast generated by the mistblower reduces the contamination risk to human and his environment, by carrying the spray away from the operator and depositing it on the target. The penetration and delivery achieved means that spray can be deposited in the all areas of the plant canopy that are within the range of heights reachable by the air blast.

6.2. Material and methods

Field trials were carried out during the Dubas bug spring generation of 2012 in the field of Al-Makina village at Rustaq region in Oman. For the purpose of the comparison trials, MM AU8000 and PS sprayers were used for routine spraying. A power sprayer (9hp) at 35 bar was used to apply at a high volume rate (HV). The AU8000 is a mistblower fitted with a rotary cage atomizer in place of the common air-shear nozzle fitted to conventional mist-blowers. It incorporates a 15 liter chemical tank and a 2-stroke engine driving an air blower (Figure 6. 1). A flexible air duct connects the blower to an AU8000 spray head. This contains a rotary atomizer which is driven by adjustable fan blades in the airstream from the blower. The atomizer is fitted with cylindrical metal gauze which produces spray droplets of a fairly controlled size by rotary atomization. The airstream carries the droplets away from the sprayer to reach high foliage and provide penetration and coverage of the target.

6.2.1. Experimental design and treatments

Field trials involved three treatments at height of 3-4 m, 5-6 m and over 8 meters and four replicates using both the MM and PS sprayers to treat trees within a Randomized Block Design. Deltamethrin 2.5% EC was delivered in the low volume MM sprayer, and the high volume power sprayer (PS), with the same amount of active ingredient applied through both sprayers. There was also an unsprayed (control). Two test volume rates were applied with each sprayer: a recommended volume treatment according to MAF recommendation (full dose a.i/ha in the tank mix concentration) and a half volume treatment (half dose a.i/ha in the tank mix concentration), the treatments decided on assumption is that reduce the recommended dosage often be possible. Using a recommended volume treatment to compare sprayer performance may be valid if it is demonstrated that each sprayer was used optimally (Ebert et al., 2003), but that not meaning the recommended dose may not be a discriminating dose and both sprayers may give the same efficacy since there is a safety margin built into the dose. To assess spray distribution and coverage, water sensitive papers (WSP), (76 mm x 26 mm) were placed parallel along a line within the Date Palm trees to determine the highest vertical carry the spray plume could reach. Deposit was recorded at a height of 3-4, 5-6 and over 8 meters from base of the ground.

6.2.2. Calibration

The first step in preparing for an insecticide application is to determine the flow rate of the application equipment; which can be affected by a number of factors such as nozzle aperture size and hydraulic pressure. However, the volume of liquid applied per unit area will depend not only on the flow rate of the sprayer but also on swath width and the speed of sprayer movement.

6.2.2.1. Motorised Knapsack Mistblower

Certain assumptions were made to determine the application rates. It was estimated that the operator would be able to walk during spraying in Date Palm fields at a speed of about 1.5 km/h. The target application rate was 200 litres/ha. Field tests in native Date Palm fields were conducted to determine the actual application rate, and the spray operator practiced walking at a constant speed. Swath width estimates for the sprayer were made using water and the recommended restrictor to achieve the desired flow rate. Because the canopy volume of trees and bushes can vary enormously between crop and their stage of development giving a single rate for volume application and amount of pesticide is inappropriate. For manual and motorized knapsack mistblower spraying to larger trees it is most useful to work on a spray volume (spraying time) per tree basis, therefore an accurate assessment of planting rate made and hence calculate the volume applied to each tree from volume application rate per hectare (Anon, 2007). The sprayer was positioned approximately 4 meters from the tree base and angled at a 45 degree angle (Figure 6.2). During application, wind speed was approximately 1 meter per second. Spray reached a height of approximately 6-7 meters. Regarding droplet size, (Bateman and Alves, 2000) carried out a number of spray measurements and discussed the droplet size distributions for mistblowers, with an optimum thought to be between 40-120 μm depending on the formulation used and spray volume, to achieve sufficient coverage of foliage. For water basis formulation the highest proportion by volume within the sizes 55-126 μm expected to remain in the air stream as it is projected into the tree canopy (Jessop and Bateman, 2007).

From these trials, the time taken to spray one tree from all direction, by given these values, with 1 litres per minute as flow rate and time required to treat individual tree was one minute, the application rate would be 200 litres per hectare (Table 6.2).

Figure 6.2 AU8000 Micronair motorized backpack mistblower sprayer in use during field trials.

6.2.2.2. Power Sprayer

The sprayer consisted of a 200 liters external spray tank, a petrol engine connected to a high-pressure pump, a pressure-regulation valve, and a 50 meter long hose which ends with a spray gun. The pressure was fixed at 35 bars to give a constant flow rate. Hydraulic nozzles on this type of power sprayer produce a wide range of droplet sizes mainly over 300 μm. The volume of liquid needed is dictated by the ultimate target, so that the output (litres/min) spray pattern and droplet size are appropriate. Cone nozzles are preferred for application of insecticides to Date Palm foliage for the reasons cited previously.

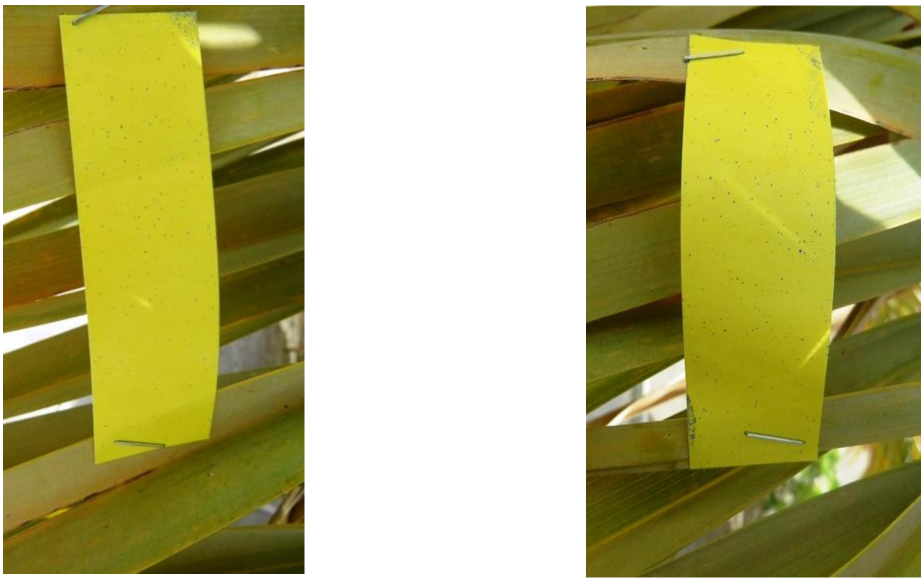
The throughput for the nozzle determined from output of the pump, which in this treatment gave a throughput of 12 litre/ min. The volume output from the PS was determined by collecting the spray liquid in a measuring plastic bucket over a period of one minute. The rate of application per unit area (in this case a tree) was determined by measuring the time taken to spray one tree from all direction, and calculating the flow rate required to deliver the required dose in the measured time. Then by calculating the number of trees per hectare and dividing the pesticide application rate in litres per hectare by the number of trees per hectare, the dose of pesticides per tree is derived. Noting that to deliver the same dose for each tree the tank mix concentration of PS was reduced to one twelfth (1/12) to applied the same dose of the MM (Table 6.2).

Table 6. 2 Typical flow rate, swath width, walking speed and application rate for used sprayer.

Spray type	Flow rate (l/min)	Time required to treat individual tree (min)	VAR (l/ha)	Tank mix concentration (a.i/l)	Dose (l/ha)
MM	1	1	200	0.025	5
PS	12	1	2400	0.025	12

6.2.3. Determination of spray efficacy in controlling the pest

The evaluation for the efficacy in terms of population reduction was based on the reduction of honey dew droplets secreted by Dubas bug, as described by (Mokhtar and Al-Mjeni, 1999) (Section 4.2.1.1). Ten Date Palm trees were selected randomly in the infested area before spraying, and four water sensitive papers (WSP) (76 mm x 26 mm) were kept in polystyrene Petri dish (90 mm diameter) and placed on the ground beneath the Date Palm canopy about 1.5 m from the trunk. WSP were put in four directions (east, west, north and south) around each Date Palm tree for two hours starting from 08.00 in the morning. The papers were then collected and the numbers of honey dew droplets on them were counted. Efficacy of the insecticide (less honeydew exudate indicating fewer surviving insects) was evaluated after 7 days of application on the same Date Palm trees and at the same time as described above. The insecticide efficacies was estimated by calculating the difference in Dubas bug honey dew before and after application as described by Henderson and Tilton, 1955 and these percentages were statically compared. WSP was also placed in the trees canopy to the top and bottom of the trees for quick evaluation of spray coverage and droplet size (Figure 6.3).



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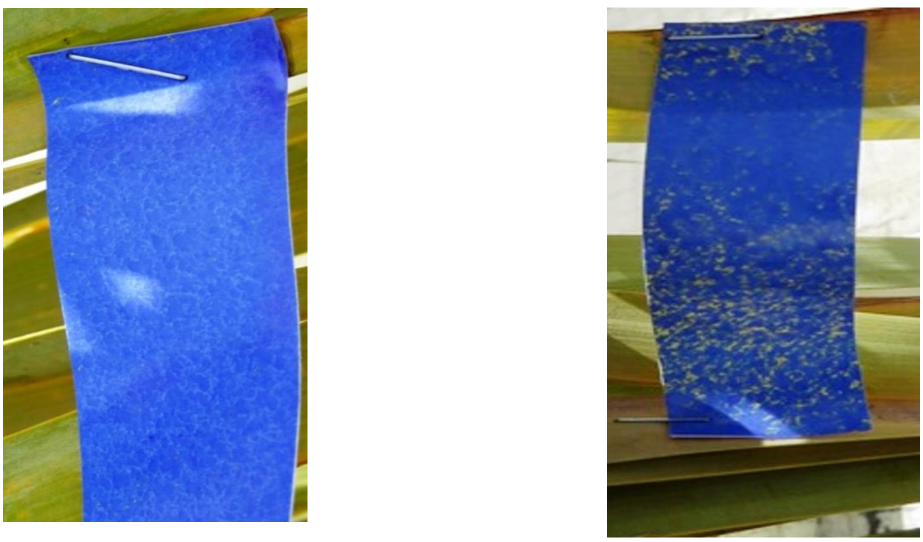

b.

Figure 6.3 Water sensitive papers exposed to aqueous sprays. a, MM 4 meter (left) and 6 meter (right). b, PS 4 meter(left) and 6 meter (right).

6.3. Results

The best results were obtained by the PS used at high volume application (HVA), which gave 96.6% reduction in number of Dubas honey dew droplets after 7 days with the recommended dosage of insecticide at trees between 4 and 6 meters height. This was followed by results using the MM at medium volume application (MVA) which produced 94.8 % when the palm trees height were 4 meters and no significant difference was observed between the sprayers. At half dose (50% of the rate recommended) the reduction in number of Dubas honey dew droplets was 76.8% in PS and 73.8% with MM at 4 meter height. Efficacy was less when 6 meters height trees: with PS there was a 77.6% reduction percentage at recommended dosage and 57.8% at half dosage, and with MM the reduction was 66.8% and 51.6% respectively.

At same volume application rate with both sprayer as described above, the plots with trees that exceeded 6 meter height that were sprayed using MM did not receive adequate application rate and did not show any improvement on the level of Dubas control. The percentages of efficacy after seven days of treatment application were 17% and 9% for full and half dose respectively. Although PS showed slightly better results with droplet numbers reaching 64% and 39% with recommended and half dose respectively (Figure 6.4).

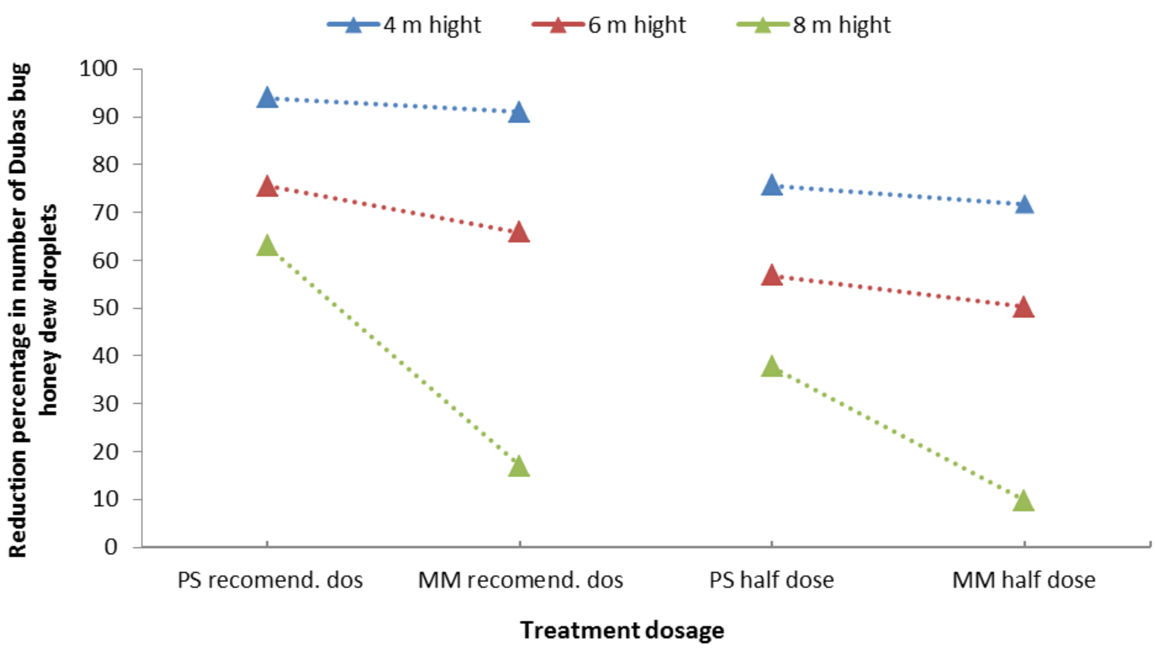

Figure 6.4 Effect of spray treatments of Date Palm at different heights and Dubas bug mortality using two sprayer; PS and MM, and reduction in number of honey dew droplets secreted by Dubas bug.

6.4. Discussion

The vertical projection of sprayers was measured using artificial target (WSP) attached in each Date Palm tree in deferent height to indicates successful application of the sprayer which is compatible with the technique used by (Jessop and Bateman, 2007). Movement of the spray head up-down and side-to-side created varying deposit pattern swath in the stand, with the lowest deposit in the upper crown and on the tree's side opposite from sprayer.

Overall, ground-based insecticide applications to Date Palm trees in Oman were found to be effective from the point of view of managing damage cause by Dubas bug except in trees above 10 m height for high volume and under 6 meter for medium application. In all cases, significant waste of insecticide occurs as the ground around trees would seem to receive a substantial proportion of the volume delivered during conventional application.

In mountain areas and where there are shortages of water, the use of high volume pesticide applications becomes really problematic due to the significant volumes of clean water required. However, quantifying the magnitude in Date Palm plantation of these losses and determining exactly what should be done in relation to improving pesticide application to Date Palm tree for controlling Dubas bug infestation should be considered.

When sprays are applied at high volume, the aim is complete coverage of the crop, although in practice this can rarely be achieved. Reduction in the volume of spray has necessitated application of better quality spray (smaller, more evenly sized drops) and except in a few cases; control has been as good as that obtained with large volumes. This practical finding is illustrated by the results of this experiment because the results of spraying using both sprayers are generally close in the case of spraying the smaller trees, were not statistically significant, although the results differed in the spraying of large trees due to the inability of the MM's air blast to reach the height of more than 6 meters, and therefore coverage was low above that height.

The motorized mistblower sprayer does provide good spray coverage if time is taken to apply the insecticide in a uniform movement, but this additional care reduces application speed. Date Palm's dense of canopy will also inhibit the height of the coverage, as the lower crown will reduce the plume velocity that governs the distance the spray will travel (horizontal and vertical). If the treated area is small, the trees are short and widely spaced, then the MM sprayer can give good spray coverage. The quantity of spray deposited on different types was different in terms of uniformity of droplet distribution, and in this respect the air-assisted system was usually superior. The air-assisted sprayer generally produces more drift than the standard sprayer (Cooke et al., 1990) and this was observed in this trial. Comparison of comparing spray drift from PS with that from an air-assisted sprayer on Date Palm confirms that the air-assisted sprayer generally produced more drift than a power sprayer.

Although wind can assist the movement of the spray within the Date Palm canopy, the tops of trees (those greater than 6 meters) may not receive adequate insecticide deposit or protection. The spray head and air velocity at outlet (approximately 125 m/sec), kept the spray plume in a tight pattern which does not have time to expand within the Date Palm stand before encountering tree foliage.

The height of the Date Palm trees is one of the significant factors, especially for the mistblower equipment which results in limited performance because the effect of the sprayer does not extend beyond around 6 metres. The data for mistblower sprayer shows an effective distance achieved for 4 m and 6 m height respectively, but the proportion of the spray within the desired range is poor in comparison with the PS at 8 m height.

Logistics

With a weight of 18 - 20 kg the spray operator needs to be strong. Walking on uneven ground within Date Palm plantation was difficult and reduced travel speed. For mistblower and an application rate of 0.05 l/min, a single worker would need about 18-20 hours or more to treat one hectare. The sprayer’s fuel consumption is approximately 2 l/hr, which would require 40 l of gasoline/oil (25:1) mixture per hectare. For large Date Palm tracts this would limit the feasibility of using mistblower sprayers. If the Date Palm plantation were dense, then travel speeds and work rate would be expected to be further reduced. Dense plantation would also reduce the effective swath width of the sprayer. Even low wind speeds reduced the height to which the spray could reach. This was to be expected, given the small droplet size and small spray plume produced by the mistblower.

From the above it can be concluded that using the mistblower at medium volume application (MVA) for the treatment of small trees that not exceed 6 meters height in small area is an option. The PS at high volume application (HVA) can be used in the spraying of variable trees height, but it would be necessary to use equipment with higher power or an extended delivery tube to release spray at a greater height in order to reach heights of 10 m and above.

Such equipment could become a good alternative to the PS especially against pests lodging on the external parts of the tree.

The large amount of water used by the PS and the resulting amount falling back down again can easily contaminate casual labour with pesticides unless effective personal protective equipment (PPE) is worn. The use of appropriate personnel protection equipment when operating the sprayer is essential. This may be the major downside of using PS for controlling Dubas bug in Date Palm plantation. Effective PPE would include gloves, long-sleeve shirt, ear protection of a 27-30 decibel rating, head cover and goggles for eye protection from blowing spray and low tree branches (Bateman, 2008; Jessop and Bateman, 2007). Work clothes should cover as much of the body as possible and be comfortable.

Overall, the PS was comfortable to work with and it did prove a repeatable controlled volume of spray that was applied directly to the place it was required, and it is believed that the volume rate may be reduced by a significant amount by changing nozzles and using modified nozzles which could be compatible with the PS. However this would require further work to validate the hypothesis.

The surprisingly good performance of hydraulic sprayer suggests that we do not fully understand even this well-known application equipment, and the poor performance of one sprayer may not be a fair evaluation of its potential if used in a different way (Ebert et al., 2003). The choice of equipment is only part of the issue. Without a full knowledge of the biology of the target and correct timing of treatment, much of the insecticide will inevitable be wasted. There is a pressing need for other ways to reduce the damage caused by pests of Date Palm, including the integration of biological control and perhaps the use of other novel technologies, rather than the reliance on insecticidal sprays.

One useful outcome of the work is that it has demonstrated that water-sensitive papers can be used successfully to estimate the abundance of Dubas and other bugs. Use of WSP as a monitoring tool can provide farmer with early indications of the need to spray especially with height trees wherever cannot detect Dubas infestation easily.

Chapter 7. **Movement of Dubas bug and its relation to survival and development**

7.1. Introduction

Al-Shamsi (2003) reported that Dubas bug only remains in one place for a short period for feeding. Movement of the bug is greatly influenced by field temperature. Information on how temperature can influence this movement is an important element in the understanding of the biological activities and pest status of the Dubas bug. The most active period was recorded in the range between 15-32˚C with less movement observed at temperatures lower than 15˚C and higher than 39˚C (Mokhtar, 2006). It was reported that the optimum temperature needed for development and survival of immature stages of Dubas bug is between 25 to 27˚C in Oman, 26-28˚C in Yemen and 30 ˚C in Iran. Higher mortality was recorded among immature stages when insects were reared at temperatures outside this range (Ba Angood, 2009; Mokhtar and Nabhani, 2010; Payandeh and Dehghan, 2011).

Elwan and Al-Tamimi (1999) studied the biology of Dubas bugs under controlled conditions in Oman. They reported that the duration of a generation ranged from 155.6 to 161.9 days for the spring generation, and 149.4 to 155.1 days for the autumn generation. When the insects were reared at temperatures between 28.3˚C and 29.2˚C and relative humidity between 51.1% to 53.4 %, the females oviposited 99 to 120 and 113 to 128 eggs respectively for spring and autumn generations. In Iraq, Dubas bug females were reported to oviposit from 76 to 137 eggs in spring and 92 to 163 eggs in autumn under field conditions (Al-Shamsi, 2003). Al-Garabi (2006) reported that in Yemen the spring generation ranged from 82 to 88 days when temperatures ranged from 24-26˚C with 62% relative humidity, while the autumn generation ranged from 153 to 156 days when temperatures ranged from 28-30˚C with 72% R.H. The number of eggs laid ranged between 96 to 135.

Tang et al. (1999) considered that geographically separated populations of the same species might differ genetically and biologically, although (Al-Abbasi, 1988b) pointed out that, Dubas bug nymphs have similar growth rate under variable temperatures and fixed temperatures, provided the variable temperature has the same average value as the fixed temperature.

One paradox of Dubas bug control programmes is that in spite of control operations being carried out regularly twice a year, either by aerial or ground application, there have been many instances in which both generations have re-emerged, resulting in severe infestations (Alalawi, 2010; AlJubouri, 2000; Alkhatri, 2005). It has been hypothesized that, the rapid movement of the pest within and between Date Palm plantations may play an important role in maintaining the survival of a considerable number of insects that are subsequently able to lay eggs and produce a new generation of the pests. Continuous movement of Dubas can be observed in and between trees for long periods during the day, and this behaviour gives them the opportunity to hide themselves from exposure to conditions that reduce their well-being. This includes high temperatures, predation by their natural enemies, rain, wind, dust storms and pesticide sprays applied during control operations (Al-Izzi et al., 1989; Ali et al., 2009). Avoidance of factors that could harm them is assisted by the sense organs with waxy filaments. The sensory organs are a bundle of long waxy caudal filaments like structures that can be seen sticking up on (Figure 6.1 c), with number of dorsal grey lines along Dubas body can be use to distinguished the nymphal instars as reported by (AL-Abbasi, 1988a). The author studied the role of the nymph's waxy filaments on the sensory organs, which he pointed out may play important olfactory function in the orientation of insect to its host plants and in detecting and escaping from natural enemies (Figure 7.1.a, b & c).

(a)

(b)

(c)

Figure 7.1 (a) Intensity of offshoots and variation of Date Palm farming in single field; (b) close up photograph showing different stages of Dubas nymphs hiding between leaves bases at mid day, when temperatures are relatively high; (c) close up photo showing distribution of Dubas on leaves on a tree branch during morning and afternoon where temperature moderate, showing waxy filaments on the sensory organs.

Despite the economic importance of this insect, little is known about the effect of Dubas bug movements and their spatial distribution within orchards. Nor is there much published data on population dynamics, egg density and seasonal occurrence (MAF, 2005b). Other aspects regarding the detailed behavior of the pest, such as the daily activity and the influence of temperature and relative humidity on movement have apparently not been fully investigated, although it is known that wind direction and speed, and rainfall can have considerable influence on insect movement (Dysart, 1962; Piienkowski and Medler, 1964; Schowalter, 2006).

While studies on seasonal and daily movements of a range of arthropod pests have been carried out, including the brown speckled leafhopper, *Paraphlepsius irroratus* (Larsen and Whalon, 1987), various thrips species such as *Frankliniella occidentalis* (Pearsall, 2002), the American grapevine leafhopper, *Scaphoideus titanus* (Lessio and Alma, 2004), the leafhopper, *Neoaliturus fenestratus* (Weintraub and Beanland, 2006), the whitefly, *Bemisia tabaci* (Blackmer and Byrne, 1993; Byrne et al., 1996) and various aphid species (Wiktelius, 1981), no such information was found for Dubas bug. Accordingly, the present study was designed to understand the dynamic movement of Dubas bug, as it moves between Date Palm trees at different times, and to investigate the effect of movements on the survival of developmental immature stages to the next generation. Intensity

7.2. Material and methods

Howard et al. (2001) reviewed the techniques used to gain access to various palm species in order to study insects. The techniques included the use of rope loops, tree spikes, tree grips, mounted ladders and truck-mounted hydraulic-lifts. One of the most common methods for canopy access which has been recommended by researchers is use of a ladder, scaffolding or stationery tower (Tucker and Powell, 1991). In the present study, steel scaffolding was used to access the medium to tall trees at heights over 6 m, in order to have a secure position to be able to count the number of Dubas bugs and monitor their movements (Figure 7.2). This access method was also useful in reducing any disturbance to Dubas bugs, which may cause them to flee, making counting difficult and inaccurate (Hussain, 1974).

Figure 7.2 Steel scaffolding was used to access the medium to tall trees at heights above 6 meters

7.2.1. Field's Experiments

Field's trials were conducted in Rustaq Region during October to December 2009 to study the autumn generation of Dubas bugs. The region is 150 Km North West of Muscat, and is an area with a record of heavy infestations over the last 30 years. The study site is located in an isolated area, away from chemical control operations in Date Palm plantations that are owned by families from the village. A one hectare plot was used to sample this study. The trees are usually irrigated by traditional Al-falaj system in which ground water flows by gravity from galleries or surface springs on neighboring mountain slopes (Abdel-Rahman and Omezzine, 1996; MAF, 1995) (Section 2.5.1.2).

7.2.2. Date Palm pest sampling programme

A sample of five palm trees was randomly selected in areas with trees in each of the three height categories: offshoots up to 2 m height, 3-4 m and 5-6 m height, in order to study

Dubas bug movement within and between trees. Additionally, five offshoots about 1.5 m in height, and connected with mother trees whose height was around 6 meters (Figure 7.1 a). For comparison, another five offshoots which were not connected to mother trees were selected. The aim was to determine the behaviour of the Dubas between the tall mother trees and the two types of offshoots – particularly the movement from the offshoot tree to the mother trees and vice versa, yellow sticky traps were used to monitor this movement.

7.2.3. Sampling methods

7.2.3.1. Visual counting

Counting the individuals in a "sample" part of the tree or habitat and then use this sample to estimate the total population instead of counts insect in a large field which can be quite a challenge, labourers intensive and time consuming. Earlier work by (Mokhtar et al., 2001c) on absolute and relative sampling methods, indicated that relative sampling method were the best way to detect short term movement of Dubas bugs into and out of orchard, so this method was used.

The abundance of the Dubas bugs was estimated by taking weekly counts of the bugs from the date of their appearance on the trees until the end of December, when the all population became adult and numbers of insects in the nymphal stage declined.

Visual counting of individual bugs on the leaves was used to assess population density on the palms (Al-Shamsi, 2003; Alkhatri, 2005; Morris, 1960) (Figure 7.1c). In order to study the degree of infestation, distribution and movement, 60 leaflets were observed from three layers of leaves from different sides of each tree (Hussain, 1974; Mokhtar et al., 2001b). Counting was done on one particular day each week (one day per week) every two hours between 08.00 am to 08.00 am next day. The total number of leaflets checked each week was 10,800. Much care was taken in order to avoid any disturbance of the insects on the inspected fronds. The daily temperature and the relative humidity for the study area were recorded using a portable data logger fitted on a tree.

7.2.3.2. Yellow sticky traps

In monitoring the population it is difficult to monitor the population of both adults and nymphs as they take off or walk fast and land on the trunk of the palm tree. Therefore yellow sticky traps were fixed around the tree trunk at 1.5 m above the ground. The traps were made of yellow corrugated plastic, 3mm in thickness and measuring 16 by 20 cm. They were coated with sticky paste base (Polyisobutane). Five Date Palm trees were fitted with traps placed horizontally around mother trees connected with offshoots and another five trees unconnected with offshoots in order to determine Dubas movement mechanism between the trees (offshoot and mother trees). Traps were left for 24 hrs in the field from 08.00 am to 08.00 am next day. The insects caught on the traps were counted every hour. Figure 7.3 shows Dubas bugs caught on a yellow sticky trap.

There were no reports found in the literature about using the yellow traps for evaluating the population level and dispersal patterns of Dubas bug, so the technique had to be developed for this work. However, yellow sticky traps have been used to study other pests some examples are; evaluating whitefly population level (Gennadius) (Gerling and Horowitz, 1984; Wool et al., 1989), allocating the spread of leafhopper in orchard (Cwikla, 1987; Lessio and Alma, 2004; Nestel and Klein, 1995), comparative methods (Kersting et al., 1997) and in assessing diurnal flight activity of thrips species (Aliakbarpour and Rawi, 2010), monitoring cotton insect pests (Atakan and Canhilal, 2004) and others. In addition, (Haynes et al., 1986) used yellow sticky card to monitoring leaf miners in work to study resistance to insecticides.

a.

b.

Figure 7.3 a. Close up photo showing crawling Dubas bug nymph and adults on a tree branch. b. Yellow sticky traps fitted on Date Palm tree about 1.5 m above the ground to monitor Dubas bug movement (crawling and landing) during the day and night.

7.3. Results

7.3.1. Interactions between Dubas movement and tree heights

The results of Dubas appearance on the trees are presented (Figure 7.4). Overall, the peak of the Dubas population was in the middle of November (16.11.2009). These results are slightly different from data previously published on this bug (Mokhtar and Al-Mjeni, 1999). Data in Figure 7.4 indicate that the development time of the nymph population density during the second week of September, October, November and December of 2009. The first nymphs were detected on 18^{th} September and the first new adults were detected on tree leaves on 26^{th} of October.

Tree height was statistically significant for Dubas movement. The population density of three type of trees, that an increasing number of insect were on the middle height trees (3-4 m) compare to offshoots (1-2 m) and tall trees (5-6 m) (Figure 7.5). Date Palm height also had a significant effect on movement of Dubas (Figure 7.6). Interaction terms (Dubas movement and palm heights) were significant for offshoots (F=26.58, P<0.0001), medium trees (F=66.38, P<0.0001) and tall trees (F=29.31, P<0.0001). Insect counts in the 8^{th} week were significantly greater than other weeks for all type of trees, i.e. offshoots (t-value=26.19, P<0.0001), medium trees (t-value =15.71, P<0.0001) and tall trees (t-value=16.82, P< 0.00).

The results revealed that the movement of Dubas bug (mean) in offshoots and medium trees were non-significant in terms of timing (hours) (F=0.69, P=0.63) for offshoots and (F=0.51, P=0.76) for medium trees, but was found significant higher than at tall trees (F= 0.00, P<0.0001). During the day, it was found that the first hour from (8 am-10 am) had the greatest number of insects on all type of trees (offshoot, medium and tall) follow by (06 am-08 am). The lowest number was found during the 5^{th} hours on offshoot compared with other hours (t-value=13.27, P< 0.0001), on medium tree (t-value= 15.71, P<0.0001) and on tall trees (t-value=16.82, P< 0.0001). The overall mean of insects number estimated for the 1^{st} hour showed that the medium-height trees had the greatest number (570.88± 34.44) (t-value=2.04, P<0.05) compared with offshoots (t-1930, P<0.0001) and with tall trees (t-4702, p<0.0001).

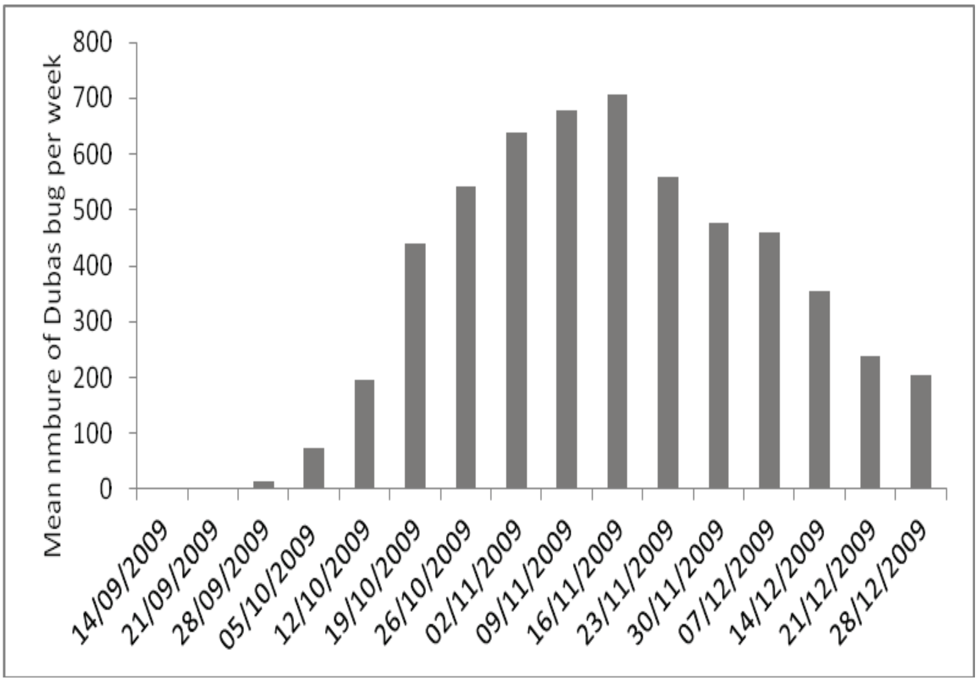

Figure 7.4 Number of Dubas bug, adults and nymphs counted on Date Palm thought visual counting during the trial period. The first nymphs observed at low number in 18th of September.

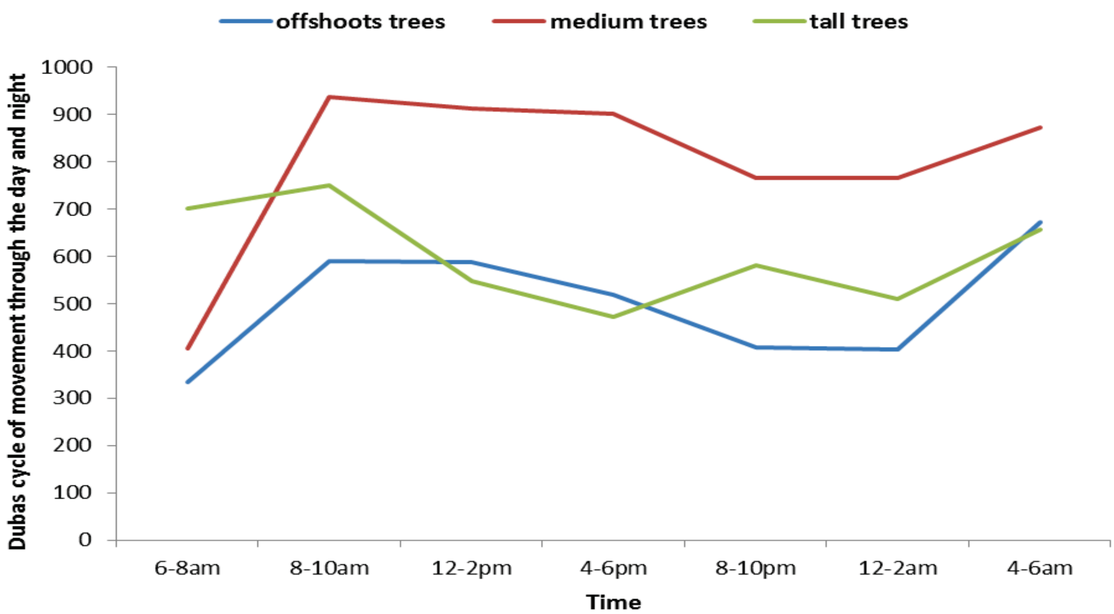

Figure 7.5 Average hourly position of Dubas bugs at different times of the day on trees of different height. Thus more bugs were detected after 10 am up to 12 noon as bugs movement decreased gradually until 4 am before starting to be active again around 6 am.

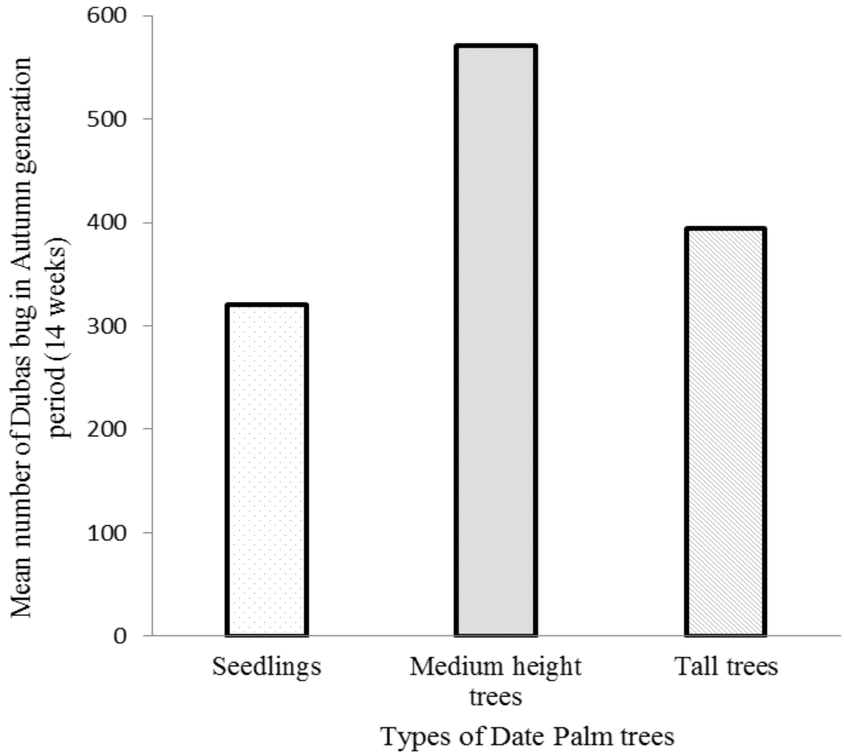

Figure 7.6 Mean numbers of Dubas bug counted on tree leaves in autumn generation in three different heights of Date Palms.

7.3.2. Interaction between Dubas movement and tree type (offshots connected with trees / not conected with trees)

The numbers given in the Figure 7.7 are the total number caught by the yellow sticky traps during study period 21st September to 28th December 2009. The results demonstrated that movement of Dubas is similar, whether or not the trees connected or not connected with offshoots, as for most of the observation period there was no significant difference between the two different trees ($P<0.0001$). Interactions between traps and Date palm type, the offshoot linked with mother tree was not statistically significant for capturing more Dubas bug (Figure 7.7). Therefore, the assumption that surrounding trees with presence of offshoots would lead to more opportunities for Dubas to move up and down between trees, was not correct.

The traps results showed that Dubas bug movement between Date Palm trees commences early in the morning from around 6 am (sometimes even earlier), coinciding with the onset of sunshine and consequent increase in temperature. The period of movement continues up to noon, when the elevated temperatures reduced activity in the period of time (12-2 or 3 pm) with highest ambient temperature (> 32 °C). After this period, when the temperature started to decline gradually, movement of insects started again, and continued after sunset, but movement then declined up until midnight when activity almost completely stopped due to low temperatures (< 15 °C).

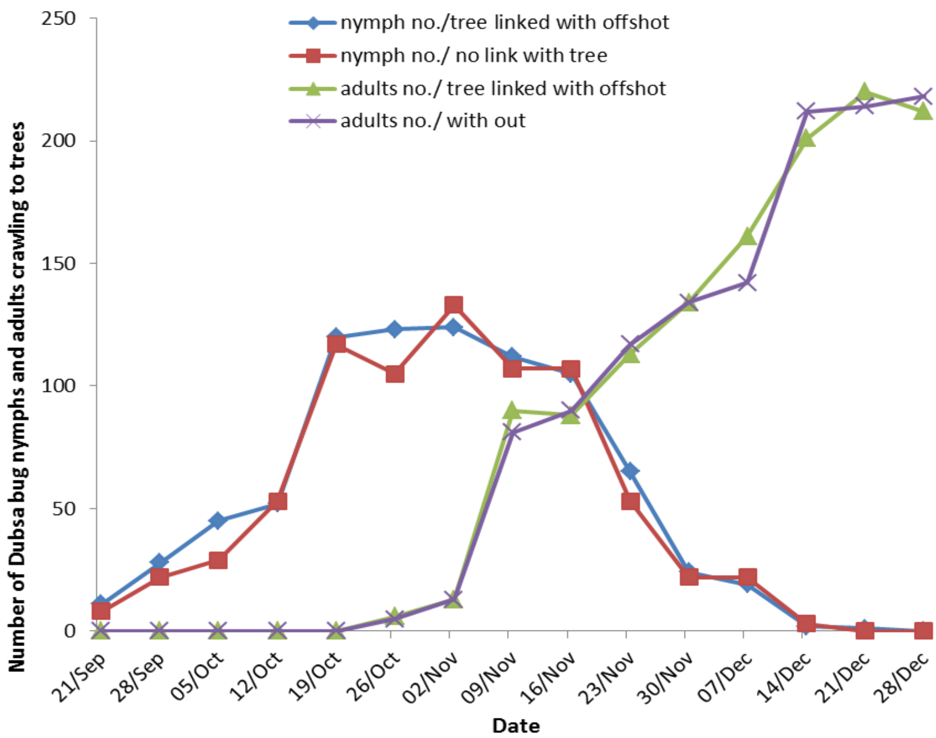

Figure 7.7 Dubas bug nymph/adult catches by yellow trap at Date palm trees linkedwith offshot/not linked with offshots.

7.4. Discussion

The data presented in this study represents the results from a continuous sampling operation to assess the behaviour of the autumn generation. The work was carried out at one field location over a protracted period of time using a visual counting method. The results showed the peak of Dubas population activity was similar to previous studies (Mokhtar and Al-Mjeni, 1999; Thacker et al., 2003), although the pest population peak in the present study was one week later (week 10^{th}) compared to their reports. This difference may be due to differences in temperature and humidity – it is recorded that there have been such changes in the last few years (Bale et al., 2002; Kwarteng et al., 2009; Porter et al., 1991). Dubas eggs hatched also one week later (21^{st} September) than in previous studies. This is consistent with (Al-Izzi et al., 1989) result, egg hatching date differed among regions depending on the environmental conditions.

It was found that the greatest movement from plant to plant and leaf to leaf took place during moderate temperatures average of 23-28˚C and when there was 37- 40% R.H. which was in the period between 06-11am. The lowest activity occurred at midday (12 am-02 pm, temperature > 30˚C and 23-30 % R.H) and at night (08 pm-04 am, temperature < 15 and 33 – 79 R.H.) when insect movements were almost non-existent. These results indicate that 23-28˚C could be the optimum temperature for the biological activities of Dubas bug. This is consistent with the results of a (Mokhtar and Nabhani, 2010; Payandeh and Dehghan, 2011).

The present research reported in this thesis demonstrated the significant effect of differences of temperature on the movement of the pest. To reach this conclusion the temperature parameters were recorded and compared with the activity level and positional preference of the bugs. The higher numbers of both stages (nymph and adults) were found within the shaded, inner bases of the leaves. Therefore, based on activity level observed Dubas bugs preferred to gather in parts of Date Palms trees that are shaded to escape from heat and high temperature during mid day (Al-Izzi et al., 1989; Hussain, 1974). Temperatures above 30°C caused most of the biological activities of the Dubas bug to be disrupted and high temperatures dramatically reduced development, survival and fecundity (Payandeh and Dehghan, 2011).

The data reported in scientific literature is consistent with the results obtained from yellow sticky traps exposed in the field trials, where Dubas crawling, take-off and landing to and from different parts of trees reached a peak during mornings and there was a period of almost complete inactivity in the period from midnight to sunrise. The work has demonstrated that visual counting, supplemented by use of yellow sticky traps, can be used as a reliable technique to sample Dubas bug density on offshoots and middle height of Date Palm and also movement of the bug. Additionally, the combination of sticky traps and pest assessments to estimate population densities of these insect would provide more cost-effective monitoring programs in Dubas bug operation.

The distribution of the Dubas bug in leaf, branches and trunk moved due to diffusion that occurs when a Dubas travels from an area of high concentration to an area of low concentration, then this movement accelerated by the sunshine gradually during the day. Dubas moves very rapidly in tree branch, the high movements recorded at midday when temperature around 28°C and the lower movement at <15°C, this indicate that these temperatures have effect on Dubas movements. Therefore, the Dubas bug activity is greatly influenced by the field temperature and relative humidity in timing control operations and particularly in optimizing spraying efficacy. The insect tried to moved away toward the ground to the bases of young trees and tree leaves in order to find hiding place.

However, this movement allows Dubas to move to safer areas surrounded by tree leaves which provides the bug with a more favourable microclimate and not exposed to spray drift where lower parts receive less active ingredient on aerial spraying compared to the top portion (Ebert et al., 1999), and vies versa on ground application where Dubas move upward to the top portion of the tall trees (Chapter 4 and 5). The results showed that Dubas movement is an important factor causing survival large numbers of Dubas. Also found that timing is another important factor which constitutes a challenge for Dubas control in the Date Palm groves and should taken in consideration in management practice.

In conclusion, the current status of the Palm plantations does not serve the control operations and there is a necessity to improve of agriculture practices of Date Palm for sanitation programme which include; propagation or spacing, pruning and thinning, cutting and burning old leaves, planting of offshoots and irrigation would assist in control operation to be more effective. These required, in addition to other requirements, enhancing the technical capacity of Date Palm workers, improvement of control operation, particularly ground application which is consider as an essential tool in Dubas control programme will contribute to maintaining the pest population at non damage levels and maybe elimination of Dubas from many regions.

Chapter 8. **Screening for insecticide resistance in the field population of Dubas bug**

8.1. Introduction

Resistance is a genetically-based characteristic that allows an organism to survive exposure to a pesticide dose that would normally have killed a susceptible population. Resistance is the microevolutionary process whereby genetic adaption through selection results in populations of insects which present unique and often more difficult management challenges (Whalon et al., 2008). Resistance genes occur naturally in individual pests because of genetic mutation and inheritance. Resistance genes spread throughout pest populations due to a process of selection brought about by repeated exposure to a pesticide. Certain pest control practices have consistently been shown to exacerbate the loss of susceptible pest populations and the development of resistance (FAO, 2012).

Resistance risk, or the potential for development of field resistance to pesticides depend on genetic and biological characteristic of the pest species, operational factors, e.g. continued and frequent use of a single pesticide or closely related pesticides on a pest population; the use of application rates that are below or above those recommended on the label; poor coverage of the area being treated; frequent treatment of organisms with large populations and short generation times; failure to incorporate non-pesticidal control practices when possible; and simultaneous treatment of larval and adult stages with single or related compounds (Keiding, 1986). In addition, failure to adhere to good farming practice such as crop rotation and other culture practices, which helps prevent the spread of weed seeds and fungal spores, can exacerbate the spread of resistance (FAO, 2012).

Resistance to pesticides in pest populations imposes substantial economic costs on agricultural production. In the 1940s, farmers in the U.S. lost seven percent of their crops due to pest damage, while since the 1980s; the percentage lost has increased to 13 percent, even though more pesticides are being used. In California, the pest management cost in cotton reached approximately $45 to $120 per hectare and totalling $348 million per year. Extrapolating these results to other pesticide- intensive crops, nationwide costs of resistance in the United State are estimated at $1.4 per year in 1992 and $1.5 billion in 2005 (Pimentel, 2005; Pimentel et al., 1992).

In the past two decades pest resistance has become a global problem, threatening the effective pest management of vectors of human disease, agricultural and household arthropod pests (Yoon et al., 2008). Resistant pests continue to destroy crops, and the inadvertent removal of natural enemies through pesticide applications exacerbates the problem. Moreover, pesticide resistance in agriculture systems has been recognised as one of the world's most significant environmental problems for nearly two decades (UNEP, 1979). According to Michigan State University database 2012, 574 species of insects have developed resistance to a pesticide, 10,357 cases of resistance of 338 compounds have been reported in168 countries around the world.

Several mechanisms of pesticide resistance have been reported: detoxification of the pesticide; alteration of the target site (part of the organism's metabolism affected by the pesticide) to reduce its sensitivity or the pesticide's ability to bind; reduced pesticide penetration. A single resistance mechanism can confer resistance to two or more pesticides that have similar modes of action – this is called cross-resistance. Multiple resistances can also occur i.e. the ability to cope with pesticides of different modes of action.

Organophosphate (OPs) compounds are the most widely used group of insecticides in the world. OPs have a wide range of pest control applications as contact, systemic and fumigant insecticides. In most countries OPs are widely used because they are cheaper than the newer alternatives. They are typically also fairly unstable and therefore break down relatively quickly in the environment.

The second main group of pesticides are Synthetic pyrethroids (PYr). PYr were introduced at the end of 1970's and their use has increased in agriculture, commercial pest control, and residential consumer use. Pyrethroids are a cost-effective and relatively environmentally benign type of insecticides due to their low toxicity to mammals, and minimal accumulation in the environment, although some have negative impact on aquatic and terrestrial non-target organisms.

In the 1990s, the OPs dominated the global insecticide market, with sales of US$ 2,880 billion out of a total insecticide market of US$7,400 billion. This makes OPs the most widely used group of insecticides, worth nearly 40% of the market. Currently, more than 30 % of the registered pesticides in the world market and about 45 % of those registered with U.S. Environmental Protection Agency (EPA) are OPs (Arthur Grube et al., 2011; Stoytcheva et al., 2011). However, recent EPA data showed organophosphate use as a percent of total insecticide used has decreased from 70 % of all insecticides in 2001 to 36% in 2007 (EPA, 2013). This decrease is attributed to the phase-out of organophosphates in residential areas, beginning in 2000 (EPA, 2009). As well as the increasing use of pyrethroids.

However, since 1983, their effectiveness has been threatened by reports of resistance in major cotton producing areas of the world. The increasing costs of discovering, developing and marketing new insect control technologies underscores the seriousness of this situation. In response, a number of programs involving collaboration between government, academia and industry have been initiated to monitor for the spread of OPs and PYr resistance in insect species and to manage the use of these pesticides (Hoque et al., 2000; Kranthi et al., 2001).

8.1.1. Assessment of the efficacy of insecticides on the Dubas bug

In Oman the Dubas bug, is recognized as the one of the key pests of Date Palm. Since its recording in 1962 various control methods have been used to control this pests, e.g. ground and aerial application technology (Chapter 4 and 5).

MAF (2007) reported that, about 550 tons of insecticides were used in aerial and ground spraying to control Dubas bug during the period 1993-2007. The recommended insecticides for aerial application were dichlorvos 50 EC, malathion 96% ULV, fenitrothion 50% ULV, compound of fenitrothion 49% + esfenvalerate 1% (Sumi Combi Alfa 50% ULV), pirimiphos methyl 50% EC, etofenprox 30% ULV and deltamethrin 12.5 ULV. Dichlorvos 50% EC, fenitrothion EC 50%, deltamethrin 2.5% EC and esfenvalerate 5% EC were used for ground application. All insecticides used belong to either OP or Pyr group except etofenprox which is non-ester pyrethroid (MAF, 2008a; MAF, 2008b) (Table 8.1) also see Appendix 1.

Table 8.1 Insecticides applied for controlling Dubas bug from 2006 to 2011

Year	Compound	Chemical name	Chemical Group
2006	Sumi Combi Alfa	fenitrithion + esfenvalerate	Organophosphate + Pyrethroid
2007	Actellic 50% EC	pirimiphos methyl	organophosphate
2008 & 2009	Trebon 30% ULV	etofenprox	non-ester pyrethroid
2010 & 2011	Decis 12.5 ULV	deltamethrin	Pyrethroid

Chemical control of many pests is unsatisfactory in some cases, and resistance to insecticide has been observed on several occasions in Dubas bug control in Oman (MAF, 2006b; MAF, 2007). These observations of reduced efficacy of some insecticides since 2003 underline the need to carry out bioassays of product efficacy in order to discriminate between the effects of resistance and other factors that might reduce efficacy such as poor application. Despite the economic importance of these insects in many countries in the Arab Peninsula and Middle East, only one report has been found on the reduced susceptibility of Dubas bug to organophosphates on Date Palms - in the Arava region in Palestine (Ausher and Palti, 1990).

The aim of this experiment was to evaluate the efficacy of different commercially available insecticides against Dubas bug nymphs and adults for effective pest management.

8.2. Materials and methods

8.2.1. Insect collection and rearing

A field strain of Dubas bug was collected during the 2011 spring season, from a small village at Samail (Interior Governorate) 70 km southwest of Muscat, to evaluate the efficacy of three type of insecticides that were used for controlling Dubas bug. Another study was conducted in spring 2012 in which a field strain of Dubas bug was collected from two different locations; Samail (Interior Governorate) and Al-Rustaq (Al-Batinah Governorate) north of Oman where spray operations are usually conducted twice a year. A lab strain that has gone through three generation in the lab was used as a control. These strains were reared on Date Palm seedlings planted in plastic pots (20 cm diameter) inside transparent cages (50cm×50 cm×70cm) at room temperature, ranging between 25 and 27°C. The technique is described by (Mokhtar and Nabhani, 2010).

8.2.2. Insecticides tested

Commercial formulations of different insecticides were used as shown in (Table 8. 2), these insecticides are recommended by MAF and widely used for Dubas bug control.

Table 8.2 List for insecticides used for the trial

Trade Name	Chemical Name	Chemical Group
Sumithion 50% EC	Fenitrothion	Organophosphate
Trebon 20% ULV	Etofenprox	Non-ester pyrethroid
Decis 12.5 % ULV	deltamethrin	Pyrethroid

8.2.3. Concentration-mortality bioassays

Bioassays using formulation grades of pesticides were carried out using a completely randomized experimental design with five replicates. The methodology developed by (MAF, 2011) was used. Each replicate comprised a glass Petri dish (9 cm diameter x 2 cm height), with its inner walls treated with insecticide as well as an identical Petri dish with no insecticide treatment – the untreated control. The insecticides were applied as a solvent (acetone) solution (1 ml/dish) using at least seven different concentrations as part per million (ppm) to estimate LC_{50} value. Twenty insects (4^{th} instars nymph stage and adults) were transferred separately to each dish containing dried insecticide residue and every treatment was repeated three times (Fragoso et al., 2003; Ribeiro et al., 2003). The control was treated only with acetone (Zewen et al., 2003). Mortalities were assessed after 24-h of exposure. Those insects unable to walk when prodded with a fine hair brush were considered to be dead.

8.2.4. Data analyses

The LC_{50} (lethal concentration) values were calculated using the procedure PROBIT of SAS (SAS, 2002). In all cases differences between values were considered significant ($P < 0.05$) if the respective 95% confidence limits did not overlap. Relative Potency (R.P.) values were calculated by dividing the highest LC_{50} value of an insecticide by the LC_{50} values of the other insecticides. To determine resistance factors (R F), the LC_{50} value of each insecticide for the field strain was divided by the corresponding LC_{50} value for the lab strain.

8.3. Result

8.3.1. Toxicity to field strain

The LC_{50} values of deltamethrin (Decis), etofenprox (Trebon) and fenitrothion (Sumithion) for Dubas bug nymphs were 0.309, 0.310 and 0.485 ppm, respectively. The Relative Potency values were 1.570 and 1.565 for deltamethrin and etofenprox respectively (Table 8.3). There were no significant differences in LC_{50} and R.P. values between deltamethrin and etofenprox in term of efficacy (Figure 8.2). The LC_{50} value for fenitrothion was significantly higher than those for deltamethrin and etofenprox.

Table 8.3 Response of field strain of Dubas bug nymph to deltamethrin, etofenprox and fenitrothion after 24 hours.

Insecticide	LC_{50} (ppm)	N	Slope ±SE	LC_{50} (95% C.L.) Lower	Upper	R.P.
deltamethrin 12.5% ULV	0.309	20	2.666 ± 0.645	0.187	0.401	1.570
etofenprox 20% SP	0.310	20	2.688 ± 0.557	0.203	0.398	1.565
fenitrothion 50%EC	0.485	20	1.688 ± 0.586	0.326	1.932	1

R.P.= Relative Potency; C.L.= Confidence Limits

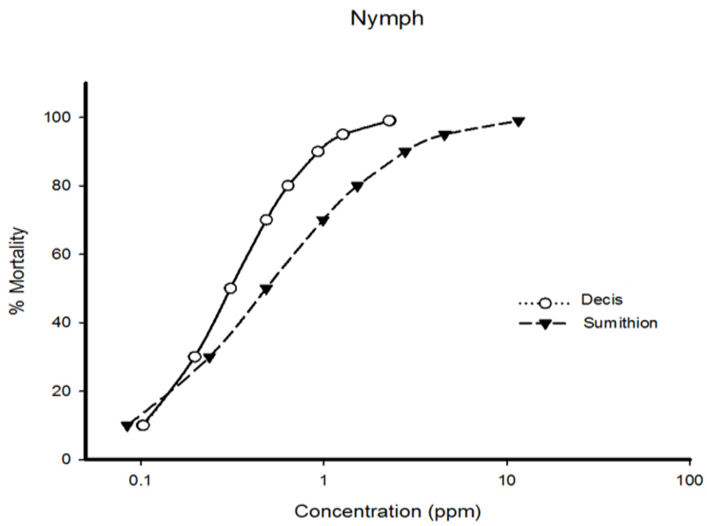

Figure 8.2 Dose-response regression for detamethrin and fenitrothion to Dubas bug nymph.

For adults, the LC_{50} values of detamethrin, etofenprox and fenitrothion to adults were 0.005, 0.057 and 0.091 ppm, respectively. The R.P. values were 18.2 and 1.5 for detamethrin and etofenprox respectively. Significant differences among all tested insecticides in LC_{50} and R.P. values were observed ($P < 0.01$). The LC_{50} value of fenitrothion was significantly higher than those of detamethrin and etofenprox (Table 8.4).

Table 8.4 Response of field strain of Dubas bug adults to detamethrin, etofenprox and fenitrothion assessed after 24hours.

Insecticide	LC_{50} (ppm)	N	Slope ±SE	LC_{50} (95% C.L.) Lower	Upper	R.P.
detamethrin 12.5 ULV	0.005	20	0.095 ± 0.351	0.0005	0.079	18.200
etofenprox 20% EC	0.057	20	2.241 ± 0.642	0.023	0.0093	1.596
fenitrothion 50% EC	0.091	20	1.321 ± 0.362	0.008	0.124	1

R.P. = Relative Potency; C.L. = Confidence Limits;

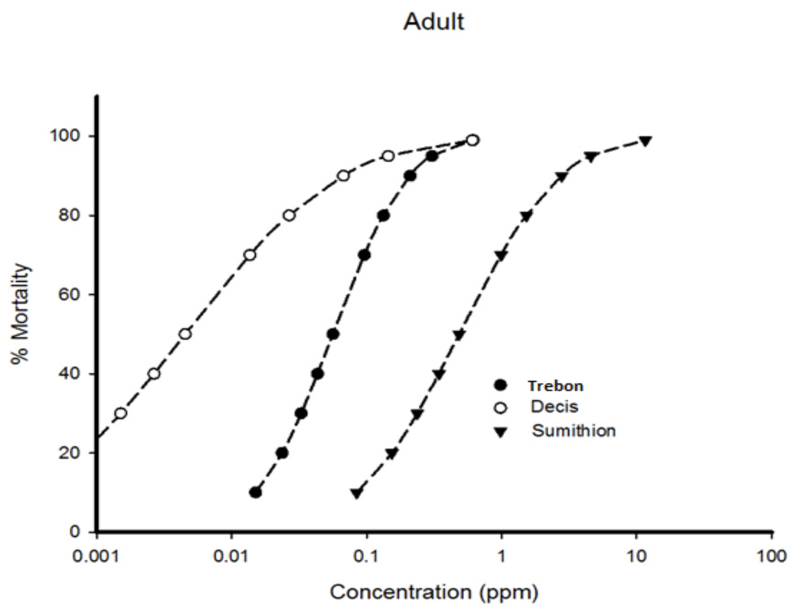

Figure 8.3 Dose-response regressions for evaluated insecticides to Dubas bug adult.

8.3.2. Toxicity of insecticides to Dubas bugs from different field locations and the Laboratory strain.

The resistance ratios (R.R) to field strain at Samail and Al-Ruastaq were 1.3, 0.87 and 3.0, 2.9 and 2.1, 1.2 fold for deltamethrin, etofenprox and fenitrothion respectively compared with laboratory strain (Table 8.5).

Table 8.5 Response of Samail and Al-Rustaq field strains of Dubas bug nymph to detamethrin, etofenprox and fenitrothion after 24 hours.

Insecticide	Strain	LC_{50} (ppm)	N	Slope ±SE	LC_{50} (95% C.L.)*		R.R.**
detamethrin 12.5 ULV	F. Samail	0.309	20	2.666 ± 0.645	0.187	0.401	1.29
	F. Al-Rustaq	0.207	20	3.327 ± 0.658	0.163	0.255	0.86
etofenprox 20% EC	F. Samail	0.844	20	1.594 ± 0.805	0.701	0.987	3.02
	F. Al-Rustaq	0.822	20	1.594 ± 0.843	0.203	0.398	2.94
fenitrothion 50% EC	F. Samail	0.389	20	1.296 ± 1.863	0.250	0.2.059	1.01
	F. Al-Rustaq	0.484	20	0.744 ± 0.586	0.326	1.932	1.26
detamethrin 12.5 ULV	Lab	0.238	20	2.499 ± 1.075	0.136	0.341	
etofenprox 20% EC		0.279	20	2.277 ± 0.968	0.168	0.392	
fenitrothion		0.384	20	1.427	0.224	0.543	

50% EC	± 0.807

*C.L.= Confidence Limits ** R.R. = Resistance Ratio F= Field strain

R.R. values were calculated by dividing the LC_{50} value of Field strain by LC_{50} value of the lab strain for each insecticide.

8.3.3. Slopes of regression lines

The analysis of Dubas bug dose–response regression lines based on LC_{50} and results indicated that Dubas collected from Al-Ruataq were slightly less susceptibility than populations collected from Samail to detamethrin, etofenprox and fenitrothion (Table 8.5). When comparing the efficacy of insecticides to Dubas, only fenitrothion and detamethrin were statistically different. Detamethrin was approximately eighteen times more effective to adult than nymph.

Slopes of regression lines of fenitrothion and etofenprox for the resistance were mostly low (<5). In contrast, slopes of regression lines of detamethrin very low. The field populations all exhibited low slopes (<2) for all insecticides tested. This is a behaviour typical of field populations and indicates a genetic heterogeneity of susceptibility to the pesticide.

8.1. Discussion

Results of the experiments showed the presence of low to moderate resistance in field strains of Dubas bug nymph and adults to fenitrothion and etofenprox respectively. There were no significant differences in LC_{50} and R.P. values between detamethrin and etofenprox. The fenitrothion result indicated that Dubas bug nymph collected from Samail and Al-Rustaq field strain was more susceptible to etofenprox then to fenitrothion.

When comparing the efficacy of insecticides to nymph and adult, only detamethrin was statically different. Efficacy of detamethrin was between 11 and 18-fold as compared with etofenprox and fenitrothion for Dubas adult and was significantly greater ($p < 0.01$). However, the greater efficacy against adult to nymph on the detamethrin is not obvious, but it could be that the detamethrin molecule is more active to adult than the nymph. Based on this result, the difference in efficacy between field and the laboratory strain showed virtually no resistance, as the RR was very low. A moderate tolerance to etofenprox and fenitrothion was observed on Dubas adults. These data are valuable in that they can serve as a comparison point of efficacy of these insecticides.

Development of resistance in Dubas bug to OPs was reported on date palms tree in the Arava region in Palestine (Ausher and Palti, 1990). The intensive used of pesticides to manage Dubas bug with OPs and PYr in last 40 years might lead to resistance. The repeated use of similar insecticides or mode of action for a long time should be avoided, and in the absence of resistance management systems, there is a need for alternative insecticide groups to control the Dubas bug. A rotation of effective insecticides with different modes of action is suggested to avoid the development of resistance even with one or two applications per year rotational schemes of insecticidal treatments have been found to be effective in delaying the onset of resistance in whiteflies and preserving the efficacy of insecticides in many countries (Ahmad et al., 2002).

Roush (1997) stresses the importance of a scouting system that eliminates unnecessary sprays, and targeting sprays only on those areas where sprays are truly needed is also an important feature of any resistance management strategy. Overall, effective, safe, and lasting pest management programs have been targeted primarily toward development of new and better products with which to replace conventional pesticides. Lewis et al. (1997) assert that the key weakness with pest management strategies is not so much the products we use but our central operating philosophy.

8.4.1. Resistance management

The broad spectrum of resistance to OPs and PYr that has evolved in some crops is of serious concern. A comprehensive insecticide resistance management (IRM) strategy is therefore needed to extend the effective life of current and new insecticides for controlling Dubas bug. Insecticides with novel modes of action can be incorporated into the IRM strategy. Improvements in chemical control require spraying methods that improve coverage, especially underneath leaves and under the plant canopy, and the selective use of effective insecticides at economic threshold levels.

However, insecticidal control should be used as a supplement to other integrated pest management (IPM) tactics, especially cultural practices such as thinning, maintaining the distance between trees, irrigation management, and uprooting old trees stumps that may sprout and harbour Dubas bugs.

In conclusion, before significant resistance occurs in Oman, there should be a cycle of using different insecticides. This could be by changing to a different insecticide after a year or alternate for the spring and autumn populations or divide the country into sections to implement a rotation of insecticides with different modes of action e.g. pyrethroid, OPs etc.

Chapter 9. **Summary and General Discussion**

9.1. Summary of experimental findings

9.2. Chapter 4: Determine an effective droplet spectrum for controlling Dubas bug on Date Palm when applying an aerial spray

Droplet diameter plays a major role in determining the efficacy of Dubas bug spraying. Droplets with a diameter 75-150 μm obtain better percentage mortality of insects and the insecticides efficacy can be determined either after 7 or 14 and 21 days. The spray efficacy of insecticides against Dubas bug can be assessed either by WSP assessment of honey dew droplets or a visual count of the insects themselves. Reduction in the number of Dubas bug on offshoot trees can be considered as an indicator of good efficacy on tall trees with aerial spraying. This is based on the assumption that aerial sprays will give better coverage of the upper canopy but sufficient droplets penetrate the canopy to achieve control on the lower offshoot trees. The distribution of spray droplets on OSP should be used as parameter to ensure that adequate control of Dubas bug will be achieved over the whole swath width.

9.3. Chapter 5: Evaluation of ground application efficiency to control Dubas bug and its impact on re-infestation

The quantity of pesticide reaching the Date Palm canopy is influenced by application method, and applications from the ground to Date Palm trees are an effective way of managing damage from Dubas bug on small and medium height trees (<8m) but not effective on tall trees above 10 meter. Incorrect implementation of the process by grower/ laborer negatively affects the level of control achieved. The implementation of ground application by casual laborers and power sprayers was not sufficient to stop re-infestation by the Dubas bugs appear in the next generation. Even with 95 to 99% control the remaining 1 or 5 % breeding up to the original numbers in one generation. Therefore the percentage control required to prevent the next generation being significant is not known. Date Palm canopy in the mountain and valley areas were difficult to spray from the ground, which results in limited deposition on the upper canopy of taller trees. Sprayer operators should be well trained and have good feedback on how the spray was distributed on the target canopy and what dose was achieved. For efficacy assessment a comparison of WSP and visual count methods gave similar results and either can be used for the evaluation of control efficacy. In general specialist ground application equipment needs to be developed to reach tall trees.

9.4. Chapter 6: Evaluating the potential efficiency of an air assisted sprayer as an alternative to conventional methods of Dubas bug control

Ground-based insecticide applications with Power Sprayers at HV to Date Palm trees are effective at managing damage by Dubas bug except in trees above 10 m height, while motorized mistblowers at MV are effective up to 6 m height. There is significant waste of insecticides occurs on the ground around trees during conventional application. That make contamination of casual laborers with pesticides during application which is the major downside of using PS for controlling Dubas bug plus the need for huge amounts of water to dilute insecticides. Therefore, use of appropriate personal protective equipment when operating the sprayer is essential. For the quick evaluation of the Dubas density WSP could be used to provide farmers with early indications of the need to spray especially with tall trees orchards.

9.5. Chapter 7: Movement of Dubas bug and its relation to survival and development

The optimal temperature and relative humidity for Dubas bug biological activities were 23-28 ˚C and 37- 40% R.H. This condition provide the greatest movement of Dubas bug that took place between 06-11 am, the lowest activity occurred at midday (12 am- 02 pm) at temperature > 30˚C and (23-30 %R.H) and at night (08 pm-04 am, temperature < 15 and 33–79% R.H.). Temperature parameters played an important role on the daily movement of Dubas bug. The highest numbers of both stages (nymph and adults) were found within the shaded, inner bases of the leaflet. For monitoring Dubas bug movement yellow sticky traps, a relative sample were found to be an effective tool, also visual counting was found to be a reliable method of sampling Dubas bug density on offshoots and mid-height Date Palm trees.

Further to that WSP can given a pointer on the extent of the infestation in tall trees but does not give a true indication of the existing density of insects. The result indicates that daily movements allow Dubas bugs to hide from natural enemies, unsuitable conditions and to move out to untreated areas. Also timing is another important factor and should taken in consideration in management practice.

9.6. Chapter 8: Screening for insecticides resistance in the field population of Dubas bug

Low to moderate resistant to Sumithion and Etofenprox for field strains of Dubas bug nymph and adult were observed in different locations. Field strains from Interior Governorate (Samail) were more susceptible to insecticides effect than (AL-Rustaq) AlBatinah Governorate strain. Baseline surveys of Dubas bug susceptibility to Organophosphates and Pyrethroids need to be implemented. An effective Insect Resistance Management strategy is needed for controlling Dubas bug. That includes; repeated use of the same pesticides or similar mode of action for a long time should be avoided, a rotation of effective insecticides with different modes of action should be implemented, eliminates unnecessary sprays, and targeting sprays only on those areas where sprays are truly needed.

9.7. General discussion

Over the past forty year Date Palm trees in Oman have suffered from the negative impact of Dubas bug in its various stages on the production of Date Palm, quantitatively and qualitatively (Anon, 2008). In spite of all efforts made by the Ministry of Agriculture (MAF) since the detection of this pest, to manage and control it, those efforts have had relatively little long term success. Therefore, Dubas bug continues to play a major role in damaging Date Palm trees and dates production.

With changes in Oman's economic situation, from a country depending mainly on agricultural production to an oil dependent economy at the beginning of 1970s, interest in the agricultural sector decreased, therefore, Date Palm suffered even more from negative influence of Dubas bug infestation. In addition, changes in the climatic conditions in the last two decades have included an increase in temperatures and a reduction in rainfall. Added to that, the emergence of new insects such as Red Palm weevil, attacking Date Palm, contributing to an increasing negative impact on Date Palm trees and the degradation of date production. That was met with a continued reluctance by most landlords towards their farms as a result of an increase in their income from other resources other than agriculture. This convinced them of the futility of investing in Date Palm cultivation, taking into account the low income compared to what is being invested. Also, relying on expatriate labourers without experience in this dynamic and important sector, and the fragmentation of agricultural land into small pieces of land amongst many owners (MAF, 2009d), led to further neglect and lack of awareness by the farm owners.

Despite the tireless efforts made by MAF and the allocation of particular programs to manage and control Dubas bug, those programmes were mainly focused on chemical control and neglected other aspects (Anon, 2008). On the other hand, the farmers/growers relied on the efforts made by MAF without making the necessary investment of time or energy to provide essential care of their trees. Perhaps one of the main reasons contributing to continued survival of Dubas bug insect throughout those years were Date palm locations and geographical condition especially between the valleys and mountain areas. Furthermore incorrect agricultural practices and Date Palm density per unit area <300 ha (ICARDA, 2004). These conditions have contributed to the survival of this insect and increased damage to an unprecedented level > 15000 ha (MAF, 2009a), thus reducing the yield of Date Palms and lowering the grade of the crop. Therefore, the interest of the agricultural community in Date Palm further decreased.

To overcome these problems the concerned authorities relied mainly on increasing the use of insecticides to manage the pest. Aerial and ground applications of selected insecticides have been used extensively over the last 40 years. Although there has been diversification in application technology and introduction of modern aerial and ground application techniques, this still had a limited impact and produced only temporary declines in the Dubas bug infestation rates. Also, rotation among chemical families with different modes of action as an important practice for management of resistance was not applied - OPs and PYr, were used extensively. As a result, Dubas bug has become less susceptible to these groups. Perhaps, it could be said that, the weakness of research results in this field and not finding alternatives to resolve this problem had another role in the survival of Dubas bug over those years.

These present studies shed light on some fundamental aspects of Dubas bug Management Programmes. Ground and aerial application are still considered to be the main pillars for control operations and are complementary to each other. Successful control of the targeted insect is greatly influenced by the use of the right application equipment and its correct manipulation. Although the efficiency of aerial spraying is well known to control targeted pests in many countries over the world, the temporary efficacy (Dubas return back next season) of this operation in Oman, prompted an important question about the feasibility of continuing using it. A similar argument also applies to the efficiency of ground application.

The results of these studies have shown that aerial spraying was effective in reducing the Dubas bug populations by up to 98%, and optimise spray parameters were respected to ensure maximum dose at target site, taking into account the environment of Date Palms plantation and difficulty of spraying in mountainous terrain. Quality control that includes; calibrating the rate of the flow from the nozzles and characterizing the atomization are important procedures (Barry, 1993). Attention to flow rate becomes even more critical when applying sprays to Date Palme at ULV rates. However, the terrain makes spraying extremely difficult, and so some areas clearly cannot not be sprayed to an acceptable standard (Aston, 2005). Also experiments showed that the volume median diameter (VMD) for aerial spraying was in the range of 75 to 150 µm which is slight dissimilar to the MAF recommendations of the VMD of droplet spectrum between 80-100 µm, but no sign difference and the experiments confirmed the ministry recommendations (Chapter 4).

Ground application with power sprayers mainly gave good efficacy for the range of tree heights up to 10 m. There are concerns regarding the safety to operators and the environment with ground-based application due to spray falling back down or running off the canopy. Although it is possible to reduce Dubas bug populations significantly with this method, it is less effective than aerial application (Thacker et al., 2003) due to different reasons. Motorized backpack mistblower sprayers can also be used to apply pesticides in special situations. The combination of air assistance and production of relatively small droplets, enabled mistblower to achieve good coverage at low volume application rate up to tree heights of 6 m. The height of the Date Palm trees varies from small offshoots (1-2 meter) to over 10 meter, and this is one of the significant factors, especially for the air-assisted sprayer which results in limited deposition on the upper canopy of taller trees (Juste et al., 1990), because the effect of the fan does not extend beyond about 6 m.

However, poor performance of some sprayers suggested the need to design better application equipment with more appropriate spray characteristics. Studies of application on various fruit crops showed that in some cases over 50% of dilution does not reach the target (Salyani et al., 2007). Having said that, insecticide distribution plays a role that may be more important than quantity at least within the range encountered in these trials (Chapter 5 and 7). It has become evident from these studies, that using casual labourers in the implementation of ground application had a negative impact on application efficiency and efficacy, to the extent that it was necessary to re-spray infested locations by skilled sprayer operators, to achieve 97% reduction on Dubas population. In addition, severe infestation at the next generation was recorded in the locations sprayed by casual labourers (Chapter 5). Reducing exposure to pesticides is extremely important to worker safety. Although personal protective equipment is uncomfortable for the labourers, particularly in hot and humid conditions but it's essential practice in pest control operations (Landers, 2004), and use of PPE remain adequate for the products being used. Additional research is needed to establish worker standard protection for agriculture pesticides (Chapter 5 and 7) and training programmes must raise awareness of risks if these standards are not adhered to (FAO, 2001).

The influence of Date Palm density and cultivation per unit area and age variation among the Palm trees level is important; too tall >10 meters, medium level < 6 m, small < 3 m and small offshoots are often scattered around the mother trees, providing Dubas bug with a variety of caches and shelters from natural conditions (heat, humidity-winds and rain) (Ali, 2011; Jasim and Al-Zubaidy, 2010a). Ground application was effective on target surface and optimum performance of ground application obtained when full coverage of target crop is achieved. Dubas bug breeding must be considered, as new hatching is usually not protected by previously applied application. Re-application of effective insecticides may be needed to maintain protection across the season. Obviously, the infested Date Palm trees that are not treated during the season, the Dubas infestation becomes higher than in controlled locations.

Date Palm planted at high density provide Dubas bugs with a higher chance of survival and breeding. Nymphs are very active and will quickly move during the day crawling between Dates Palm leaves and from offshoot to tall trees. Adults also like crawling most of the time and fly lower down on the plants when disturbed. Because of this movement of the insect from offshoot to tall trees and vice versa, they are able to reach un- sprayed parts. Movement of Dubas is likely to vary from field to field and from year to year depending on cultural practices and governing environment factors (Al-Wahaibi et al., 2013). Effective population monitoring is crucial for successful implementation of insect control programmes, for properly timing control application and for assessing their effects (Atakan and Canhilal, 2004). Developing a more comprehensive understanding of movement patterns of Dubas bug is also crucial for their control. Movement and behaviour of Dubas bug affected by weather conditions, especially temperature and humidity. The behaviour of Dubas bug on Palms tree can have pronounced effects on the efficacy of control by spray application, since Dubas bugs can hide in the trees canopy and inside offshoots between the branches and leaves or even move to tall trees. Accordingly, if spray does not cover all branches, leaves and most parts of trees, Dubas bug will have a better chance of survival. Also control operators should monitor movement level at predetermined sites. Such monitoring requires simple techniques that are accurate, repeatable and usable in the field. The yellow sticky traps described in this thesis were shown to be effective for monitoring populations of Dubas bugs and are also used with many other insect species (Atakan and Canhilal, 2004; Haynes et al., 1986) (Chapter 6).

Intensive use of similar insecticide groups or mode of action for a long time for Dubas bug control without real change or rotational policy results in the development of resistance to those insecticides particularly OPs. Therefore, the current insecticide strategy should be amended to include a wider range of products. Any strategy for mitigating resistance must not be instead of, but be in addition to the implementation of alternative pest management strategies including cultural, sanitation, and biological control that can reduce reliance on pesticides (Chapter 8). Poor insecticide coverage resulting from the use of inefficient application equipment, wrong timing, irregularity and wrong technique of spraying are capable of accelerating the rate at which insects develop resistance to pesticides (Asogwa et al., 2009). Hence, along with the screening of new insecticides, new spraying equipment should be evaluated by the relevant authority, before they are recommended for use in the application of Dubas bug insecticides.

Finally, despite the efforts of the Ministry of Agriculture, Oman to control Dubas bug, it is still a serious problem, underlining the need to develop a sustainable strategy based on integrated pest management (IPM).

9.8. Future work

Despite the importance of Dubas bug as a major pest of Date Palm trees in the Arabian Peninsula and many other countries, research in this area is still limited. As mentioned earlier, to solve the serious problems caused by Dubas bug, there is a need to develop a sustainable strategy based on integrated pest management (IPM). Research trials need to develop control solutions that reduce crop losses, increase the quality and market value of Date Palm and reduce the use of pesticides to a minimum. There is a need for numerous studies;

- Quantify the effect of different cultural practices on Dubas bug infestation (e.g. plant spacing, pruning, irrigation etc) should be investigated to estimate their influence on the infestation of Dubas bug and to improve the understanding of the effect of the horticultural and cultural practices on the infestation status of Dubas bug.
- The factors that affect the population dynamics of Dubas bug in Date Palm grove such as; climatic condition, topography, Date Palm age etc.
- Dubas bug immigration, intensity, the factors that affects the migration routes and their influence on Date Palm damage by Dubas bugs.
- Improve insecticide application methods for better efficacy, efficiency and safe use.
- Development of ground application sprayers and methods that are able to reach the highest Date Palm canopy.
- For a range of insecticides, measure the susceptibility of different Dubas bug populations occurring in different provinces.
- Determine the ability to use biological control agents in controlling the infestation of Dubas bug.
- Identification the genetic variance of Dubas bug to investigate the prevalence of Dubas in different regions.
- Establish guidelines on effective and practical personal protective equipment for different date palm insecticide application methods.

Bibliography

Abd-Allah F.F., Al-Zidjali T.S., AL-Khatri S.A. (1998) Biology of *Ommatissus lybicus* Bergevin under field and laboratory conditions during spring 1995. *In: Proceedings of International Conference on Integrated Pest Management, 23–25 February 1998*. Sultan Qaboos University, Muscat 75-79.

Abdel-Rahman H.A., Omezzine A. (1996) Alfaj water resources management: Tradable water rights to improve irrigation productivity in Oman. *Water International* **21**:70-75.

Abdul-Sattar M. (2009) *Implementation of IPM for Control of Dubas bugs Ommatissus lybicus on Date Palm in Seiyun, Hadramout* (progress report 2), Ministry of Agriculture and Irrigation, Groundwater and Soil Conservation Project, Sana'a.

Abdul-Sattar M.H., A-Haq A.S. (2009) Implementation of IPM for Control of Dubas Bugs *Ommatissus labycaus* on date palm in Seiyun, Hadhramout (September- December, 2009), Ministry of Agriculture and Irrigation Yemen, Hadhramout. pp. 1-22.

Abdurrahman W.A., Al-Nabulsi Y.A. (1996) Irrigation water use of date palm, Proc. *3rd Symposium on the Date Palm,* held on Jan. 17-20, 1993, King Faisal University, Research Center, Al-Hassa, S. Arabia, . pp. 273-28.

AFDF. (2009) Integrated Pest Management of Dubas bug (phase three), Agricultural and Fisheries Development Fund, Muscat. pp. 22.

Agoudjil B., Benchabane A., Boudenne A., Ibos L., Fois M. (2010) Renewable materials to reduce building heat loss: Characterization of date palm wood. *Energy and Buildings* **43**:491-497.

Ahmad M. (1996) *Sustainable Water Policies in the Arab Region, 14th International Symposium, Water and Arab Gulf Development:Problems and Policies*, University of Exeter 10-12 September.

Ahmad M., Arif M.I., Ahmad Z., Denholm I. (2002) Cotton whitefly (*Bemisia tabaci)* resistance to organophosphate and pyrethroid insecticides in Pakistan. *Pest Management Science* **58**:203-208.

Ahmed I.A., Ahmed A.W.K., Robinson R.K. (1995) Chemical composition of date varieties as influenced by the stage of ripening. *Food Chemistry* **54**:305-309.

Akyurt M., Rehbini E., Bogis H., Aljinaidi A. (2002a) A survey of mechanization efforts on date palm crown operations. World 2208:2645.

Akyurt M., Rehbini E., Bogis H., Aljinaidi A.A. (2002b) A survey of mechanization efforts on date palm crown operations, *The 6th Saudi Engineering Conference* KFUPM, Dhahran, December 2002. pp. 475-489.

AL-Abbasi S.H. (1988a) Antennal sense organs of *Ommatissus binotatus* De Berg (Tropiduchidae: Homoptera*). Date Palm Journal* **6**:426–431.

Al-Abbasi S.H. (1988b) Biology of *Ommatissus binotatus* De Berg (Tropiduchidae: Homoptera) Under Laboratory Conditions. *Date Palm Journal* **6**:412-425.

Al-Alawi M.K. (2010) *Dubas Bug Insest*, in: P. P. D. M. o. A. g. Oman (Ed.), Ministry of A griculture. Oman, Muscat.

Al-Amoud A.I. (2010) Subsurface drip irrigationfor date palm trees to conserve water, in: A. Zaid and G. A. Alhadrami (Eds.), *IV International Date Palm Conference,* Acta Hort. (ISHS) Abu Dhabi UAE. pp. 103-114.

Al-Azawi A.F. (1986) A survey of insect pests of date palms in Qatar. *Date palm Journal* **4**:247-266.

Al-Farsi M., Alasalvar C., Morris A., Baron M., Shahidi F. (2005a) Comparison of Antioxidant Activity, Anthocyanins, Carotenoids, and Phenolics of Three Native Fresh and Sun-Dried Date (*Phoenix dactylifera L.*) Varieties Grown in Oman. *Journal of Agricultural and Food Chemistry* **53**:7592-7599.

Al-Farsi M., Alasalvar C., Morris A., Baron M., Shahidi F. (2005b) Compositional and Sensory Characteristics of Three Native Sun-Dried Date (*Phoenix dactylifera L.*) Varieties Grown in Oman. *Journal of Agricultural and Food Chemistry* **53**:7586-7591.

Al-Farsi M.A., Lee C.Y. (2008) Nutritional and Functional Properties of Dates: A Review. Critical Reviews in Food Science and Nutrition **48**:877-887.

Al-Garabi. (2006) Biology of Dubas bug *Ommatissus lybicus* and their control in Hadramout costal area in Yemen, Nasser Faculty of Agricultural Sciences, Aden univirsity, Aden.

Al-Izai M.A. (2000) The Technical Obstacles for Implement Dubas bug Control in Oman, Arab Agricultural Development Organization, Al-Khartum. pp. 1-15.

Al-Izzi M.A.J., Al-Maliky S.K., Jabbo N.P. (1989) Seasonal Occurrence and field Biology of Dubas bug *Ommatissus binotassus lybicus*, in Iraq, 3rd *National Conference of pests and disease of vegetables and fruits in Egypt and Arab countries,* Ismailia Egypt 1989. pp. 310-320.

Al-Marshudi A.S. (2002) Oman Traditional Date Palms: Production and Improvement of Date Palms in Oman *Tropicultra* **20**:203-209.

Al-shahib W., Marshall R.J. (2003) The fruit of the date palm: its possible use as the best food for the future? *International Journal of Food Sciences and Nutrition* **54**:247-259.

Al-Shamsi B.H. (2003) Biological Performance of Dubas Bug *Ommatissus lybicus* De Berg.(Homoptera : Tropiduchidae) Under Field Conditions and Predicting of its Appearance by Using Degree-Day Model College of Agriculture, University of Baghdad Baghdad. pp. 91.

Al-Shamsi B.H., Salman A.H., Naher F.H., Hamood J.B. (2003) A description of New Parasitoide on Dubas bug eggs *Ommatissus Lybicus* DeBereg. in Iraq, Integrated Pest Management Centre, Ministry of High Education and Technology, Baghdad. pp. 1-6.

Al-Suhaibani S.A., Babeir A.S., Kilgour J., Flynn J.C. (1988) The design of a date palm service machine. *Journal of Agricultural Engineering Research* **40**:143-157.

Al-Wahaibi A., Al Raeesi Ali, Al Oufi Mohammed, Al Hinai Zakariya , Al Alawi Abdullah , Al Jahwariyeh Leila, Basem A.K. (2013) *The fight to understand Dubas bug*, Horizon, Sultan Qaboos University, Muscat, Sultanate of Oman., Muscat,. pp. 1-8.

Al-watan. (1976) Aerial spray of Dubas bug, Al-watan, Oman, Al-watan news paper and press, Muscat.

Al-Yahyai R. (2007) Improvment of date palm production in the Sultanate of Oman, *Acta Hort*. (ISHS), ABU. pp. 337-343.

Al Deeb M.A. (2012) 8 Date Palm Insect and Mite Pests and Their Management. Dates: Production, Processing, Food, and Medicinal Values 50:113.

Albaker A. (1972) Date Palm Trees, Ministry of Higher Education, Baghdad Iraq in Arabic. pp. 255.

Alfieri A. (1934) Su rune nouvelle maladie du dattier. *Bulletin de la Societe Entomologiqued'* Egypt **18**:445-448.

Ali A.A., A M.A., zier R.M., K A.K. (2009) Influence of climatic conditions in the new deployment of Dubas bug *Ommatissuse Lybicus* Deberg. in the date palm trees in the upper El-phrates river. *Arab Journal of Plant Protection* 27.

Ali A.S.A. (2011) Influence of Climatic Factors on the Recent Spread of Dubas Bug *Ommatissus lybicus* (Debergevin) on Date Palm Trees in Some Upper Euphrates Regions of. *Journal of Agricultural Science and Technology*:544-549.

Aliakbarpour H., Rawi C.S.M. (2010) Diurnal Activity of Four Species of Thrips (Thysanoptera: Thripidae) and Efficiencies of Three Nondestructive Sampling Techniques for Thrips in Mango Inflorescences. *Journal of Economic Entomology* **103**:631-640.

AlJubouri A.J. (2000) Dubas bug *Ommatisuss binotatus lybicus*, in: U. o. Baghdad (Ed.), Ministry of Higher Education Iraq, Bagdad.

Alkhatri S.A. (2005) Effectiveness of some insecticides agent Dubas bug *Ommatisuss lybicus* De Bergevin during Autumn generation 2005, in: C. r. l. o. Entomology (Ed.), Biennial Agricultural Research Report 2005/2006, Ministry of Agriculture, Muscat. pp. 185-191.

Allaith A.A.A. (2008) Antioxidant activity of Bahraini date palm (*Phoenix dactylifera L.*) fruit of various cultivars. *International Journal of Food Science & Technology* **43**:1033-1040.

Alm S.R., Reichard D.L., Hall F.R. (1987) Effects of Spray Drop Size and Distribution of Drops Containing Bifenthrin on *Tetranychus urticae* (Acari: Tetranychidae). *Journal of Economic Entomology* **80**:517-520.

Alzadjali K.M. (2011) Coffee from Omani Date Palm fruits Seed, in: A.-a. M (Ed.), Muscat.

Amer W. (1994) *Taxonomic and documentary study of food plants in Ancient Egypt*, Cairo University, Cairo.

Aminaee M.M., Zare R., Assari M.J. (2010) Isolation and selection of virulent isolates of *Beauveria bassiana* for biological control of *Ommatissus lybicus* in Kerman province. *Archives Of Phytopathology And Plant Protection* **43**:761-768.

Anon. (1978) Agriculture, Research and Development Surveys,Northern Oman, Final Report, University of Durham, Muscat.

Anon. (1981) *A shell Guide to the Aerial Application of Pesticides*, Shell Agriculture Company.

Anon. (2007) *Micronair AU8000 Sprayer*, Micron Sprayers Limited Bromyard.

Anon. (2008) Developing Integrated Pest Management for Dubas Bug *Ommatissud lybicus* DeBerg., in the Sultanate of Oman, in: D. G. o. A. L. Rsearch (Ed.), Ministry of Agriculture, Muscat. pp. 51.

Anonymous. (2005) The spread of Dubas bug insec in date palms in Wadi Hadhramaut, Research Valley Magazine Public Authority for Agricultural Research and Extension Yemen, Hadramawt

Anwar R., Syed S.A., Hussain Z., Ahmad S. (2005) Present scenario and future prospects of date industry, in: M. *e. al* (Ed.), *International Conference on Mango and Dtae palm*: Culture and export, University of Agriculture, Faisalabad

Arthur Grube, David Donaldson, Timothy Kiely a., Wu L. (2011) Pesticides Industry Sales and Usage 2006 and 2007 Market Estimates, Pesticides Industry Sales and Usage, U.S. Environmental Protection Agency Washington, DC pp. 1-30.

Asche M., Wilson M.R. (1989) The palm - feeding plan thooper genus *Ommatissus* (Homoptera: Fulgoridea: Tropiduchidae). *Systematic Entomology* **14**:127-147.

Askari M., Bagheri A. (2005) Study on the Effect of Imidacloprid on Date Palm Hopper by Soil Application and Injection, in: M. *e. al* (Ed.), *International Conference on Mango* *and Date Palm*: Cultural and Export, University of Agriculture Faisalabad. pp. 247-251.

Asogwa E., Ndubuaku T., Anikwe J., Mokwunye I., Okelana F. (2009) Evaluation of different sprayers used for the protection of cocoa farms in Nigeria. *Afr. J. Gen. Agric*. AJGA/2009/026 5.

Aston R. (2005) *Visit Report Dubas Bug Control in Oman*, Ministry of Agriculture and Fisheries, Oman, Muscat.

Atakan E., Canhilal R. (2004) Evaluation of yellow sticky traps at various heights for monitoring cotton insect pests. *J Agric Urban Entomol* **21:**15-24.

Ausher R., Palti J. (1990) Yaacov Golan (1936–1990) in memoriam. *Phytoparasitica* **18**:271-272.

Ayers J.E., Phene C.J., Schoneman R.A., Meso B., Dale F., Penland J. (1995) Impact of bed location on the operation of subsurface drip irrigation systeme, *5th International Microirrigation Congeress AESP*. pp. 168-174.

Ayers R.S., Wescot D.W. (1985) Water Quality for Agriculture, FAo Irrigation and Drainage paper No.29, Rome. pp. 174.

Ba Angood S.A. (2009) Biology and chemical control of the old world bug (Doubas bug) *Ommatissus lybicus* DeBerg on bate palm trees in the coastal areas of Hadramout governorate, Republic of Yemen. *Arab Journal of Plant Protection* **27**:1.

Bale J.S., Masters G.J., Hodkinson I.D., Awmack C., Bezemer T.M., Brown V.K., Butterfield J., Buse A., Coulson J.C., Farrar J., Good J.E.G., Harrington R., Hartley S., Jones T.H., Lindroth R.L., Press M.C., Symrnioudis I., Watt A.D., Whittaker J.B. (2002) Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology* **8**:1-16.

Baliga M.S., Baliga B.R.V., Kandathil S.M., Bhat H.P., Vayalil P.K. (2011) A review of the chemistry and pharmacology of the date fruits (*Phoenix dactylifera* L.). *Food Research International* **44**:1812-1822.

Bankhar A.A., Akyurt M. (1995) *A Tree-Climbing Buggy for Date Palms*, The Fourth Saudi

Engineering Conference, College of Engineering King Abdulaziz University Jeddah. pp. 171-177.

Barry J.W. (1984) Deposition of Chemical and Biological Agents in Conifers, In Garner W.T. and Harvey J. (eds.) *Chemical and Biological Controls in Forestry*, American Chemical Society. ACS Series 238 pp. 117-137.

Barry J.W. (1993) Aerial Application to Forest, in: G. A. Matthews, and E. C. Hislop. (Ed.), *Application technology for crop protection*., CAB International, Wallingford, UK. pp. 241 - 273.

Barth H.K. (1995) Resource conservation and preservation through a new subsurface irrigation system, 5th International Microirrigation Congress, ASAE. pp. 168-174.

Bateman R. (1993) Simple, standardized methods for recording droplet measurements and estimation of deposits from controlled droplet applications. *Crop Protection* **12**:201-206.

Bateman R. (2004) The use of narrow-angle cone nozzles to spray cocoa pods and other slender biological targets. *Crop Protection 23*:989-999.

Bateman R. (2008) Pesticide Use in Cocoa, A guide for training, administrative and research staff. *International Coffee and Cocoa Organization* (ICCO).

Bateman R., Alves R. (2000) Delivery systems for mycoinsecticides using oil-based formulations. *Aspects of applied biology* **57**:163-170.

Beg M., H. A. L.M., M. A. S.A. (1994) *Biological control of some important insect pests*, Agricultural Research Annual Report, Ministry of Agriculture and Fisheries ، Sultanate of Oman, Musact pp. 325 - 341

Bergevin E.d. (1930) Note sur trois especes d' Hemipteres recuellis in Egypt et description d' une nouvelle espece d' Urentius (Hemiptere: Tingitidae) et d' une nouvelle variete d'*Ommatissus binotatus* Fieb. (Homoptera: Cixiidae). Entomologique d' Eygypt. *Le cair Bulletine dela Socciete* **1**:17-20.

Bitaw A.A., Ben-Saad A.A. (1990) Survey of date palm trees insect pests in Libya. *Arab Journal of Plant Protection* **8**, 72-76.

Blackmer J.L., Byrne D.N. (1993) Flight behaviour of *Bemisia tabaci* in a vertical flight chamber: effect of time of day, sex, age and host quality. *Physiological Entomology* **18**:223-232.

Brooks G.D. (1970) Preliminary studies on the use of ultra-low-volume applications of malathion for control of Aedes simpsoni. *Bulletin of the World Health Organization* **42**:37.

Busby D.G., Pearce P.A., Garrity N.R., Reynolds L.M. (1983) Effect on an Organophosphorus Insecticide on Brain Cholinesterase Activity in White-Throated Sparrows Exposed to Aerial Forest Spraying. *Journal of Applied Ecology* ***20***:255-263.

Buxton P.A. (1920) Insect Pests of Dates and the Date palm in Mesopotamia and elsewhere. *Bulletin of Entomological Research* **11**:287-304.

Byrne D.N., Rathman R.J., Orum T.V., Palumbo J.C. (1996) Localized migration and dispersal by the sweet potato whitefly;*Bemisia tabaci*. *Oecologia* **105**:320-328.

Cameron G.S. (1921) *Afulgorid bug of sub-family Cixiini*, Report to Dept. Agr. Baghdad.Cited by Hussain A. Ali 1963, Baghdad.

Carpenter J.B., Elmer H.S. (1978) *Pests and diseases of the date palm*. Agriculture Handbook, United States Department of Agriculture, (527).

Chao C.T., Krueger R.R. (2007) The Date Palm (*Phoenix dactylifera* L.): Overview of Biology, Uses, and Cultivation. *HortScience* **42**:1077-1082.

Cook B.K., Hislop E.C. (1993) Spray Tracing Techniques, in: G. A. Matthews and E. C. Hislop (Eds.), *Application Technology for Crop Protection* CABI International. pp. 359

Cooke B., Hislop E., Herrington P., Western N., Humpherson-Jones F. (1990) Air-assisted spraying of arable crops, in relation to deposition, drift and pesticide performance. *Crop Protection* **9**:303-311.

Cookson P. (1999) Spatial Variation of Soil Urease Activity Around Irrigated Date Palms. *Arid Soil Research and Rehabilitation* **13**:155-169.

Cwikla P.S. (1987) Annotated list of leafhoppers (Homoptera: Cicadellidae) from two Ohio fens with a description of a new Chlorotettix. *The Ohio journal of science* **87**:134.

Daily G.C. et al., (2000) The value of nature and the nature of value. *Science*: 289, 395-396

Dobson H.M. (2001) *Desert Locust Guidelines* (*Control*), Food and Agriculture Organization of the United Nations Rome pp. 47.

Doorenbos J., Pruitt W.O. (1997) *Guidelines for Predicting Crop Water Requirements*, FAO Irrigation and Drainage paper No. 24 Rome. pp. 144.

Dowson V.H.W. (1936) A serious pest of date palms, *Ommatissus binotatus* Fieb. Homoptera: Tropiduchidae, in: Cited by Hussain. A. Ali (Ed.), *Tropical Agriculture* pp. 180-181.

Dowson V.H.W. (1982) *Date production and protection : with special reference to North Africa and the Near East* Rome (Italy). FA0. 1982.

Dysart R.J. (1962) *Local movement of the Potato Leafhopper in Alfalfa*. Central branch Entomologica society of America.

Ebert T.A., Derksen R.C., Downer R.A., Krause C.R. (2003) Comparing greenhouse sprayers: The dose-transfer process. *Pest Management Science* **60**:507-513.

Ebert T.A., Taylor R.A.J., Downer R.A., Hall F.R. (1999) Deposit structure and efficacy of pesticide application. 1: Interactions between deposit size, toxicant concentration and deposit number. *Pesticide Science* **55**:783-792.

El-Haidari H.S. (1980) *Insects Date Palm in the Near East and North Africa Regional Project for Research on Date Palm in the Near East and North Africa*, Food and Agriculture Organization, Baghdad, Iraq.

El-Haidari H.S. (1981) *Ommatissus binotatus* De Bergevin Homoptera: Tropiduchidae. *Date Palm Journal*:133.

El-Haidari H.S., Al-Tijani M.A. (1977) Report on a visit to Sulatatne of Oman,Control of Dubas bug and Citrus black fly, Arabic Organization of Agricultural Development, Khartoum.

El-Juhany L.I. (2010) Degradation of date palm trees and date production in Arab countries: causes and potential rehabilitation. *Australian Journal of Basic and Applied Sciences* **4**:3998-4010.

Elwan A A., AL-Tamimi S.S. (1999) Life cycle of Dubas bug *Ommatissus binotatus* lybicus De Berg (Homoptera:Tropiduchidae) in Sultanate of Oman. *Egypt. J.Agri. Res.* **77**:1547-1553.

EPA. (2009) A Review of the Relationship between Pyrethrins, Pyrethroid Exposure and Asthma and Allergies, US Environmental Protection Agency. pp. 28.

EPA. (2013) 2006-2007 Pesticide Market Estimates, EPA pp. 3.

FAO. (1982) Plant protection and prodection paperNo.35 Date protection and prodection, FAO, Rome. pp. 294.

FAO. (1998) Field tests on an integrated Differential GPS navigation and spray monitoring system for aerial Desert Locust control operations, Desert Locust Technical Series, Food and Agriculture Organization of the United Nations. pp. 35.

FAO. (2001) G*uidelines on good practice for ground application of pesticides*, in: FAO, Agriculture and Consumer Protection, Rome. pp. 7.

FAO. (2002) Workshop on Spray Equipment Used in Desert Locust, Cairo, Egypt. pp. 40.

FAO. (2012) *Guidelines on Prevention and Management of Pesticide Resistance*, FAO, Rome.

Fragoso D., Guedes R., Rezende S. (2003) Glutathione-S-transferase detoxification as a potential pyrethroid resistance mechanism in the maize weevil, *Sitophilus zeamais*. *Entomol. Exp. Appl* **109**: 21-29.

Friedrich T. (1998) Pesticide problems. (pesticide application)." Resource: Engineering & Technology for a Sustainable World. *American Society of Agricultural Engineers.*

Fritz B.K., López J.D., Latheef J.M.A., Martin D.E., Hoffmann W.C., Lan Y. (2008) Deposition of Insecticides on Corn Silks Applied at High and Low Spray Rates for Control of Corn Earworm. *American Society of Agriculture and Biology Engineers*

1360:1-6.

Gad A.S., Kholif A.M., Sayed A.F. (2010) Evaluation of the nutritional value of functional yoghurt resulting from a combination of date palm syrup and skim milk, *Acta Hort*. pp. 583-592.

Gardisser D.R., Kulhman D. (1993) Agricultural aircraft calibration and setup for spraying. MP.

Gassouma, M. S.; Proceedings of the regional workshop on date palm development in the GCC countries of the Arabian Peninsula, Abu Dhabi, 29-31 May 2004, 2004, pp unpaginated

Gerling D., Horowitz A.R. (1984) Yellow traps for evaluating the population levels and dispersal patterns of *Bemisia tabaci* (Gennadius)(Homoptera: Aleyrodidae). *Annals of the Entomological Society of America* 77:753.

Glare T.R., Walsh P.J., Kay M., Barlow N.D. (2003) *Strategies for the eradication or control of gypsy moth in New Zealand.* Report for the Forest Health Research Collaborative of New Zealand. :178pp.

Gordon M., Richter E.D. (1991) Hazards Associated with Aerial Spraying of Organophosphate Insectcides in Israel. *Reviews on Enviromental Health* **9**:229-238.

Habib H.M., Ibrahim W.H. (2011) Nutritional quality of 18 date fruit varieties. *International Journal of Food Sciences and Nutrition* **62**:544-551.

Hadrami I.E., Hadrami A.E. (2009) Breeding Date Palm, in: S. M. Jain and P. M. Priyadarshan (Eds.), *Breeding Plantation Tree Crops: Tropical Species,* Springer New York. pp. 191-216.

Hall F.R., Thacker a.J.R.M. (1994) Effects of droplet size on the topical toxicity of two pyrethroids to the cabbage looper *Trichoplusia ni* (Hubner). *Crop Protection* **13**:225-229.

Hall F.R. (1994) Application to plantation Crops, in: G. A Matthews and E. Hislop (Eds.), *Application Technology for Crop Protection*, CABI International, Wallingford. pp. 187-213.

Hamad B.S. (2005) Biology of *Chrysoperla mutata* MacLachlan (Neuroptera:Chrysopidae) The natural enemy of *Ommatissus lybicus* DeBerg (Homoptera:Tropiduchidae), Faculty of Science University of Baghdad, Baghdad. pp. 86.

Hasson H.A. (1988) Biological and environmental study of Dubas bug *Ommatissus lybicus* De Berg (Homoptera : Tropiduchidae) in lab, College of Agriculture, University of Al Basra, Al Basra Iraq.

Haynes K., Parrella M., Trumble J., Miller T. (1986) Monitoring insecticide resistance with yellow sticky cards. *California Agriculture* **40**:11-12.

Henderson C.F., Tilton E.W. (1955) Tests with acaricides against the brown wheat mite. *Journal of Economic Entomology* **48**:157-161.

Hill D. (1975) *Agricultural Insect Pest of the Tropics & their Control* Cambridge Universty Press, London.

Hołownicki R., Doruchowski G., Świechowski W., Jaeken P. (2002) Methods of evaluation of spray deposit and coverage on artificial targets. *Electronic Journal of Polish Agriculture* Universities 5.

Hoque Z., Farquharson B., Dillon M., Kauter G. (2000) An economic assessment of Insecticide Resistance Management strategies in the Australian Cotton Industry, 2000 Conference (44th), January 23-25, 2000, Sydney, Australia, *Australian Agricultural and Resource Economics Society.*

Howard F. (2001) Insect pests of palms and their control. *Pesticide Outlook* **12**:240-243.

Howard F.W., D. Moore R.M., Giblin-Davis, Abad R.G. (2001) *Insects on palms* CABI Bioscience.

Hubaishan M.A., Ba-Saheeh J.S., El-Zubairy A.M. (2005) Date Palm "Dubas" in Yemen, Arab and Near East Plat Protection Newsletter, Arab Society for Plant Protection and the Near East Regional Office of the FAO, Beirut, Lebanon. pp. 31.

Hussain A.A. (1963) Biology and control of the Dubas bug *Ommatissus binotatus* lybicus De Berg. (Homoptera : Tropiduchidae) infesting date palms in Iraq. *Bull. Entomol Res* **53**:737-745.

Hussain A.A. (1974) *Dates Palms and Dates with their Pests in Iraq*, The Press of local administration, Baghdad. pp. Pages.

Hussain A.A. (1985) *Date and date palm trees pests* Faculty of Agriculture University of Al Basra, Al Basra- Iraq.

ICARDA. (2004) Development of Sustainable Date Palm Production System in the GCC countries of Arabian Peninsula (project proposal), International Center for Agricultural Research in the Dry Areas., Aleppo, Syria.

ICARDA. (2009) *Integrated Control for Dubas Bug of Date Palm in Iraq*, ICARDA, Amman pp. 4.

Ismail B., Haffar I., Baalbaki R., Mechref Y., Henry J. (2006a) Physico-chemical characteristics and total quality of five date varieties grown in the United Arab Emirates. I*nternational Journal of Food Science & Technology* **41**:919-926.

Ismail B., Henry J., Haffar I., Baalbaki R. (2006b) Date consumption and dietary significance in the United Arab Emirates. *Journal of the Science of Food and Agriculture* **86**:1196-1201.

Jahromi M.K., Jafari A., Rafiee S., Mohasebi s.S. (2007) A Survey on some physical properties of the Date Palm tree. *Jornal of Agricultural Technology* **3**:317-233.

Jaradat A.A., Zaid A. (2004) Quality traits of date palm fruits in a center of origin and center of diversity. *Journal of food, agriculture and environment* **2**:208-217.

Jasim H., Al-Zubaidy H. (2010a) Eggs Distribution of Old World Bug (Dubas Bug) *Ommatissus lybicus* (Derbeg) Asche and Wilson (Homoptera: Tropiduchidae) on Fronds Rows and Effect of Dust Storms on Three Varieties of Date Palm Trees, I*V International Date Palm Conference* 882. pp. 465-470.

Jasim H.K., Al-Zubaidy H.K. (2010b) Eggs Distribution of Old World Bug (Dubas bug) *Ommatissus lybicus* (Debreg) Asche and Wilson (Homoptera: Tropiduchidae) on fronds rows and effect of dust storms on three varieties of date palm trees in: G. A. A. A. Zaid (Ed.), *IV International Date Palm Conference, Acta Hort*. (ISHS) 882, Abu-Dhabi, United Arab Emirates pp. 465-470.

Jessop N., Bateman R. (2007) Optimising the use of motorised knapsack mistblowers for control of insect pests of cocoa. *International Pest Control* **49**:86.

Johnstone D., Rendell C., Sutherland J. (1977) The short-term fate of droplets of coarse aerosol size in ultra-low-volume insecticide application on to a tropical field crop. *Journal of Aerosol Science* **8**:395-407.

Juste F., Sanchez S., Ibañez R., Val L., Garcia C. (1990) Measurement of spray deposition and efficiency of pesticide application in citrus orchards. *Journal of Agricultural Engineering Research* **46**:187-196.

Keiding J. (1986) Prediction or resistance risk assessment. In: *Pesticide Resistance: Strategies and Tactics for Management* National Academy Press, Washington DC. 279

Kersting U., Başpinar H., Uygun N., Satar S. (1997) Comparison of two sampling methods for leafhoppers (Homoptera, Cicadellidae) associated with sesame in the east Mediterranean region of Turkey. *Anzeiger für Schädlingskunde* **70**:131-135.

Khan M.M., Prathapar S. (2011) 4 *Water Management in Date Palm Groves.*

Kilpatrick J.W., Tonn R.J., Jatanasen S. (1970) Evaluation of ultra-low-volume insecticide dispensing systems for use in single-engined aircraft and their effectiveness against *Aedes aegypti* populations in South-East Asia. *Bulletin of the World Health Organization* **42**:1.

Kinawi M.M. (2005) *Date palm and date pests in Sultanate of Oman*. Royal Court Affairs. Sultanate of Oman Royal Court Affairs, Muscat.

Klein M., Venezian A. (1985) The dubas date tropiduchid, *Ommatissus binotatus lybicus* a threat to date palms in Israel. *Phytoparasitica* **13:**95-101.

Koh L.P. (2008) Birds defend oil palms from herbivorous insects. *Ecological applications* **18**:821.

Kranthi K.R., Jadhav D., Wanjari R., Kranthi S., Russell D. (2001) Pyrethroid resistance and mechanisms of resistance in field strains of *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Journal of Economic Entomology* **94**:253-263.

Kranz J., Schmutterer H., Koch W. (1978) Diseases, pests, and weeds in tropical crops. *Soil Science* **125**:272.

Kwarteng A.Y., Dorvlo A.S., Vijaya Kumar G.T. (2009) Analysis of a 27-year rainfall data (1977–2003) in the Sultanate of Oman. I*nternational Journal of Climatology* **29**:605-617.

Lal O.P., Naji A.H. (1979) Observation on some new insect pests and parasites from the Socialist Peoples libyan Arab Jamahiriya. *Rivista di Agricoltura Subtropicale eTropicale* **73**: 219-232.

Lambiote B.i. (1982) *Some aspects of the role of dates in human nutrition*, The First International Symposium on Date Palm King Faisal University, Saudi Arabia, 23-25 March (1982).

Landers A. (2004) Protecting the operator-are we making an impact? *Aspects of Applied Biology* **71**:357-364.

Larsen K.J., Whalon M.E. (1987) Grepuscular Movement of *Paraphlepsius irroratus* (Say) (Homoptera; Cicadellidae) Between the Groundcover and Cherry Trees. *Entomological Society of America* **16**:1103-1106.

Lavers A. (1993b) Aerial Application to Ground Crops, in: G. A. Matthews and E. C. Hislop. (Eds.), *Application technology for crop protection*, CAB International, Wallingford. pp. 215-239.

Lepsme P. (1947) *Les insects des palmiers*. Paul Iechenalir. Editeur paris, Cited byHussain. A. Ali, 1963:903.

Lessio F., Alma a.A. (2004) Seasonal and Daily Movement of *Scaphoideus titanus* Ball (Homoptera: Cicadellidae). *Environmental Entomology* **33**:1689-1694.

Lever R.J.A.W. (1969) *Pests of the Cocount Palm*. First edition ed. FAO Plant Protectio and Prodection series, Rome.

Lewis W.J., van Lenteren J.C., Phatak S.C., Tumlinson J.H. (1997) A total system approach to sustainable pest management. *Proceedings of the National Academy of Sciences* **94**:12243-12248.

Linnavuori R. (1973) Hemiptera of the Sudan, with remarks on some species of the adjacent countries. *Notulae Entomologica* **53**:65-137.

Livingston S. (2002) Chemical Control of Leaf Spot of Date Palm (Phoenix dactylifera) in Sultanate of Oman. *Plant Pathology Journal* **18**:165.

Lofgren C.S. (1972) Ultralow Volume (ULV) application of insecticides. *The American journal of tropical medicine and hygiene* **21**:819.

Maccollom G.B., Currier W.W., Baumann G.L. (1986) Drift Comparisons Between Aerial and Ground Orchard Application. *Journal of Economic Entomology* **79**:459-464.

MAF. (1981) Dubas bug insect, in: M. o. Agriculture (Ed.), Ministiry of Agriculture, Muscat. pp. 5-15.

MAF. (1983) Economic damage caused by Dubas bug in the productivity of the date palm trees, in: D. G. o. A. Research (Ed.), Ministiry of Agriculture and Fisheries, Muscat.

MAF. (1993) South Batinah integrated study in: D. G. o. A. Research (Ed.), Ministry of Agriculture and Fisheries, Sultanate of Oman. pp. 19.

MAF. (1995) The Progression of Agriculture and Fisheries Development from 1970 to 1995, Ministry of Agriculture and Fisheries, Sultanate of Oman, Muscat.

MAF. (1997) Dubas bug, *Ommtissus lybicusa*, in: P. P. D. P. P. R. Centre (Ed.), Ministry of Agriculture and Fisheries December 1997, Muscat. pp. 3-18.

MAF. (2000) Dubas bug control on date palm (tender 2000), in: P. P. Department (Ed.), Ministry of Agricultur and Fisheries, Muscat.

MAF. (2004a) Abstracts of Results of Agricultural Research Ministry of Agriculture and Fisheries.Sultanate of Oman, Muscat. pp. 61.

MAF. (2004b) Directorate of Agriculture: Annual report Ministry of Agriculture and Fisheries, Muscat.

MAF. (2004c) Specification of Aerial spraying aircraft, in: P. P. Department (Ed.), Ministry of Agriculture and Fisheries, Muscat. pp. 17.

MAF. (2005a) Agricultural census of the Sultanate of Oman, in: D. o. statistic (Ed.), 2006, Muscat.

MAF. (2005b) Population intensity and egg density of *Ommatissus lybicus* de Berg. on date palm leaves in consecutive seasons under field condition, in: P. P. R. Centre (Ed.), Ministry of Agriculture and Fisheries, Muscat. pp. 210-213.

MAF. (2005c) Production of dates in Sultanat of Oman, in: D. o. statistic (Ed.), Ministry of Agriculture and Fisheries Muscat.

MAF. (2006a) Biennial agricultural research report 2005/2006, in: l. o. E. Directorate general of agricultural research Ministry of Agriculture Research (Ed.), Ministry of Agriculture 2006, Muscat. pp. 185-191.

MAF. (2006b) evaluated efficiency of insecticides agents Dubas bug during Autumn generation 2005-2006, in: R. l. o. E. Pant protection research center (Ed.), Ministry of Agriculture, Muscat.

MAF. (2007) Dubas bug control in the Sultanate of Oman, Ministry of Agriculture and Fisheries. Sultanate of Oman, Muscat.

MAF. (2008a) Annual Report of Plant Protection Programmers, Plant Protection Department,Ministry of Agriculture and Fisheries, Sultanate of Oman, Muscat.

MAF. (2008b) Developing Integrated Pest Management for Dubas bug *Ommatissus lybicus* De Berg., in the Sultanate of Oman, in: D. G. o. A. L. Research (Ed.), Integrated Pest Management for Dubas bug, Ministry of Agriculture, Muscat, Oman. pp. 51.

MAF. (2008c) Efficacy of some insecticdes against Dubas bug *Ommatissus lybicus* De Bergevin during autumn generation 2008, Ministry of Agriculture and Fisheries, Muscat. pp. 92-95.

MAF. (2009a) Annual Report of Plant ProtectionProgrammers, Plant Protection Department, Ministry of Agriculture and Fisheries, Sultanate of Oman., Muscat.

MAF. (2009b) Efficacy of some insecticdes against Dubas bug *Ommatissus lybicus* De Bergevin during autumn generation 2009. , in: E. LAB (Ed.), Ministry of Agriculture and Fisheries., Muscat.

MAF. (2009c) Production of dates in Oman, in: D. o. Statistic (Ed.), Ministry of Agriculture, Muscat. pp. 71.

MAF. (2009d) Production of dates in Oman, in: D. O. e. STATISTIC (Ed.), Ministry of Agriculture, Muscat: Ministry of Agriculture.

MAF. (2010a) Cropped area and Dates production in Oman 2010 (under print), in: D. o. Statistic (Ed.), Ministry of Agriculture and Fisheries, Muscat.

MAF. (2010b) Dubas Bug Control Programme, final report for the third phase Agriculture and Fishery Development Fund, Sultanate of Oman Muscat. pp. 25.

Mahmoudi H., Hosseininia G., Azadi H., Fatemi M. (2008) Enhancin date palm processing, marketing and pest controlthrough organic culture. *Journal of Organic Systems* **3**:29-39.

Mahmoudi M., Sahragard A., Pezhman H., Ghadamyari M. (2014) Efficacy of biorational insecticides against Dubas bug, *Ommatissus lybicus* (Hem.: Tropiduchidae) in a date palm orchard and evaluation of kaolin and mineral oil in the laboratory.

Manktelow D., Gurnsey S., MacGregor A. (2004) Deposit variability and prediction in fruit crops: What use are label rates anyway? *Aspects of Applied Biology* **71**:269-278.

Martin H.E. (1972) *Report to the Goverment of Saudi Arabia on Research in Plant Protection* pp. 38.

Matson P.A. (1997) Agricultural intensification and ecosystem properties. *Science* **277**:504-509.

Matthews G.A. (1973) Ultra Low Volume Spraying of Cotton in Malawi, *Cotton Growing Review*. **50**: 242-276.

Matthews G.A. (1979) *Pesticide application methods* 1st Edition Longman, New York and London.

Matthews G.A. (1982) New developments in pesticide-application technology. *Crop Protection* **1**:131-145.

Matthews G.A. (1992) *Pesticides Application Methods* 2nd Edition Longman Scientific &

Technical, Harlow.

Matthews G.A. (1999) *Application of Pesticides to Crops* Imperial College Press, London.

Matthews G.A. (2000) *Pesticide Application Methods* 3rd Edition ed. Blackwell Science, London.

Matthews G.A. (2006) *Pesticides Health, Safety and the environment*. 1st Edition Blackwell, Oxford.

Michael G.E., Ratcliffe S.T., Rice M.E. (2009) The IPM paradigm: concepts, strategies and tactics, in: Radcliffe E.B., et al. (Eds.), *Integrated Pest Management* Cambridge University Press Cambridge, United Kingdom pp. 549s.

Micron. (2007) AU6534 Electric Atomizer and Speed Controller Operator Hand book and Parts Catalogue, Micron Sprayer Limited, Bromyard

Miller C.J., Dunn E.V., Hashim I.B. (2003) The glycaemic index of dates and date//yoghurt mixed meals. Are dates / the candy that grows on trees/? Eur J Clin Nutr **57**:427-430.

Mohammed R.H. (2010) Aerial application of Dubas bug, in: M. A. Alawi (Ed.), Muscat.

Mokhtar A.M., Al-Mjeni A.M. (1999) A novel approach to determine the efficacy of control measures against dubas bug, *Ommatissus lybicus* deberg, on date palms. Sultan Qaboos University Journal for Scientific Research - *Agricultural Sciences* **4**:1-4.

Mokhtar A.M., AL-Nabahani S.S., AL-Tamimi S.S. (2001a) *Ovipostion pattern of Dubas bug Ommatissua Lybicus* De Berg. *on date palm*, Research Annual Report of Entomology, Jimah Research Station Ministry of Agriculture and Fishieries, Bahla Sultanate of Oman. pp. 3-13.

Mokhtar A.M., Al-Nabahani S.S., Al-Tamimi S.S. (2001b) *Using the production of honeydew as indication to estimate the population of Dubas bug Ommatissua Lybicus* De Berg. in the date palm grooves in Oman, Research Annual Report of Entomology, Jimah Research Station Ministry of Agriculture and Fishieries., Bahla Sultanate of Oman. pp. 3-13.

Mokhtar A.M., Nabhani S. (2010) Temperature-dependent development of Dubas bug, *Ommatissus lybicus* (Hemiptera: Tropiduchidae), an endemic pest of date palm, Phoenix dactylifera. *Eur. J. Entomol* **107**:681-685.

Mokhtar M.A. (2006) Influence of temperature on the development of *Ommatissus lybicus* de Berg. (Homoptera: Tropoduchidae) in vitro, Ministry of Agriculture and Fisheries, Muscat. pp. 214-218.

Morris R.F. (1960) Sampling insect populaton. *Annual Review of Entomology* **5**:243-264.

Nestel D., Klein M. (1995) Geostatistical Analysis of Leafhopper (Homoptera: Cicadellidae) Colonization and Spread in Deciduous Orchards. *Environmental Entomology* **24**:1032-1039.

Nimah M. (1985) Localized versus trickle irrigation system, 3rd Trickle Irrigation Congress, Fresno, Califorinia USA. pp. 552-554.

Nixon R. (1951) Date palm, A tree of life ™. *Economic Botany* **5**:274-301.

Norman W.R., Shayya W.H., Al-Ghafri A.S., McCann I.R. (1997) Aflaj irrigation and on-farm water management in northern Oman. *Irrigation and Drainage Systems* **12**:35-48.

Payandeh A., Dehghan A. (2011) Life table parameters of the dubas bug, *Ommatissus lybicus* (Hem: Tropiduchidae) at three constant temperatures. *African Journal of Biotechnology* **10**:19489-19493.

Payandeh A., Kamali K., Fathipour Y. (2010) Population structure and seasonal activity of *Ommatissus lybicus* in Bam region of Iran (Homoptera: Tropiduchidae). *Munis Entomology and Zoology* **5**:726-733.

Payne N. (2000) Factors Influencing Aerial Insecticide Application to Forests. *Integrated Pest Management Reviews* **5**:1-10.

Payne N., Retnakaran A., Cadogan B. (1997) Development and evaluation of a method for the design of spray applications: aerial tebufenozide applications to control the eastern spruce budworm, Choristoneura fumiferana (Clem.). *Crop protection* **16**:285-290.

Pearsall I.A. (2002) Daily flight activity of the western flower thrips (Thysan., Thripidae) in nectarine orchards in British Columbia, Canada. *Journal of Applied Entomology* **126**:293-302.

Piienkowski R.L., Medler J.T. (1964) Synoptic Weather Conditions Associated with Long-Range Movement of the Potato Leafhopper, *Empoasca fabae*, in to Wisconsin. *Annals of the Entomological Society of America* **57**:588-591.

Pimentel D. (1995) Amounts of pesticides reaching target pests: environmental impacts and ethics. *Journal of Agricultural and Environmental Ethics* **8**:17-29.

Pimentel D. (2005) Environmental and economic costs of the application of pesticides primarily in the United States. Environment, development and sustainability **7**:229-252.

Pimentel D., Acquay H., Biltonen M., Rice P., Silva M., Nelson J., Lipner V., Giordano S., Horowitz A., D'amore M. (1992) Environmental and economic costs of pesticide use. *BioScience* **42**:750-760.

Polles S.G., Vinson B.S. (1969) Effect of Droplet Size on Persistence of ULV Malathion and Comparison of Toxicity of ULV and EC Malathion to Tobacco Bud worm Larvae1. *Journal of Economic Entomology* **62**:90-94.

Porter B.N. (1993) Sacred Trees, Date Palms, and the Royal Persona of Ashurnasirpal II. J*ournal of Near Eastern Studies* **52**:129-139.

Porter J., Parry M., Carter T. (1991) The potential effects of climatic change on agricultural insect pests. *Agricultural and Forest Meteorology* **57**:221-240.

Rao Y.R., Dutt A. (1922) The pests of the date palm in the Iraq Department of Agriculture.Cited by Hussain. A. Ali, 1963. *Bulletin of Entomological Society of Egypt* **6**: 1-21.

Reardon R. (1991) *Aerial spraying for gypsy moth control,* US Dep. *Agric. For., Hamden*. pp. Pages.

Rhouma S. (2010) Genetic Variation in the Tunisian Date Palm (*Phoenix dactylifera* L.). Desert plants:355-370.

Rhouma S., Zehdi-Azouzi S., Dakhlaoui-Dkhil S., Ould Mohamed Salem A., Othmani A., Cherif E., Marrakchi M., Trifi M. (2010) Genetic Variation in the Tunisian Date Palm (Phoenix dactylifera L.), in: K. G. Ramawat (Ed.), Desert Plants, *Springer Berlin Heidelberg.* pp. 355-370.

Ribeiro B.M., Guedes R.N.C., Oliveira E.E., Santos J.P. (2003) Insecticide resistance and synergism in Brazilian populations of *Sitophilus zeamais* (Coleoptera: Curculionidae). *J. Stored Prod* **39**:21-31.

Rose R.I. (2001) Pesticides and public health: integrated methods of mosquito management. *Emerging infectious diseases* **7**:17.

Roush R.T. (1997) Insecticide resistance management in diamondback moth: quo vadis, Proc. Third Int. Workshop on the Management of Diamondback Moth and other Crucifer Pests. Sivapragasam, A., WH Loke, AH Kadir, and GS Lim,(eds). MARDI, Ministry of Agriculture. Malaysia. pp. pp. 21-24.

Salyani M., Farooq M., Sweeb R. (2007) Spray deposition and mass balance in citrus orchard applications. Transactions of the ASABE **50**:1963-1969.

Salyani M., Fox R.D. (1999) Evaluation of Spray Quality by Oil and Water Sensitive Papers. *American Society of Agriculture and Biology Engineers* **42**:37-43.

SAS. (2002) SAS Program 2002, SAS Institute,USA., Cary, NC, USA.

Schowalter T.D. (2006) *Insect ecology*; anecosystem approch. Second edition ed. Elsevier Inc.

Sfih M.S., H M.R.M., Al-Pnayan M.A. (2009) Effect of Some Fungi and Plant Extracts in *Ommatissus binotatus* var. *lybicus* De Berg. (Tropiduchidae : Homoptera) Basrah *Journal For Date Palm Research* **8**:117-133

Shah A., Mohsin A., Hafeez Z., Naeem M., Haq M. (2012) Eggs Distribution Behaviour of Dubas Bug (*Ommatissus Lybicus*: Homoptera: Tropiduchidae) in Relation to Seasons and Some Physico- Morphic Characters of Date Palm Leaves. *Journal of Insect Behavior*:**1**-16.

Siebert S., Nagieb M., Buerkert A. (2007) Climate and irrigation water use of a mountain oasis in northern Oman. Agricultural Water Management **89**:1-14.

Snijder B., Stassen P. (1999) *Pruning mature and encroached avocado trees to restimulate and maintain production and fruit quality.* South African Avocado Growers' Association Yearbook **22**:51-54.

Stoytcheva M., Zlatev R., Velkova Z., Valdez B. (2011) *Organophosphorus pesticides determination by electrochemical biosensors*. Pesticides-Strategies for Pesticides Analysis, InTech, Croatia:359-372.

Sugiura M., Horibe Y., Kawada H., Takagi M. (2011) Effect of different droplet size on the knockdown efficacy of directly sprayed insecticides. *Pest Management Science* **67**:1115-1123.

Symmons P. (1992) *Desert Locust Guidelines*. First edition. Food and Agriculture Organization of the United Nations. Rome:25.

Symmons P.M., Dobson H.M., Sissoko M. (1991) Pesticide droplet size and efficacy: a series of trials on grasshoppers. *Crop Protection* **10**:136-144.

Syngenta. (2008) Water Sensitive Paper in, Syngenta Crop Protection.Basle, Switzerland., Basle.

Talhouk A. (1979) Über landwirtschaftliche und soziologische Einflüsse auf das Auftreten und die Bekämpfung von Schädlingen in Saudi-Arabien. *Anzeiger für Schädlingskunde* **52**:90-92.

Talhouk A.S. (1991) On the management of the date palm and its arthropod enemies in the Arabian Peninsula. *J.Appl.Ent* **111**:514-520.

Thacker J.R.M., Al-Mahmooli I.H.S., Deadman M.L. (2003) *Population dynamics and control of the dubas bug Ommatissus lybicus in the Sultanate of Oman*, The BCPC International Congress: Crop Science and Technology, Cabi, SECC, Glasgow, Scotland, UK, 10-12 November 2003. pp. 987-992.

Thorp T., Stowell B. (2001) Pruning height and selective limb removal affect yield of large'hass' avocado trees. *HortScience* **36**:699-702.

Tsai H.J., Wang K. (1996) Development and reprodaction of *Bemisia argentifolii* (Homopytera: Aleyrodidae) on five host plants. *Environ.Entomol*. **25**:810:816.

Tucker G.F., Powell J.R. (1991) An Improved Canopy Access Technique. *Journal of Forestry* **89**:31-35.

UNEP. (1979) The State of the Environment: UNEP Governing Council Sevenenth Section., United Nations Environmental Programme, Nairobi- Kenya.

Vayalil P.K. (2002) Antioxidant and Antimutagenic Properties of Aqueous Extract of Date Fruit (*Phoenix dactylifera* L. Arecaceae). *Journal of Agricultural and Food Chemistry* **50**:610-617.

Venezian A., Klein M. (1985) The Dubas bug tropiduchid, *Ommatissus binotatus lybicus*, a threat to date palms in occupied Palestine. *Phytoparasitica* **13**:95-101.

Weintraub P.G., Beanland L. (2006) Insect Vectors of Phytoplasmas A*nnual Review of Entomology* **51**:91-111.

Whalon M., Mota-Sanchez D., Hollingworth R. (2008) Analysis of global pesticide resistance in arthropods. *Global Pesticide Resistance in Arthropods*:**5**-31.

Wiktelius S. (1981) Diurnal flight periodicities and temperature thresholds for flight for different migrant forms of Rhopalosiphum padi L. (Hom., Aphididae). *Zeitschrift für Angewandte Entomologie* **92**:449-457.

William E., Ahmed M.t., Ahmed O.E., Lashine Z., Nejatian A., Badwi T., Ragy S.M. (2004) *Date palm in the GCC Countries of the Arabian Peninsula, Aleppo* (Syria).

Wilson M.R. (1987a) The Auchenorrhyncha (Homoptera) associated with palms, Proceedings of the second International Workshop on Leafhoppers and Planthoppers of Economic Importance. pp. 327-342.

Wilson M.R. (1987b) The Auchenorrhyncha(Homoptera) Assosiated with Plams, in: M. R. W. and. L. R. Nault (Ed.), *The Auchenorrhyncha (Homoptera) Associated with Palms*, Provo, Utah USA. pp. 327-342.

Woods N. (2001) Spray drift of pesticides arising from aerial application in cotton. *Journal of*

Environmental Quality **30**:697.

Woods N. (2003) *The Aerial Application of Pesticides*. Optimising Pesticide Use:97. Australia

Woods N.N., Ian C., Gary D., Brian Y. (2001) Spray drift of pesticides arising from aerial application in cotton. *Journal of Environmental Quality* **30**:697-701.

Wool D., Gerling D., Nolt B.L., Constantino L.M., Bellotti A.C., Morales F.J. (1989) The use of electrophoresis for identification of adult Whiteflies (Homoptera, Aleyrodidae) in Israel and Colombia. *Journal of Applied Entomology* **107**:344-350.

Yaacoob A. (1996) Irrigation of Date Palm Trees. Basel Scientific *Journal for Agricultural Engineering Sciences* **1**:85-88.

Yoon K.S., Kwon D.H., Strycharz J.P., Hollingsworth C.S., Lee S.H., Clark J.M. (2008) Biochemical and molecular analysis of deltamethrin resistance in the common bed bug (Hemiptera: Cimicidae). J*ournal of Medical Entomology* **45**:1092-1101.

Zande J.C.V.d., Parkn C.S., Gilbert A.J. (2003) Application Technologies, in: M. Wilson (Ed.), *Optimising Pesticide Use*, John Wiley & Sons. pp. 23.

Zewen L., Zhaojun H., Yinchang W., Lingchun Z., Hongwei Z., Chengjun L. (2003) Selection for imidacloprid resistance in *Nilaparvata lugens*: cross resistance patterns and possible mechanisms. *Pest Management Science* **59**:1355-1359.

Appendices

Appendix 1. Average total area sprayed and insecticides used in aerial applications during period from 1976 to 2011.

Year	Insecticides	Sprayed area (hectare) generation		Dosage "total volume of spray (hectare)
		Spring	Autumn	
1976	DDT		anon	2.4
1977-1979	malathion		13000	2.4
1980	dichlorovos		17300	3.6
1981-1991	dichlorovos		anon	3.6
1992	Malathion &dichlorovos		7040	2.4 & 3.6
1993	=		13000	2.4 & 3.6
1994	=		6800	2.4 & 3.6
1995	=		9160	2.4 & 3.6
1996	=		11600	2.4 & 3.6
1997	=		13260	2.4 & 3.6
1998	Fenitrothion & dichlorovos		8100	1.92 &3.6
1999	fenitrothion	5500		1.92
2000	Fenitrothion & Dichlorovos	4400	6030	2.4 & 3.6
2001	Fenitrothion & dichlorovos		13100	2.4 & 3.6
2002	fenitrothion	12000	12125	2.4
2003	sumi-combi alpha		11240	3.6
2004	sumi-combi alpha		10315	3.6
2005	sumi-combi alpha	12850	8680	3.6
2006	sumi-combialpha & deltamethrin	11715		3.6 & 3.6
2007	etofenprox	8840		3.6
2008	etofenprox	10590		3.6

2009	etofenprox	13200	3.6
2010	deltamethrin	12500	3.6
2011	Deltamethrine	5000	3.6

Sources: MAF(2010 and 2011).