Lygus hesperus Knight IN THE TEXAS HIGH PLAINS: COTTON

COMPENSATION AFTER FRUIT DAMAGE AND HOST

PLANT SELECTION WITH IMPLICATIONS

FOR COTTON IPM

by

APURBA K. BARMAN, B.Sc., M.Sc.

A THESIS

IN

ENTOMOLOGY

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

Approved

Megha Parajulee
Chairperson of the Committee

Peter Dotray

Richard Deslippe

Accepted

John Borrelli
Dean of the Graduate School

December, 2006

ACKNOWLEDGEMENTS

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INTRODUCTION AND LITERATURE REVIEW

Cotton (*Gossypium* spp.) is the most important and popular source of natural

fiber, and comprises over 40 percent of the total fiber used in the World (USDA-ERS

2006). Although there are more than 40 different cotton species, only four are

economically important. Among these only two species, *G. hirsutum* L. and *G.

barbadense* L., are grown in the United States. More than 97% of cultivated cotton in

United States is upland cotton, *G. hirsutum* L. (NAAS, USDA 2006). There are more that

80 different cotton producing countries in the world and the contribution of the United

States to the world's cotton production is significant. In 2005, more than 5 million

hectares of cotton was grown in the United States with a total production of 23.25 million

bales which comprises 20 percent of world cotton production (FAS-USDA 2006). The

United States is the second largest cotton producer after China, and due to low

consumption in its domestic market, about 60 percent of the U.S. cotton is exported. In

the United States, the cotton industry has a significant impact on the overall economy of

the country. Cotton utilizes or supports different business enterprises other than textiles,

such as seed production, agrochemicals, fertilizers, ginning, farm machinery and cattle

feed. Products of these numerous industries and their related job opportunities account

for approximately $120 billion of business revenue (Anonymous 2004).

Cotton is grown under a wide range of climatic conditions in 17 U.S. states

stretching from Virginia to California. Among these states, Texas dedicates the most land

to the production of cotton and contributes more than 25 percent of the nation's total

cotton production. The Texas High Plains (THP) region, which is the world's most concentrated cotton growing area, produces more than half of Texas cotton, and 25 percent of the nation's cotton crop (Lubbock Chamber of Commerce 2006). Therefore, any change or manipulation in the THP production system will have a direct impact on the nation's cotton production as well as the state and local economies.

Modernization of farming systems, introduction of genetically modified plants, application of more selective pesticides and pest eradication programs have created a different scenario from a pest management point of view than that of the last two decades. Introduction of Bt (*Bacillus thuringiensis*) cotton has significantly reduced damage caused by the most yield reducing lepidopteran pests (i.e., *Helicoverpa zea and Heliothis virescens* or bollworm-budworm complex) of cotton in many of the cotton producing regions of the nation. Prior to the implementation of cotton boll weevil eradication programs across the cotton belt, the boll weevil (*Anthonomus grandis* Boheman) was a major pest of cotton. Eradication programs are not complete in some areas at this time but overall progress has been impressive. These two events are believed to be important from a cotton pest management prospective. Use of Bt-cotton has greatly reduced the need for pesticide applications particularly during the early growth stage of the crop. As a result, secondary or occasional pests, such as plant bugs (*Lygus* spp.), thrips (*Frankliniella occidentalis*) and aphids (*Aphis gossypii*), which were previously suppressed by early insecticide applications now have the opportunity to build populations and can inflict losses in the early growth stages of cotton. Nevertheless, boll weevil eradication programs aim to remove the weevil through careful monitoring of the population to avoid undue effect on natural arthropod predator/parasite complex. There

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may be a "void" in terms of major pests in cotton since Heliothines and boll weevils are now held in check. It is possible that plant bugs such as *Lygus*, fleahoppers (*Pseudatomoscelis seriatus*), green stink bugs (*Nezara viridula*), aphids and thrips are competing for this new niche and at this time *Lygus* appears to be emerging as a potential pest in many areas. Infestation or crop loss caused by these secondary pests during the last decade was very low, whereas today *Lygus* bugs are the second most damaging pests throughout the cotton belt of the United States (Table 1.1, Williams 2005).

There are about 20 different arthropod pests generally found in cotton agroecosystems and 10 of them are most common in the Texas High Plains (Table 1.2). Of course, the intensity and species composition varies among the cotton regions of the United States. Looking at the major pests and their infestation levels across the entire U.S. cotton belt (Table 1.1) and Texas alone (Table 1.3), it is clear that Heliothine species remain a major pest of cotton (Williams 2005). However, plant bugs including *Lygus*, fleahoppers, and stink bugs also can cause a considerable amount of loss.

Scott and Layton (2000) discussed several reasons for the appearance of *Lygus* as a pest of concern in United States. First, the boll weevil has been suppressed by eradication programs in the Mid-South and much of Texas. Second, *Lygus* has shown resistance to pyrethroid insecticides over the last decade, especially in the Mid-South (Xu and Brindley 1993, Snodgrass and Elzen 1995, Snodgrass 1996). Third, large scale adoption of transgenic cottons expressing the insecticidal protein produced by *Bacillus thuringiensis* (Bt) has since its introduction in 1996, changed the cotton pest management scenario, removing much of the insecticide applied for bollworm complex control. Thus few or no pesticide applications during early stages of cotton crop provide an opportunity

for other pest populations to grow, where *Lygus* is no exception. Williams (1999) reported that problems with *Lygus* infestations in the Mid-South and Arizona are concurrent with the large scale use of Bt-cotton. Fourth, new selective insecticides like spinosad (Tracer®; Dow AgroSciences) are effective only for lepidopteran pests with very little efficacy on other pests. Use of these selective insecticides leaves plant bugs such as *Lygus* in the cotton field which may become a problem during the growing season. Research has indicated that fewer foliar applications of insecticides along with Bt-cotton cultivation create a favorable environment for *Lygus* infestations in cotton (Layton et al. 1998, Stewart et al. 1998).

It is important to know the biology and present status of *Lygus* behavior in relation to its hosts so that management strategies can be developed for effective suppression of this insect, thus preventing it from becoming a serious pest of cotton. Reports on *Lygus* research can be found as early as the 1930's in Louisiana but the bug was not regarded as a serious pest of cotton until presentations were given at the 1953 Beltwide Cotton Production and Research Conferences (Scott and Snodgrass 2000). A significant amount of work on *Lygus* was documented during the 1970's and 1980's when Kelton (1975) published abundance and population behavior information about different *Lygus* species found in the United States and nearby countries. Later, Scales and Furr (1968), Tugwell et al. (1976) and Hanny et al. (1977) reported the effect of *Lygus* infestations on the cotton crop.

The genus *Lygus* comes under the order Hemiptera and family Miridae. Being a true bug, it feeds on tender parts of plants and fruiting structures (Tugwell et al. 1976, Tingey and Pillemer 1977). As many as 43 different species of *Lygus* have been reported

from different areas of the world including North and South America, the United

Kingdom, Europe, Africa, India, Russia, China, Japan, Hawaii, Australia, Fiji and New

Zealand (Graham et al. 1984, Wise 1977). Thirty-four of these species have been reported

in the United States. The species composition of *Lygus* varies depending on the region.

Three commonly found species in United States are tarnished plant bug (TBP) *Lygus*

lineolaris (Palisot de Beauvois), western tarnished plant bug (WTPB) *L. hesperus*

(Knight) and pale legume bug *L. elisus* (Van Duzee). *L. rugulipennis* (Popius) is the most

abundant species in Europe (Accinelli et al. 2005). Similarly, another two species, *L.*

borealis (Kelton) and *L. desertinus* (Knight), are prevalent in Canada. As mentioned

earlier, numerous research studies have been conducted to describe *Lygus* behavior, host

preference, biology and population dynamics during the last four or five decades.

However, reevaluation of this information is necessary considering changing technology.

 The described species of *Lygus* around the World are mostly plant feeders which

suck sap from young stems, leaves, fruits and flowers. Some species are even reported to

be omnivorous feeders, taking other small insects (Rosentheim et al. 2004). Both WTPB

and TBP are known for causing shedding of developing flowering buds (squares) in

cotton (Tugwell et al. 1976). However, damage to pre-squaring cotton and developing

fruit (bolls) can also occur (Scales and Furr 1968, Hanny et al. 1977, Layton 2000). The

tarnished plant bug, *L. lineolaris,* which is an important pest in the southeastern United

States feeds on leaves and stems but mostly on fruiting bodies of a wide variety of plants

(375 reported species), including numerous agronomically important crops such as

cotton, alfalfa (*Medicago sativa*), apple (*Malus domestica*), strawberries (*Fragaria*

ananassa), cherry (*Prunus avium*), peach (*Prunus persica*), beans (*Pheseolus vulgaris*)

and lettuce (*Lactuca sativa*) (Kelton 1975). Similarly, *L. hesperus*, which is more

prevalent in the southwestern United States has a wide host range including wild weed

hosts and cultivated crops such as cotton and alfalfa. *Lygus* bugs are highly mobile, active

during early spring to early fall, multivoltine, can complete one generation in about 20 to

24 days during warm weather, relatively cryptic, and overwinter as adults in plant

materials (Leigh et al. 1996, Raulston et al. 1996, Stefferaud 1952, Wagner et al. 1996).

These characteristics make *Lygus* a potential pest for any crop. *Lygus* may also be hard to

manage at the farm level and possibly needs an area-wide approach to control.

Although, *L. lineolaris* and *L. hesperus* are two different species found in separate

locations, they are biologically similar and cause similar damage to cotton. Even in

Texas, *L. lineolaris* is dominant in the eastern Blacklands region whereas *L. hesperus* is

dominant in the western High Plains. *Lygus* enter overwintering sites as adults in late

autumn in weeds or other ground cover and in the spring move to weeds including

volunteer alfalfa. In alfalfa, *Lygus* produce five to seven generations per year but are able

to develop only three generations in cotton (Leigh et al. 1996). The number of

generations that develop in non-crop hosts are determined by the heat units accumulated

during the growing season. The development threshold for *L. hesperus* ranges from

46.4^{o}F (Champlain and Butler 1967) to 53.6^{o}F and (50°F for *L. lineolaris*) (Fleischer and

Gaylor 1988). Nymphs are mostly responsive to photoperiod changes which also

determine when developing adults will undergo diapause. Beards and Strong (1966) after

several years of study reported that in mid-autumn, when day length is lower than 13

hours, nymphs of *L. hesperus* will develop into diapausing adults. At the onset of spring

following precipitation and emergence of fresh vegetation, the diapausing adults begin

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laying eggs. Egg numbers per female vary depending upon the time of year and

environmental conditions although an average of 200 eggs is deposited over a 30-day

period at this time of year (Leigh 1963). Average time for completion of the *Lygus* life

cycle varies with the host on which the insect developed and the time of year. Leigh

(1963) reported that on green beans *L. hesperus* required 7 days (200 degree days at 52°F

base) and about 13 days (370 degree days) from eclosion and nymphal development to

adults, respectively. Adult longevity is another life cycle parameter which has

considerable importance since adults are equally injurious as nymphs to the crop (unlike

the bollworm complex where adults are non-injurious). Again, the length of time that

adults survive on different hosts varies depending upon suitability and nutritional value of

the host. A study by Barlow et al. (1999) showed *L. hesperus* lived longer on spring

broadleaf weeds (shepherd's purse, *Capsella bursa-pastoris*: 20.4 days; common

groundsel, *Senecio vulgaris*: 19.7 days) as compared to spring grassy weeds (wild oat,

Avena fatua: 6.6 days; foxtail barley, *Hordeum jubatum*: 7.9 days; annual blue grass, *Poa*

annua: 13.2 days) or alfalfa, *Medicago sativa* (12.1 days). It is assumed that broadleaf

weeds are nutritionally more suitable compared to monocot weeds (Al-Munshi et al.

1982). Bariola (1969) found the average time required to complete one generation on

cotton at 80°F to be approximately 33 days, with the approximate number of days

required for each stage as follows: egg – 8; nymphs – 17, pre-ovipositional period – 8

days.

Traditionally, many pest management efforts rely heavily on chemical control and

the control of *Lygus* bugs is no exception. Therefore much work on insecticidal efficacy

and insecticide application methods to control *Lygus* has been reported during the last

few decades. Almost all groups of insecticides (organochlorines, organophosphates, carbamates, pyrethroids, nicotinoids) of different commercial formulations (e.g., DDT, malathion, monocrotophos, chlorpyriphos, dicrotophos, dimethoate, trichlorfon, acephate, aldicarb, carbaryl, cyfluthrin, lamda-cyhalothrin, fenvalerate, bifenthrin) were tested for efficacy against *Lygus* bugs in cotton production systems (Lentz 1982, Gallaher and Kowalski 1983, Burris et al. 1994, Leonard et al. 1987, Scott et al. 1986, Snodgrass and Elzen 1994, Reed et al. 1994, Teague and Tugwell 1996, Shaw et al. 1997, Kharboutli et al. 1998). Although their efficacy varies within the insecticide groups, no failure of insecticide control was reported to this point in time. Most of these insecticides were being used against bollworm or boll weevil and not specifically for *Lygus* bugs. However, after introduction of Bt-cotton and the suppression of boll weevil populations by eradication programs, pyrethroids are the most used insecticide group for control of other pests in cotton (Scott and Snodgrass 2000). Insecticide resistance to pyrethroid in *Lygus* populations was documented in 1993 in Mississippi and since Mississippi has recommended using alternative insecticides such as acephate and imidacloprid.

Reliance on the chemical control for *Lygus* has been in practice since the 1950's but the present situation of reduced insecticide load in cotton production system encourages the use of alternative control methods such as biological or cultural control. In today's scenario, availability of Bt-cotton and diminishing populations of boll weevils brings relief to growers who may avoid costly insecticide applications. The presence of *Lygus* may make growers consider spraying insecticides even in the early growing season. This practice will have a negative impact on natural enemy build up due to fewer insecticide applications and its benefits (Scott and Snodgrass 2000). To avoid this

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situation, biological control and cultural management of *Lygus* have received growing interest and much work has already been targeted for implementation.

Biological control of *Lygus* bugs in cotton has not yet been fully established commercially or widely accepted among growers. Work has been done to identify indigenous as well as imported species of natural enemies. There are several hymenopteran egg parasitoids of *Lygus* bugs which include *Anaphes iole* Girault, *A. ovijentatus* (Crosby and Leonard), *Polyneman pratensiphagum* Walley and *Erythemelus miridiphagus* Dozier, reported from different cropping as well as natural systems (Clancy and Pierce 1966, Ruberson and Williams 2000). Out of these parasitoids, *A. oile* has been extensively used for biological control of *L. hesperus* in commercial crops like strawberry (Udayagiri et al. 2000). A *Lygus* nymphal parasitoid, *Peristenus digoneutis* Loan, is an imported species from Europe which has successfully established in North America and effectively suppresses plant bug populations in strawberry and other vegetable crops (Day et al. 2003). However, the extent of parasitization and establishment of these natural enemies vary with the host plant complex and climatic conditions. Although *Peristenus digoneutis* is reported to be well established in seven northeastern states of the U.S., it failed to adapt below 40° N latitude. *P. pallipes* (Curtis) and *P. pseudopallipes* (Loan) are two native braconids prevalent in Texas and northeastern U.S., respectively (Lim and Stewart 1976). Day et al. (1999) reported a new species, *Peristenus howardi* Shaw which parasitizes nymphs of *L. hesperus* to be prevalent in alfalfa seed crops from Idaho and New Jersey (Day et al. 1990). Although there are no specific predators reported so far, generalist predators such as *Geocoris pallens* (Say), *Nabis americoferus* Carayon, spiders and ants are reported to significantly

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reduce the number of *Lygus* nymphs under field conditions (Leigh and Gonzalez 1976, Young 1989). Young and Welbourn (1987) reported that a parasitic mite, *Lasioerythraeus johntoni* can infest up to 36 percent of early instar nymphs of TPB. Fungal pathogens are another important biological control agent having significant potential to suppress insect populations. Liu et al. (2002) assayed 32 different fungal isolates against *L. lineolaris* and found *Beauveria bassiana, Metarhizium anisopliae, Hirsutella* spp., and *Verticillium psalliotiae* are virulent enough to affect pest populations. However, only *B. bassiana* has been exploited commercially as the only mycological pathogen against *Lygus* bugs (Snodgrass and Elzen 1994, Steinkraus and Tugwell 1997).

The feasibility of cultural control depends on several factors associated with *Lygus* behavior such as, the presence of more preferred hosts other than cotton, polyphagous nature, high mobility, destructive potential of both adults and nymphs and host switching (*Lygus* spend one or two generations in weed hosts in spring before moving to cotton). These behavioral traits of *Lygus* demonstrate the tremendous scope possible while developing cultural controls. An example would be to develop a method to prevent movement of the pest to cotton after evaluating its behavior and growth patterns in surrounding host plants. Recommendations such as strip cutting of alfalfa (Stern et al. 1964), destruction of weed hosts near cotton fields (Snodgrass et al. 2000) or strip cropping of alfalfa (Sevacherian and Stern 1974) with cotton are followed to reduce the movement of this pest to cotton.

Because *Lygus* bugs are becoming a problem in many cotton growing areas of the nation, concerns about managing these pests have been addressed either by use of chemicals and or cultural control practices. In order to have a basis for *Lygus*

management, it is necessary to set the economic threshold level (ETL) of this pest for specific regions and production systems. By nature, ETL is dynamic in terms of pest population and plant reaction. Table 1.4 shows how the ETL level of this pest in cotton has been set in different parts of the United States cotton belt (Layton 2000). However, the thresholds have not been adjusted for the ability of cotton to compensate insect-induced fruit loss. Therefore, we have made an effort to evaluate the response of cotton to differential levels of *Lygus* bug pressure. In other words, to what extent can cotton tolerate *Lygus* bug pressure or can cotton compensate for the loss by producing and maturing replacement fruit without losing economic yield.

Therefore, my thesis focused to address aforementioned aspects of *Lygus hesperus* biology, with the following two objectives:

- To evaluate compensation ability of cotton crop for different levels of *Lygus* infestations.
- To evaluate comparative host preference of *Lygus* bugs to selected weed hosts along with cotton.

Table1.1 Ranking of major arthropod pests of cotton in the United States, 2004
(Williams 2005)

Pests	% Yield Reduction	Acres infested*	Ranks by % loss	% Infested
Bollworm/budworm	1.229	11,191,270	1	81.7
Lygus	1.055	7,035,540	2	51.3
Stink bugs	0.558	6,252,773	3	45.6
Thrips	0.559	13,009,249	4	94.9
Cotton fleahopper	0.192	4,789,864	5	35.0
Pink bollworm	0.170	1,002,275	6	7.3
Whitefly	0.115	1,083,702	7	7.9
Spider mites	0.080	3,160,118	8	23.1
Boll weevils	0.071	1,571,620	9	11.5
Aphids	0.056	10,479,923	10	76.5

* 1 Acre=0.40 hectare

Table 1.2 Arthropod pests of cotton in Texas High Plains region

Arthropod pests	Scientific name	Family	Order
Sucking pests			
Cotton fleahopper	*Pseudatomoscelis seriatus* [Reuter]	Miridae	Hemiptera
Lygus spp.	*Lygus hesperus* [Knight]	Miridae	Hemiptera
	Lygus elisus [Van Duzee]	Miridae	Hemiptera
Cotton aphid	*Aphis gossypii* [Glover]	Aphididae	Homoptera
Cotton whitefly	*Bemesia tabaci* [Gennadius]	Aleyrodidae	Homoptera
Western flower thrips	*Frankliniella occidentalis* [Pergande]	Thripidae	Thysanoptera
Caterpillar group			
Bollworm	*Helicoverpa zea* [Boddie]	Noctuidae	Lepidoptera
Tobacco budworm	*Heliothis virescens* [Fabricius]	Noctuidae	Lepidoptera
Beet armyworm	*Spodoptera exigua* [Hubner]	Noctuidae	Lepidoptera
Cabbage looper	*Trichoplusia ni* [Hubner]	Noctuidae	Lepidoptera
Fall armyworm	*Spodoptera frugiperda* [J.E.]	Noctuidae	Lepidoptera

Table 1.3 Cotton yield loss by major insect pests in Texas and Texas High Plains, 2004 (Williams 2005)

Pests	Acres* Infested	Acres* Treated	% reduction	Bales lost
Texas				
Boll weevil	765,171	472,000	0.20	21,733
Bollworm/budworm	5,160,671	1,821,040	1.40	153,983
Pink bollworm	848,581	85,581	0.42	46,681
Cotton fleahopper	2,550,496	1,310,780	0.31	34,489
Lygus	1,159,363	259,423	0.35	38,995
Thrips	5,774,171	472,600	1.11	122,857
Aphids	4,778,671	536,050	0.07	7,707
Texas High Plains				
Boll weevil	50,000	0	0.00	0
Bollworm/budworm	2,847,500	781,650	1.11	75,192
Pink bollworm	750,000	60,000	0.67	45,703
Cotton fleahopper	223,325	12,500	0.00	0
Lygus	761,363	175,100	0.57	38,663
Thrips	3,350,000	250,000	1.60	108,875
Aphids	3,000,000	25,000	0.09	6,094

* 1 Acre=0.40 hectare

Table 1.4 Tarnished plant bug thresholds for various cotton producing states in U.S. for early fruiting period of cotton. (Layton 2000)

States	Minimum % square retention	Threshold
Alabama	80%	1 per row ft 1 per 2 row ft, if square set <80%
Arizona (*L. hesperus*)	(25% damaged square)	15-20 bugs/100 sweeps or if damage exceeds 25% and nymphs present, (4-6 nymphs per 100 sweeps)
Arkansas	75%	1 per row ft 1 per 3 row ft, if square set <75%
California (*L. hesperus*)	(25% damaged square)	1st 3 weeks of squaring- treat if square damage exceeds 25%.
Florida	80%	7 per 100 sweeps, or 1 per row ft
Georgia	85%	Treat if square set < 85% and numerous plant bugs present
Louisiana	70%	10-25 per 100 sweeps
Mississippi	80%	8 per 100 sweeps - 2 weeks of squaring. 15 per 100 sweeps - 3rd week to 1st bloom. If square set < 80%, reduce threshold 6-8 per 100 row ft - 1st week of squaring.
Missouri	80%	8-10 per 100 row ft – 2nd week of squaring
North Carolina	80%	7.5/100 sweeps - 1st 2 week of squaring; 15/100 sweeps - 3rd week until bloom
South Carolina	75%	1 per row ft if square set <75%
Tennessee	80%	1 per 6 row ft- 1st 2 weeks of squaring; 2 per 6 row ft - 3rd week to 1st blooms.
Texas: High Plains Rolling Plains Trans Pecos Southern, Eastern and Blacklands	75%	20 *Lygus* per 100 sweeps- on two successive dates

* 1 ft=30.48 cm

REFERENCES

Accinelli G., A. Lanzoni, F. Ramilli., D. Dradi, and G. Burgio. 2005. Trap crop: An agroecological approach to the management of *Lygus rugulipennis* on lettuce. Bull. of Insectology 58: 9-14.

Al-Munshi, D. M., D. R. Scott, and H. W. Smith. 1982. Some plant host effects on *Lygus hesperus* (Hemiptera: Miridae). J. Econ. Entomol. 75: 813-815.

Anonymous. 2004. The world of cotton. National Cotton Council of America web page http://www.cotton.org/econ/world/index.cfm. (Viewed on 20 October 2006)

Bariola, L. A. 1969. The biology of the tarnished plant bug, *Lygus lineolaris* (Beauvois), and its nature of damage and control on cotton. Ph.D. Dissertation, Texas A&M University, College Station.

Barlow, V. M., L. D. Godfrey, and R. F. Norris. 1999. Population dynamics of *Lygus hesperus* (Heteroptera: Miridae) on selected weeds in comparison with alfalfa. J. Econ. Entomol. 92: 846-852.

Beards, G. W., and F. E. Strong. 1966. Photoperiod in relation to diapause in *Lygus hesperus* Knight. Hilgardia. 37: 345-362.

Burris, E., B. R. Leonard, S. H. Martin, C. A. White, J. B. Graves, R. Shaw and W. P. Scott. 1994. Fipronil: Evaluation of soil and foliar treatments for control of thrips, aphids, plant bugs, and boll weevils, pp. 838-844. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Champlain, R. A., and G. D. Butler, Jr. 1967. Temperature effects on development of the egg and nymphal stages of *Lygus hesperus* (Hemiptera: Miridae). Ann. Entomol. Soc. Am. 60: 519-521.

Clancy, D. W., and H. D. Pierce. 1966. Natural enemies of some *Lygus* bugs. J. Econ. Entomol. 59: 853-858.

Day, W. H., C. R. Baird, and S. R. Shaw. 1999. New, native species of *Peristenus* (Hymenoptera: Braconidae) parasitizing *Lygus hesperus* (Hemiptera: Miridae) in Idaho: Biology, importance, and description. Ann. Entomol. Soc. Am. 92: 370-375.

Day, W. H., A. T. Eaton, R. F. Romig, K. J. Tilmon, M. Mayer, and T. Dorsey. 2003. *Peristenus digoneutis*, a parasite of *Lygus lineolaris* in northeastern United States alfalfa, and the need for research on other crops. Entomol. News 114: 105-111.

Day, W. H., R. C. Hedlund, L. B. Saunders, and D. Coutinot. 1990. Establishment of
    Peristenus digoneutis (Hymenoptera: Braconidae), a parasite of the tarnished
    plant bug (Hemiptera: Miridae) in the United States. Environ. Entomol. 19: 1528-
    1533.

FAS-USDA. 2006. Cotton area, yield and production: World and selected countries and
    regions. Production Estimates and Crop Assessment Division, FAS, USDA.
    http://www.fas.usda.gov/cotton/ (Viewed on 15 September 2006)

Fleischer, S. J., and M. J. Gaylor. 1988. *Lygus lineolaris* (Heteroptera: Miridae) population
    dynamics: Nymphal development, life table, and Leslie matrices on selected
    weeds and cotton. Environ. Entomol. 17: 246-253.

Gallaher, M., and E. Kowalski. 1983. Insecticide control of plant bugs and effect on
    beneficials. ESA Insecticide and Acaricide Tests 8: 191.

Graham, H. M., A. A. Negm, and L. R. Ertle. 1984. Worldwide literature of the *Lygus*
    complex (Hemiptera: Miridae) 1900-1980. U.S. Dept. Agric. Bibliogr. Lit. Agric.
    30:1-205.

Hanny, B. W., T. C. Cleveland, and W. R. Meredith, Jr. 1977. Effects of tarnished plant
    bug (*Lygus lineolaris*) infestation on pre-squaring cotton (*Gossypium hirsutum*).
    Environ. Entomol. 6: 460-462.

Kelton, L. A. 1975. The *Lygus* bugs (genus *Lygus* Hahn) of North America (Heteroptera:
    Miridae). Mem. Entomol. Soc. Canada 95: 1-101.

Kharboutli, M. S., C. T. Allen, C. Capps, and L. Earnest. 1998. Insecticides for tarnished
    plant bug control in southeast Arkansas, pp. 1194-1197. *In* Proceedings, Beltwide
    Cotton Conference. National Cotton Council, Memphis, TN.

Layton, M. B. 2000. Biology and damage of the tarnished plant bug, *Lygus lineolaris*, in
    cotton. Southwest. Entomol. 23 (suppl.): 7-20.

Layton, M. B., S. D. Stewart, and M. R. Williams. 1998. Performance of Bt cotton in
    Mississippi, 1997, pp. 970-973. *In* Proceedings, Beltwide Cotton Conferences,
    National Cotton Council, Memphis, TN.

Leigh, T. F. 1963. Life history of *Lygus hesperus* (Hemiptera: Miridae) in the laboratory.
    Ann. Entomol. Soc. Am. 56: 865-867.

Leigh, T. F., and D. Gonzalez. 1976. Field cage evaluation for predators for control of
    Lygus hesperus Knight on cotton. Environ. Entomol. 5: 948-952.

Leigh, T. F., S. H. Roach, and T. F. Watson. 1996. Biology and ecology of important insect and mite pests of cotton, pp. 19-85. *In* E.G. King, J. R. Phillips, and R. J. Coleman [eds.], Cotton insects and mites: Characterization and management. The Cotton Foundation Publisher. Memphis, TN.

Lentz, G. L. 1982. Insecticide treatments for tarnished plant bug control and their effects on beneficials. ESA Insecticide and Acaricide Tests 7: 160.

Leonard, B. R., J. B. Graves, A. M. Pavloff, and G. Burris. 1987. Effects of selected insecticides on plant bugs, cotton fleahoppers, and beneficial arthropods, 1986. ESA Insecticide and Acaricide Tests 12: 233.

Lim, K. P., and R. K. Stewart. 1976. Laboratory studies on *Peristenus pallipes* and *P. pseudopallipes* (Hymenoptera: Braconidae), parasitoids of tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae). Can. Entomol. 108: 815-821.

Liu, H., M. Skinner, B. L. Parker, and M. Brownbridge. 2002. Pathogenicity of *Beauveria bassiana, Metarhizium anisopliae* (Deuteromycotina: Hyphomycetes), and other entomopathogenic fungi against *Lygus lineolaris* (Hemiptera: Miridae). J. Econ. Entomol. 95: 675-681.

Lubbock Chamber of Commerce. 2006. Agriculture, online agricultural resources/agricultural facts. www.lubbockchamber.com/lbp.html#COTTON (Viewed on 13 November 2006)

NAAS, USDA. 2006. U.S. cotton production by state. www.cottonusa.org (Viewed on 24 October 2006)

Raulston, J. R., T. J. Henneberry, J. E. Leggett, D. N. Byne, E. Grafton-Cardwell, and T. F. Leigh. 1996. Short and long range movement of insects and mites, pp. 144-162. *In* E.G. King, J. R. Phillips, and R. J. Coleman [eds.], Cotton insects and mites: Characterization and management. The Cotton Foundation Publisher. Memphis, TN.

Reed, J. T., C. S. Jackson, and R. P. Porter. 1994. Cage evaluation of spray applications on cotton for plant bug control. ESA Arthropod Management Test, p. 239.

Rosentheim, J. A., R. E. Goeriz, and E. F. Thacher. 2004. Omnivore or herbivore? Field observations of foraging by *Lygus hesperus* (Hemiptera: Miridae). Environ. Entomol. 35: 1362-1370.

Ruberson, J. R., and L. H. Williams, III. 2000. Biological control of *Lygus* spp.: A component of areawide management. Southwest. Entomol. 23(suppl.): 96-110.

Scales, A. L., and R. E. Furr. 1968. Relationship between the tarnished plant bug and deformed cotton plants. J. Econ. Entomol. 61: 114-118.

Scott, D. S., and M. B. Layton. 2000. Cultural control for the management of *Lygus* populations in cotton. Southwest. Entomol. 23(suppl.): 83-95.

Scott, W. P., and G. L. Snodgrass. 2000. A review of chemical control of the tarnished plant bug in cotton. Southwest. Entomol. 23(suppl.): 67-81.

Scott, W. P., J. W. Smith, and G. L. Snodgrass. 1986. Impact of early season use of selected insecticides on cotton arthropod populations and yield. J. Econ. Entomol. 79: 797-803.

Sevacherian, V., and V. M. Stern. 1974. Host plant preference of *Lygus* bugs in alfalfa-interplanted cotton fields. Environ. Entomol. 3: 761-766.

Shaw, R., H. S. Yang, B. K. Rowe, and H. R. Smith. 1997. Summary of research trials with fipronil for control of plant bugs on cotton, pp. 1043-1046. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Snodgrass, G. L. 1996. Insecticide resistance in field populations of the tarnished plant bug (Heteroptera: Miridae) in cotton in the Mississippi Delta. J. Econ. Entomol. 89: 783-790.

Snodgrass, G. L., and G. W. Elzen. 1994. Efficacy of Naturalist-L for adults and nymphs of the tarnished plant bug in cotton, pp. 1103-1104. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Snodgrass, G. L., and G. W. Elzen. 1995. Insecticide resistance in a tarnished plant bug-population in the Mississippi Delta. Southwest. Entomol. 20: 317-323.

Snodgrass, G. L., W. P. Scott, J. T. Robbins, and D. D. Hardee. 2000. Area-wide management of the tarnished plant bug by reduction of early-season wild host plant density. Southwest. Entomol. 23(suppl.): 59-66.

Stefferaud, A. 1952. Insects, The Yearbook of Agriculture, 1952. U.S. Department of Agriculture, Washington, D.C. 780 pp.

Steinkraus, D. C., and N. P. Tugwell. 1997. *Beauveria bassiana* (Deuteromycotina: Moniliales) effects on *Lygus lineolaris* (Hemiptera: Miridae). J. Entomol. Sci. 32: 79-90.

Stern, V. M., R. van den Bosch, and T. F. Leigh. 1964. Strip cutting alfalfa for *Lygus* bug control. Calif. Agric. 18: 4-6.

Stewart, S. D., J. Reed, R. G. Luttrell, and F. A. Harris. 1998. Cotton insect control strategy project: Comparing Bt and conventional cotton management and plant bug control strategies at five locations in Mississippi, 1995-1997, pp. 1199-1203. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Teague, T. G., and N. P. Tugwell. 1996. Chemical control of tarnished plant bug - results from field cage studies and laboratory bioassay, pp. 850-853. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Tingey, W. M., and E. A. Pillemer. 1977. *Lygus* bug: Crops resistance and physiological nature of feeding injury. Entomol. Soc. Amer. Bull. 23: 277-287.

Tugwell, P. S., S. C. Young, B. A. Dumas, and J. R. Phillips. 1976. Plant bugs in cotton: Importance of infestation time, types of cotton injury, and significance of wild hosts near cotton. Ark. Agric. Expt. Stn. Rept. Tech. Bull. 227. 24 pp.

Udayagiri, S., S. C. Welter, and A. P. Norton. 2000. Biological control of *Lygus hesperus* with inundative releases of *Anaphes iole* in a high cash value crop. Southwest. Entomol. 23(suppl.): 27-38.

USDA-ERS (U.S. Department of Agriculture, Economic Research Service). 2006. Cotton briefing room. http://www.ers.usda.gov/Briefing/Cotton/ (Viewed on 13, 2006)

Wagner, T. L., R. L. Olson, and J. L. Williams. 1996. Modeling and computerized decision aids, pp. 205-249. *In* E.G. King, J.R. Phillips and R.J. Coleman [eds.], Cotton insects and mites: Characterization and management. The Cotton Foundation Publisher. Memphis, TN.

Williams, M. R. 1999. Cotton insect loss estimates- 1998, pp.785-806, *In* Proceedings, Beltwide Cotton Conferences. National Cotton Council, Memphis TN.

Williams, M. R. 2005. Cotton insect loss estimates- 2004, pp. 1105-1160. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Wise, K. A. J. 1977. A synonymic checklist of the Hexapoda of the New Zealand sub-region: The smaller orders. Bull. of the Auckland Institute and Museum 11: 1-176.

Xu, G., and W. A. Brindley. 1993. Structure of populations of *Lygus hesperus* (Hemipera: Miridae) with multiple resistance mechanisms to trichlorofon. J. Econ. Entomol. 86: 1656-1663.

Young, O. P. 1989. Predators of the tarnished plant bug *Lygus lineolaris* (Heteroptera: Miridae): Laboratory evaluations. J. Entomol. Sci. 23: 174-179.

Young, O. P., and W. C. Welbourn. 1987. Biology of *Lasioerythraeus johnstoni* (Acari: Erythraeidae), ectoparasitic and predaceous on the tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae), and other arthropods. Ann. Entomol. Soc. Am. 80: 243-250.

CHAPTER II

EVALUATION OF COMPENSATION ABILITY OF COTTON

AFTER *Lygus hesperus* INFESTATION

IN TEXAS HIGH PLAINS

Abstract

Field studies were conducted during 2005 and 2006 at the Texas Agricultural

Experiment Station, Lubbock, TX to evaluate the compensation ability of cotton

(*Gossypium hirsutum* L.) after being subjected to different levels of artificial infestation

of *Lygus hesperus* (Knight) at two crop growth stages (pre-bloom and early-bloom). No

significant difference in plant height was observed during the active growing period and

at pre-harvest. The number of sympodia which could possibly increase overall yield did

not vary significantly among treatments. In 2005, percent fruit loss due to the highest

level of bug infestation (3 per plant) in the pre-bloom and early-bloom studies was 48 and

36 percent, respectively. Pre-bloom fruit loss was not compensated through yield, where

there was major loss in first position bolls in the bug-release treatments. Yield in bug-

released treatments reduced yield significantly (226.75 kg/hectare) as compared to the

control. A compensatory response of cotton was observed when the bug treatment was

established during early-bloom stage. Particularly, loss due to *Lygus* released at one per

plant was fully recovered and there was no significant difference in yield compared with

sprayed and natural control treatments. A significantly higher lint yield from second and

third position fruit was realized in treatment with 3 bugs per plant as compared to the

sprayed control. In a repeated study conducted in 2006, 30 and 34 percent fruit loss was

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observed when 3 bugs per plant were released during pre-bloom and early-bloom stage of the cotton, respectively. No difference in fiber quality was observed as an effect of bug-injury treatments. Delayed plant maturity was not observed in both the studies conducted during year 2005, which was indicated by the absence of significantly greater number of non-harvestable bolls in any treatment.

2.1 Introduction

The inherent ability of plants to withstand certain degrees of biotic or abiotic stresses is a natural phenomenon, which is called the tolerance ability. This can apply to a single plant or a crop as a whole. Among the biotic stresses, plants suffer various types of damage from insect pest attacks and the plants in turn devote resources to compensate for the losses. Plant compensation caused by arthropod damage is a physiological response of the plant and has considerable importance in natural as well as agricultural systems. Stewart and Sterling (1988) described compensation of cotton as replacement of fruit shed because of pest injury. In a natural system, tolerance or compensation of plants is measured in terms of fitness, which translates into maintenance of genotype (Trumble et al. 1993). However, in agricultural or managed systems, plant tolerance is usually assessed by recovered yield loss or growth parameters that describe fitness. Most of the studies on compensation of agricultural crops focus on yield rather than fitness. Crop response towards herbivore loss has a direct influence in determining the economic threshold level of any pest (or its pest status) and the formulation of IPM strategies (Fitt 1994, Wilson et al. 2003). Crops or crop varieties having higher compensation ability have a higher economic threshold and require fewer control measures. It is also necessary

to evaluate the compensation ability of any crop as related to a specific pest. Variation in compensatory response towards herbivore losses also affects sampling strategies and economic threshold levels which could possibly contribute in formulating integrated pest management strategies and breeding for insect resistance to key arthropod pests of any crop.

It was observed that most of the damage caused by pest attacks in early season crop growth is cosmetic (Wilson et al. 2003, Sadras and Wilson 1998) and in most cases there were no significant yield losses. There is much evidence in documented reports of a plant's compensation ability given different degrees of infestation (Kletter and Wallach 1982, Ungar et al. 1987, Rosenheim et al. 1997). Plant's compensatory ability is often regarded as controversial. Though plants demonstrate partial to overcompensation for herbivory losses, compensation is also influenced by environmental conditions such as nutrients, light, water, interspecific competition, and soil type (Belsky 1986). Hence, it is not always possible for plants to compensate for yield losses caused by insect pests particularly when plants are already stressed by other factors such as drought or insufficient nutrient supply. Examining the mechanism of the plant's compensatory response under a stable environment will make the degree of a plant's compensatory ability to insect damage clearer.

There are several mechanisms identified which explain the physiological and architectural changes in plants in response to herbivore damage (Tiffin 2000). The first and most studied mechanism of compensation is increased photosynthetic activity of plants in response to either defoliation or destruction of fruiting bodies by insects (McNaughton 1979, Crawley 1983, Whitham et al. 1991, Rosenthal and Kotanen 1994,

Strauss and Agrawal 1999, Holman and Oosterhuis 1999). A second mechanism of compensation is compensatory growth and activation of dormant meristems. Following defoliation or removal of vegetative and reproductive meristems, plants responded to the losses by re-growth and activation of dormant meristems (Inouye 1982, Paige and Whitham 1987, Prins and Verkaar 1989, Doak 1991, Bergelson et al. 1996, Mabry and Wayne 1997). Rosenheim et al. (1997) observed that compensation of cotton in relation to aphid injury manifested as enhanced apical dominance. Sometimes a biennial or perennial plant mobilizes and utilizes its stored reserves as a mechanism of compensation to losses caused by insect attack (Danckwerts and Gordon 1987, Van der Heyden and Stock 1996). Response of plants to herbivore attack may change plant phenology resulting in delayed growth, flower or fruit production. This is also a mechanism to compensate for losses (Harnett and Abrahamson 1979, Islam and Crawley 1983, Marquis 1988, Bergelson and Crawley 1992, Juenger and Bergelson 1997, Mabry and Wayne 1997, Lennartsson et al. 1998, Meyer 1998). The last mechanism of plant tolerance to herbivore attack is change of plant architecture during the time of damage. An increase of root-shoot ratio (Chapin and McNaughton 1989) or number of stems, or increased stem thickness (Rosenthal and Welter 1995) can be observed.

Compensation ability of cotton has been reported following damage by thrips (Terry 1992, Sadras and Wilson 1998) which reduce leaf area in the first few weeks after plant emergence; the larvae of *Helicoverpa* spp. (Brook et al. 1992a) which feed on fruiting forms; *Lygus* spp. (Holman and Oosterhuis 1999, Teague et al. 2001, 2002) which feed on squares, flowers or immature bolls; and the cotton aphid (Rosenheim et al. 1997) which can be a pest in early or later growth stages of the crop. It was observed that

yield loss from the first fruiting position after early herbivore damage caused a higher

contribution from second or fruiting positions even farther out on the branches (Holman

and Oosterhuis 1999). Therefore, there is a clear shift of the yield profile in cotton from

first position to either outer or upper positions in response to early fruit loss by insect

pests (Jones et al. 1996). The compensation ability of cotton varies with growth stage of

the crop which experiences insect infestation and accordingly differential responses are

exhibited. Usually, early season fruit loss by insect pests is fully recovered without any

loss in yield or delay in crop maturity (Wilson et al. 2003, Rosenheim et al. 1997).

Compensatory growth of cotton (*Gossypium hirsutum* L.) by means of altered

morphologic and physiologic patterns has been recorded after loss of its reproductive

organs. In an experiment at North Carolina State University, Wells (2001) reported that

flower removal caused an extended flowering period. This was believed to be due to

greater chlorophyll concentration and less anthocyanin pigments. Higher photosynthetic

rates in the cotton canopy with removed reproductive parts were reported by Sadras

(1995) and subsequently by Holman and Oosterhuis (1999). Brook et al. (1992a)

demonstrated that early fruit loss may be responsible for lengthening the duration of

canopy development which resulted in greater light interception by the plant canopy and

increased leaf nitrogen concentration.

Evaluation of the compensation ability of cotton is associated with several issues

such as uniform infestation of the crop by pests, duration of infestation, intensity of pest

population, influence of environment and cultural practices, and the plant parameters

which describe compensation. In reality, it is unlikely that a pest damages any crop in a

uniform manner, which makes it difficult to quantify the extent of damage and any

associated compensation. Researchers have tried to establish early-fruit loss using natural

infestations (Wilson 1981, Wilson and Bishop 1982, Brook et al. 1992a, Rosenheim et al.

1997, Holman and Oosterhuis 1999, Lei and Wilson 2004) by various cotton pests as well

as damage simulated by manual removal of floral buds in cotton (Dunman et al. 1943,

Ungar et al. 1987, 1992, Brook et al. 1992b, Jones et al. 1996, Sadras 1996, Baugh et al.

2003). When manual destruction of floral or other plant parts is used rather than actual

insect damage, it is likely that results are to greater degree inaccurate due to the lack of

several insect-induced plant responses. The effect of insect salivary toxin on plant growth

(Wilson et al. 2003), the possibility of remobilizing the resources by plants from a

damaged structure to other parts, endogenous hormonal imbalance, plant's native

chemicals that regulate feeding intensity of insects or the preference of insects to size of

fruiting structures are not addressed when conducting a study with simulated crop injury

(Tugwell et al. 1976 Stewart and Sterling 1988, Burden et al. 1989, Holman and

Oosterhuis 1999). Age or life stages of the insect and size of available fruiting structures

may influence on the final injury inflicted on a plant. Zink and Rosenheim (2005)

reported that first to third instar nymphs of *Lygus hesperus* can not feed on large cotton

squares (over 8 mm in length) but squares less than 7 mm in length are susceptible to

damage. These authors also reported that nymphs and adult females of *L. hesperus* spend

more time feeding on squares than adult males.

Numerous traits are considered in evaluating the compensatory ability of cotton,

but three key parameters are time of crop maturation, fiber yield and fiber quality

(Rosenheim et al. 1997). However, parameters including number of sympodial and

monopodial branches, height-to-node ratio, plant biomass and root-shoot ratio can also

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help in explaining the mechanism of compensation in cotton. Square retention during crop growth stages gives an estimate of final yield as there is a strong correlation between these two parameters. It is recommended in many Extension guides to obtain the information on insect numbers and percent square retention in order to make tarnished plant bug management decisions (Layton 2000).

Cotton is indeterminate in fruiting habit which allows the crop to compensate for early fruit loss in a prolonged growing season (Montez and Goodell 1994, Cook and Kennedy 2000). Presumably, once fruit loss occurs early in the season either due to biotic or abiotic stresses, plants transfer nutrients to produce more young buds or vegetative branches (Rude 1984). Such transfer of nutrients and other hormones insures equivalent or overcompensation of fruit loss in the later part of the growing season. However, available technology, a changing pest complex and regional differences in growing or climatic conditions make the topic of compensatory growth more complicated in cotton. Research done worldwide indicates that a severe infestation of an insect pest in cotton in the early growth period can translate into a significant yield reduction and also can be associated with delayed crop maturity (Stewart et al. 2001). This delay in crop maturity may vary from days to weeks. If cotton requires a long maturation period to compensate for fruit loss, compensation might not be significant in regions where the growing season is short, as in the southwestern United States (Terry 1992). The Texas High Plains has a short growing season and a late maturing cotton crop is often subjected to severe weather (Baugh et al. 2003) or late season attacks by pests such as cotton aphids or pink bollworms. Cultivars are being developed to be more determinate where a single set

fruiting cycle is desired. This makes harvest more efficient as well as retaining quality of fiber.

It is still controversial whether early season pests of cotton should be of concern to producers, particularly in a situation where the use of Bt-cotton and boll weevil eradication have almost neutralized two major pests of cotton. It may not be necessary to apply insecticides during the early growing season, which not only increases production cost but also kills natural enemies and increases the possibility of secondary pest resurgence. Farmers may be able to tolerate low levels of pests in the early season. It would be of great value to evaluate at what level of pressure a cotton crop can compensate for any early season fruit loss without delaying the crop maturity. *Lygus* bugs are a perennial problem in southern U.S. regions, and may well be causing early season damage in the Texas High Plains. It would be undesirable to use chemical control measures against *Lygus* in the early season when cotton plants can compensate the loss from that level of pest population. Considering the compensatory ability of cotton it may be possible to minimize early season insecticide usage and thus avoiding adverse environmental effects and secondary pest outbreaks. Compensatory ability of the crop will affect the action threshold against any pest while formulating an IPM strategy (Wilson et al. 2003). The objective of this study was to evaluate the compensatory ability of cotton to *L. hesperus* damage in the southern Texas High Plains.

2.2 Materials and Methods

2.2.1 Introduction

The experiment was conducted at Texas Agricultural Experiment Station, Lubbock, TX during 2005 and 2006. Paymaster™ cotton cultivars PM2326RR and ST4554B2RF were planted on 20 May 2005 and 15 May 2006, respectively. In-furrow aldicarb @ 850 gm ai/hectare was applied at planting and subsequently acephate @ 204 gm ai/hectare was sprayed on the third week after planting to protect the seedlings from thrips damage. Approximately 130,000-162,000 seeds/hectare were planted in a furrow-irrigated field fertilized with nitrogen at 90 kg/ha. Normal cultural practices for the region were performed. The study consisted of two fields in which two different phenological stages of cotton (one per field) including pre-bloom (first three weeks of squaring) and early-bloom (first three weeks of blooming) were exposed to augmentative *Lygus* bug releases in order to inflict fruit loss. There were four treatments: 1) Sprayed control (SC), plots were sprayed at regular intervals with acetamiprid at 30 gm ai/ha to exclude any bugs; 2) Natural control (NC), plots were not sprayed and no bugs were released; 3) Plots receiving 1 bug per plant (1PP) per release; and 4) Plots receiving 3 bugs per plant (3PP) per release. Three consecutive releases were made for each phenological stage of the crop. Plots were 15.24 m x 8 rows with 101-cm row width. The details of the release schedules and associated observations are shown in Table 2.1

2.2.2 Insect Culture

The requirement of having large numbers of *Lygus* bugs of similar life stage available per week for several consecutive weeks necessitated the creation of a reliable

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insect rearing facility. A nucleus culture of *Lygus hesperus* was obtained from Western Cotton Research Laboratory, USDA-ARS, Phoenix, AZ during early 2005, and was augmented with locally collected *L. hesperus* in order to maintain the colony's vigor and increase bug numbers. Initially, all life stages were fed with a pre-mixed artificial diet procured from BioServe (Frenchtown, NJ). Later the diet was prepared in our laboratory using the *L. hesperus* diet recipe described by Debolt (1982). The diet was semi-solid in consistency and was poured into diet packs made of a 5 cm by 10 cm Parafilm® pouch. Approximately 20 ml of diet was placed in each pouch and the pouch was sealed with a food storage bag sealing machine. Packs were stored for up to two weeks in the refrigerator and no degradation in quality was observed. After nymphs eclosed from eggs laid in the oviposition packs (explained later in this chapter), they were fed on a diet pack that was stretched slightly to reduce the thickness of the film to facilitate feeding of early instars (first to third instar). All nymphal instars were reared in Rubbermaid® plastic containers (17.5 cm by 17.5 cm by 10 cm), which were fitted with a fine mesh window hot-glued around an opening cut in the cages to allow ventilation. The content of the oviposition packs was made up of 2% (w/v) Gelcarin® (FMC BioPolymer, Philadelphia, PA) solution dissolved in distilled water. The solution was boiled for 4-5 minutes to dissolve properly and then allowed to cool. This content (10 ml/egg pack) was poured into a 5 cm by 10 cm Parafilm® pouch. The pouches were placed in top of a 35 cm by 22.5 by 15 cm plastic oviposition cage with wire screen affixed to a hole on the upper side of the container. This allowed gravid females to insert their eggs into the oviposition packs through the relatively large openings in the screen mesh. All life stages were reared inside electronic growth chambers (Precision™, Model 818; Winchester, VA)

programmed for a constant temperature of $26 \pm 2\ ^0C$, 40 to 50% relative humidity and a

14:10 L:D photoperiod. Under these conditions, *L. hesperus* completed a life cycle in 28-

30 days. This rearing protocol produced the required number of *Lygus* nymphs

throughout the study duration in both years.

2.2.3 Insect Releases

Three consecutive insect releases were made in each of two fields when the crop

attained the desired plant-growth stage. Initially, the two middle rows of each plot (101

cm by 8 rows) were flagged for 3.04 meter sections. Plant density was maintained at 30-

35 plants in each 3.04 meter section. Insects were released during morning hours (6:00-

9:00 AM) to avoid extreme afternoon temperatures which could hamper initial insect

establishment. Small plastic snap boxes were used to carry the insects to the field and

bug(s) were placed in top of the plant using a camel hair artist's brush. Care was taken to

keep the bugs in place on the plants until they could establish footing. Once bugs were

placed, they were observed until they started crawling on the leaves.

2.2.4 Experimental Design and Analysis

The four treatments (SC, NC, 1PP and 3PP) were assigned randomly to plots with

four replications. As the entire field was believed to be fairly homogenous in terms of

irrigation and fertility, a completely randomized design (CRD) was used. Identical tests

comprising 16 plots each were conducted in both the pre-bloom and early-bloom study

fields.

Observations were taken from the 3.04 m sections in the middle two rows which were marked at the beginning of the experiment. Once all the bug releases were complete, and observations were taken 1-week after the last bug release, all plots were sprayed with acetamiprid at 30 gm ai/hectare to kill the bugs present naturally or from releases. Plots were periodically checked to detect any other pest infestations which might need to be controlled. Observations of fruit loss before and after each bug release were taken from 10 plants each from the two marked sections of each plot. Detailed plant mapping was conducted during the season and before harvest to assess the number of fruit retained in every fruiting position, open and missing bolls and non-harvestable bolls. Plant height and number of nodes were measured during each of four observations periods. The two-row sections of each plot were later hand-harvested and ginned to obtain yield parameters. Lint samples from plots were analyzed for fiber quality. All data were subjected to statistical analysis using the General Linear Models (GLM) Procedure (SAS Institute 2003). Treatment means were separated by Fisher's protected LSD at the $P \leq 0.10$ level.

2.3 Results

2.3.1 Pre-bloom Study 2005

Results of this study are presented in two sections. The growth phenology and fruiting section examines different plant growth parameters and fruiting profile during the active crop growth stage. The second section presents an assessment of the effect of insect release treatments on in-season crop growth and fruiting profile affecting the lint yield and fiber quality parameters.

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2.3.1.1 Growth Phenology and Fruiting

2.3.1.1.a Plant Height: There was no significant variation observed in plant height among treatments by sampling date except in the second date (Fig. 2.1). On 20 July, plant height in bug-release treatments was 4.45 cm lower (df= 3,12; F=11.16; P=0.0009) than in control treatments. Overall, plant growth increased linearly from early squaring to peak bloom.

2.3.1.1.b Number of Total Nodes: Average number of nodes did not vary among treatments by sampling date except on 20 July (Fig. 2.2). On 20 July, number of nodes in bug-released treatments were significantly lower (df=3,12; F=8.12; P=0.003) than in the two control treatments. The average number of nodes increased linearly during the 5-week sampling period, with approximately 13 to14 nodes per plant at the early blooming stage on 6 August.

2.3.1.1.c Fruit Retention: Total number of fruiting positions per plant increased linearly during the five weeks of plant monitoring. Although total numbers of fruiting positions were lower in bug release treatments on 20 July (df=3, 12; F=6.79; P=0.006) and 27 July (df=3, 12; F=5.20; P=0.01), number of fruiting positions did not vary across treatments in the post treatment count (6 August) after all insect release treatments had been applied (Fig. 2.3A). Pre-treatment fruit set (7 July) was similar ($\approx$ 4 squares per plant) in all treatments and fruit retention was 100 percent (Fig. 2.3B, C). The first insect release event (7 July) did not inflict considerable damage to fruit (<5 percent fruit loss) although the first post-treatment fruit retention estimate (13 July) began to show differences between the bug-release and control treatments. Fruit retention varied significantly (df=3,12; F=6.29; P=0.008) between bug-release and control treatments

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after the second release of bugs on 13 July. Fruit retention rate was similar between 1PP

and 3PP treatments until the last post-treatment count on 6 August (df=3,12; *F*=11.61;

P>0.007) (Fig. 2.3B, C).

Effects of bug-release treatments were apparent only after the second bug release

(Fig. 2.3C). Percent fruit loss was negligible on the first two sampling dates (7 July and

13 July). On 20 July, there was wide variation (df=3,12; *F*=32.22; *P*<0.0001) in percent

fruit loss between the bug-release and control treatments. The final post-treatment

observation on 6 August reflected the cumulative effect of the three releases of *Lygus*

bugs in which percent fruit loss was greatest on 3PP (48%) followed by 1PP (32%), NC

(17%), and SC (10%); the NC and SC treatments were not different from each other.

2.3.1.1.d Pre-harvest Plant Height and Total Node: No significant difference in

plant height was observed between treatments (Fig. 2.4). The number of total vertical

nodes per plant increased with increase in percent fruit loss (Figs. 2.3C and 2.4). Both

bug release treatments had higher numbers of vertical nodes (1.48 and 2.05 nodes more)

than in the SC treatment plots. Total number of sympodial nodes generally followed the

total number of nodes in the plant, with a greater number of sympodial nodes in 3PP

compared with other treatments (Fig. 2.4).

2.3.1.1.e Pre-harvest total Fruit Retention: There was significant variation in

number of total harvestable bolls (df= 3, 12; F=5.27; P=0.01) and missing bolls (df= 3,

12; *F*=5.98; *P*=0.009) between treatments (Fig. 2.5). However, the total number of non-

harvestable bolls was similar in all treatments. The greatest number of harvestable bolls

(9.23 per plant) was found in the SC treatment while the lowest numbers (6.38 per plant)

were observed in 3PP. Pre-harvest plant mapping (Fig. 2.5) showed that 3PP lost a

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greater number of bolls (2.85 per plant) compared with other treatments (0.96 in NC, 2.15 in 1PP). A nearly three-boll per plant difference between SC and 3PP plots corresponded with the greater number of missing fruits in 3PP plots compared with that in SC plots during the fruiting period (Figs. 2.3B and 2.5). The approximate three boll deficit in 3PP compared with that in SC was due to two more missing fruits and 1 more immature boll per plant.

2.3.1.1.f Pre-harvest Fruit Retention by Nodal Position: Pre-harvest plant mapping (Fig. 2.6) showed a considerable difference in number of harvestable bolls in vertical nodes among treatments. In particular, plants in 3PP had 50 percent missing bolls in the first fruiting position compared with 27% in SC or NC plots. Averaged across all treatments, vertical positions (first positions) contributed 74% of the total harvested bolls while second and third positions contributed 23 and 3%, respectively.

2.3.1.2. Yield and Fiber Quality

2.3.1.2.a Lint Yield: The final yield data from the harvestable bolls showed differences (df=3,12; F=6.75; P=0.006) among the treatments having $Lygus$ versus other treatments with few or no bugs (Fig. 2.7). Considering total lint yield, the highest yield was found from SC plots (1121 kg/ha) whereas the lowest were from 1PP (861 kg/ha) or 3PP (895 kg/ha). There was no significant difference in yield between 1PP and 3PP treatments. The yield difference between the SC and 3PP treatments was approximately 226 kg/ha, which indicates the effects of $Lygus$ damage on final yield. The results showed about 38 percent more fruit loss (Fig. 2.3C) in 3PP as compared to SC and a reduced number (2.8 bolls/per plant) of harvestable bolls (Fig. 2.5). This reduced number of bolls

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(2.8 per plant) translated into a final lint yield reduction of about 226 kg/ha (Fig. 2.7).

Further, we separated the yield contribution from first fruiting positions from the

remaining positions. It is evident from the results that the yield from first fruiting

positions was considerably reduced (df=3,12; F=7.02; P=0.005) and proportionally

corresponded to the actual yield reduction due to treatments with bugs. The average yield

from first position bolls was reduced by 228 kg/ha in 3PP as compared to the SC

treatment. So it is evident that plants were unable to significantly compensate for the bug

infestation at the prevailing condition.

 2.3.1.2.b Fiber Quality: Fiber quality parameters including micronaire,

uniformity, and elongation did not vary among treatments (Table 2.2). However, fiber

length (F=4.76; P=0.02) and fiber strength (F=5.50; P=0.02 respectively) were greater

for 3PP treatment compared with other treatments.

2.5.2. Early-bloom Study 2005

2.3.2.1 Growth Phenology and Fruiting

 2.3.2.1.a Plant Height: Plant height increased linearly during the early bloom

period, with an average of 17.5 cm increase in height from pre-release to one week after

the final *Lygus* augmentation treatment release (Fig. 2.8). Plant height did not generally

vary among treatments during this period, but 3PP plants were 2.75 cm taller than SC

plants after three consecutive bug augmentation treatments were deployed.

 2.3.2.1.b Number of Total Nodes: Number of vertical nodes per plant increased

linearly during the early bloom period, with 4.7 more nodes added to plant from pre-

release to one week after the final *Lygus* augmentation treatment release (Fig. 2.9).

However, the total number of vertical nodes did not vary significantly between treatments after three consecutive augmentations of *Lygus* bugs.

       2.3.2.1.c Fruit Retention: The total number of fruiting positions per plant increased linearly during the three-release *Lygus* augmentation period (Fig. 2.10A). Number of total fruiting positions did not generally differ between treatments (Fig. 2.10A). Total number of fruiting positions averaged across treatments on first sampling date (16 July) was approximately 12 per plant, which increased to 22 per plant after four weeks of the early flowering period (Fig. 2.10A). Pre-treatment fruit retention (≈98%) was similar across treatments, but the effect of *Lygus* augmentation was apparent following the first release (Fig. 2.10C). The post-treatment count after the first release indicated that the total number of fruits per plant in bug-release treatments was lower than that in SC, but the difference was not significant (Fig. 2.10B). However, the percent fruit loss in bug-release plots was significantly higher than that in either control treatments one week following the first bug release (df=3, 12; *F*=11.00; *P*=0.0009; Fig. 2.10C). The subsequent two bug releases had an even greater impact on fruit retention and percent fruit loss in bug-release plots than in the control plots. After two consecutive releases, percent fruit loss increased to 27% in 3PP as compared with 8% loss in SC (df=3,12; *F*=16.41; *P*=0.0002). The cumulative effect of three consecutive releases resulted in 35 percent fruit loss in 3PP plots while 10% loss occurred in SC plots (df=3,12; *F*=24.40; *P*<0.0001). Thus, there was about 10% fruit shed attributed to environmental or plant physiological factors in addition to the damage inflicted by augmented *Lygus* bugs.

2.3.2.1.d Pre-harvest Plant Height and Total Node: Average plant height and number of nodes recorded before harvest did not vary between treatments (Fig. 2.11). Across four treatments, average plant height during that period was 62.5 cm with 19 nodes per plant.

2.3.2.1.e Pre-harvest Fruit Retention: Although there was no difference (F=1.22; P=0.34) among treatments in number of harvestable bolls (Fig. 2.12), SC plots (12.33 bolls/plant) had two more bolls per plant than 3PP plots (10.18 bolls/plant). Pre-harvest number of missing fruits increased linearly as *Lygus* numbers increased and followed the trend of the in-season fruit loss patterns (F=5.75; P=0.01; Figs. 2.10C and 2.12). Treatments with 3 bugs per plant had the greatest number (6.55 per plant) of missing bolls as compared to 3.27 bolls per plant lost in the sprayed control (SC). About 50% more missing fruit was observed in the highest bug-release (3PP) treatment in contrast to sprayed control. Although statistically significant, number of non-harvestable bolls was very low for all treatments. Nevertheless, 3PP had 0.4 non-harvestable bolls per plant which would likely cause a significant impact on yield.

2.3.2.1.f Pre-harvest Fruit Retention by Nodal Position: Averaged across all the treatments, first and second fruiting positions contributed 62 and 32 percent to the total harvestable bolls, respectively. Significant variation was observed between bug-released and control treatments for harvestable bolls and missing fruits at both the first and second positions (Fig. 2.13). For example, 3PP had 40 and 39% missing fruits in first and second positions, respectively, whereas SC had 22 and 19% missing fruits in first and second positions, respectively (Fig. 2.13). There was no difference in harvestable bolls or missing fruits in the third fruiting position between treatments.

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2.3.2.2. Yield and Fiber Quality

   2.3.2.2.a Lint Yield: Total lint yield varied from 1,110 kg/ha in SC plots to 959

kg/ha in 3PP plots, approximately a 15 percent reduction in yield between the sprayed

control and the greatest level of bug release (Fig. 2.14). There was no difference in yield

between NC and 1PP treatments which might be due to natural infestation or predation of

bugs in 1PP plots. The similarity in yield between 1PP and NC treatments corresponded

with the similarity in cumulative fruit loss between the same treatments (Fig. 2.10). These

data suggest that the plant was unable to fully compensate the 151 kg/ha lint lost due to

insect-induced fruit loss when 3 *Lygus* bugs per plant were introduced during the first

three weeks of flowering.

   Further examining the lint yield by fruiting position, the yield contribution of first

position bolls in SC treatment was approximately 73% whereas the first position

contributions in 3PP and 1PP treatments were 59 and 69%, respectively (F=6.72;

P=0.006). Therefore, it is evident from this observation that there existed much higher

contributions from second and third position bolls to total lint yield in insect-augmented

treatments compared with that in the SC treatment (F=4.18; P=0.03; Fig. 2.14). The

contribution of second and third position bolls towards total lint yield ranged from 40%

in 3PP to 27% in SC plots. This indicates that plants in the 3PP treatment contributed to

the total lint yield through horizontal contribution by as much as 13%, but this level of

compensation was not sufficient to fully compensate the total insect-induced fruit loss.

   2.3.2.2.b Fiber Quality: Fiber quality parameters were not generally affected by

Lygus augmentation treatments, except for fiber length which was greater than other

control treatments (Table 2.2).

2.3.3 Pre-bloom Study 2006

As stated in the method section, the 2006 pre-bloom study was identical to that conducted in 2005. However, more plant phenological data were obtained in 2006 than 2005. In this thesis, only growth phenology and fruiting data are presented as lint yield and quality data will not be available until the end of 2006.

2.3.3.1 Growth Phenology and Fruiting

2.3.3.1.a Plant Height: Plant height did not vary between treatments until 1 week after the third augmentation of *Lygus* bugs (Fig. 2.15). On the fourth sampling date (22 July), plants in bug-released treatments were about 7.5 cm shorter than in the SC treatment plots ($F=7.23$; $P=0.005$).

2.3.3.1.b Number of Total Nodes: Total number of vertical nodes increased linearly during the first four weeks of squaring as the augmentative releases of *Lygus* bugs were deployed (Fig. 2.16). The average number of nodes per plant varied between treatments in only the third sampling date (of four) (Fig. 2.16). However, the significant difference observed on 13 July did not seem to have any biological significance. Overall, plants gained about five nodes in four weeks.

2.3.3.1.c Fruit Retention: Fig. 2.17A suggests the number of fruiting positions considered in evaluating the percent fruit loss over the sampling period. The pre-treatment count showed that plants across treatments had 1 fruiting position per plant, but the total fruiting positions per plant increased rapidly and plants added >10 fruiting positions in four weeks (Fig. 2.17). Total number of fruiting positions did not vary significantly across treatments after the three augmentative releases were completed.

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However, the rate of fruit retention varied significantly (F=5.85; P=0.01) between treatments after the three consecutive augmentative releases (Fig. 2.17B). Fruit retention dropped by 18 and 34 percent in 1PP and 3PP plots, respectively, compared with that in sprayed control. Fruit retention between SC and NC treatments or between the two bug-release treatments was not different.

Considerable variation in percent fruit loss was observed among treatments immediately after the first augmentative release of bugs (Fig. 2.17C). In the first post-treatment count, 3PP showed a significantly higher fruit loss compared with the other three treatments. After two consecutive releases, both bug-release treatments had a higher rate of fruit loss (F=14.23; P=0.0003) compared with the two control treatments (SC and NC). After three consecutive releases, 3PP and 1PP had 30 and 19% fruit loss compared with only 5% loss in NC and SC plots (F=24.91; P<0.0001).

2.3.3.1.d Fruit Retention by Nodal Position: Total fruit retention after three consecutive bug releases varied across treatments (Fig. 2.17). Of total fruits retained per plant, 52 to 66% was in the first, 29 to 36% in second, and 4 to 7% in the third fruiting positions (Table 2.3). Percent fruit loss varied significantly (F=24.91; P<0.0001) between treatments on final sampling date (Table 2.3). As high as 31% fruit loss was recorded for 3PP treatment compared to 5% in SC and 6% in NC treatments. When percent fruit loss was separated by nodal position, all treatments lost fruit from the first position, but 1PP and 3PP also lost an additional 8 to 9% from the second position. Fruit loss in the third fruiting position was negligible.

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2.3.4 Early-bloom Study 2006

2.3.4.1 Growth Phenology and Fruiting

2.3.4.1.a Plant Height: Plant growth increased at a decreasing rate with no

significant increase in plant growth after the third consecutive release of *Lygus* bugs (Fig.

2.18). Plants were not homogeneous in height prior to the first release, but there were no

plant height differences between treatments after the first release (Fig. 2.18).

Nevertheless, plants in NC plots were generally slightly taller than in other plots. This

increase in height in NC plots is believed to be due to sampling bias for selecting taller

plants as sampling in NC plots was inadvertently not restricted to the two 4.04 m marked

sections as for other plots. Overall, plants grew by 10 cm during the four weeks period,

which was regarded as a slow growth during flowering stage.

2.3.4.1.b Number of Nodes: Because plants were somewhat stunted (Fig. 2.18),

number of vertical nodes increased linearly with a relatively flat slope (Fig. 2.19). As

with plant height, pre-treatment counts showed variation in nodes between treatments but

the difference was not significant in any of the post-treatment counts. Plants added only 2

to 3 nodes in a four week period. This slow growth was mainly due to inadequate

irrigation, hot and dry weather with no rainfall, and a root-knot nematode infestation in

the test field.

2.3.4.1.c Fruit Retention: A greater number of fruiting positions were observed in

NC plots during the first two sampling dates. However, there were no differences in total

fruiting positions between treatments during the last post-treatment observation (Fig.

2.20A). Although the fruit retention rate did not vary between the treatments during the

last post-treatment observation, plants in SC plots had 3 more fruiting positions than in

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the bug-release treatment plots (Fig. 2.20B). Percent fruit loss was higher in both bug-release treatments compared with that in control treatments after two consecutive bug releases. However, the cumulative fruit loss during the last post-treatment inspection showed that NC, 1PP and 3PP treatments all had significantly greater percent fruit loss than SC (F=15.63; P=0.0002; Fig. 2.20C). The cumulative effect of bug release caused 34% fruit loss in 3PP compared with 15% in the sprayed control treatment (SC).

 2.3.4.1.d Fruit Retention by Nodal Position: Total fruit retention after three consecutive bug releases did not vary significantly across treatments as presented in Fig. 2.20B. Of total fruits retained per plant, 65 to 76 percent was in the first, 20 to 28% in the second, and 4 to 9 percent in the third fruiting positions (Table 2.3). Percent fruit loss varied significantly (F=2.65, P=0.09) between treatments on the final sampling date (Table 2.3). As high as 34% fruit loss was recorded for 3PP treatment compared to 15% in SC plots. When percent fruit loss was separated by each nodal position, all treatments lost fruits from all three fruiting positions. Percent fruit losses were 5 to 18, 7 to 13, and 1 to 3 percent from the first, second, and third positions, respectively.

2.4 Discussion

2.4.1 Plant Height and Number of Nodes

 Plant height of cotton crop is a variable growth parameter which changes with time and in response to inputs and/or stresses. In our two-year study, there were no significant differences observed in plant height between bug-treated and untreated control plants. However, some variation in plant height was recorded during four weeks of in-season sampling. Plants may be shorter in a particular week either due to pest infestation

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or because of insufficient water. But the next week they are likely to be similar to the control plants if stresses do not persist. There was no particular trend observed for plant height as an effect of *Lygus* bug infestation in the two different studies for years 2005 and 2006. A stable measurement of plant height can be recorded during pre-harvest sampling as plants stop growing in that point. Pre-harvest observation of plant height and number of nodes can provide a proper assessment of plant response to bug infestation. This is particularly important in studying compensatory responses of the cotton plant, as any increase in number of nodes may have direct influence on final lint yield of a plant.

In the pre-bloom study of 2005, a slight increase in plant height and number of nodes in 3PP treatment was observed during pre-harvest plant mapping as compared to SC treatment (Fig. 2.4). This trend was not observed in early-bloom study in the same year. Reports on plant height and number of nodes in any compensation study are variable and depend on the approaches and input level. Although it is a commonly accepted fact that plant height increases in response to *Lygus* bug infestation or simulated early damage of floral structures (Holman and Oosterhuis 1999, Teague et al. 2001, Bednarz and Roberts 2001), reports of no significant increase in plant height (Montez and Goodell 1994, Baugh et al. 2003) and reduction in plant height (Hanny et al. 1977) were also found from previous works. In aforementioned works, early-season floral buds were removed either manually or by plant bugs. Again number of bugs, frequency of releases and crop growth stage at the time in which releases are made can give variable results on compensation factors found in cotton.

Generally, the number of nodes follows a similar trend as plant height, which might change due to *Lygus* bug infestation. In our studies, no significant increase in

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number of nodes was observed between bug-released and sprayed control treatments. Bednarz and Roberts (2001) reported an increase in number of fruiting nodes as an effect of manual removal of early floral buds in cotton. Holman and Oosterhuis (1999) showed that a tarnished plant bug infestation in the early growth stage is associated with an increase in plant height of cotton but no effect in number of sympodia was recorded. Baugh et al. (2003) in a compensation study in the Texas High Plains area reported that there was a slight increase (<1) in the number of nodes on plants having manually removed fruit as compared to untreated plants.

2.4.2 Fruit Retention and Loss

Fruit (square) retention in cotton is regarded as a basis for management decisions regarding an insect infestation, particularly *Lygus* bugs. Generally, 75 to 80% square retention in the early growth stage of cotton is considered as the threshold in various cotton growing states in United States (Layton 2000). However, this retention percentage may not stay stable over the growing season. Cotton being an indeterminate crop adds fruit throughout its growing season as long as required temperature and other growth factors are in place. Above that, 25 to 50% of the fruit are believed to be shed physiologically from a cotton plant in nature (Hall 1958). So, it is difficult to determine a constant fruit retention percentage at a particular growth stage. Provided that growth inputs are not limited, early square retention in cotton can be tracked and assessed in relation to insect related losses by comparing with insecticide treated plots. This is possible because pre-bloom square loss is mostly associated with an infestation of insect pests rather than physiological causes (Stewart and Sterling 1989).

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Fruit retention in cotton can be variable as it depends on the addition of new fruit and losses due to insect or other physiological causes. In our study, variable fruit retention was observed among treatments. This variation was more prominent as the number of releases of *Lygus* increased. This indicates that there was a considerable effect of the *Lygus* bugs on treated plots as compared to no-release plots. Assuming other growth inputs are similar across the treatments, percent fruit loss should fairly well reflect the extent of damage by released insects in the crop. In all our studies, percent fruit loss recorded during the final sampling date (after three consecutive releases of *Lygus* bugs) was considered as the standard to differentiate between bug-released and control treatments. In 2005, the highest percent loss was observed in 3PP treatment which was about 48% (Fig. 2.3 C) and 35% (Fig. 2.10 C) for the pre-bloom and early-bloom experiments, respectively. The following year (2006), 3PP treatment in the pre-bloom experiment had a 30% (Fig. 2.17 C) fruit loss while a 34% (Fig. 2.20 C) loss was observed when bugs were released in the early-bloom crop stage. In both experiments (pre-bloom and early-bloom) conducted in 2005 and 2006, sprayed control plots had significantly less fruit loss which ranged from 5 to 14% on the final sampling date.

In studying the compensation ability of cotton to early fruit loss from insect pests, percent fruit loss during the growing season was adopted as the standard measure. Researchers often report the percent fruit loss in bug-infested treatments versus no-bug or spray treatments as how much yield difference was realized from the differential fruit loss. Researchers use either mechanical destruction of early fruiting structures or actual insects in order to establish a fruit loss treatment. Although there is certain level of control and predictability in achieving desired level of square loss in mechanical

destruction, it is uncertain and variable in cases of artificially created bug infestations. However, our results are in congruence with previous work by Teague et al. (2002) in Arkansas. They found a 38% fruit loss when tarnished plant bugs were released at 3 bugs/plant for three consecutive weeks starting from first observed squaring. Whereas, a low (9%) fruit loss was observed in sprayed control treatment. Holman and Oosterhuis (1999) used tarnished plant bugs to cause early square loss and found 33% square abscission at first sympodial fruiting position in bug-release treatment as compared to 5% in control treatments by first flowering in cotton.

Experiments with actual bug populations have some limitations in achieving differential levels of fruit loss. Again, the loss may not be proportionate to the number of bugs, which was observed in our study. Damage from 3 bugs/plant did not necessarily cause three times more damage as compared to damage with 1 bug per plant. Presence of predators, such as *Geocoris* spp., ants and spiders might be a challenge in establishing the artificial bug infestation treatment, which was also observed in our study. It is not yet documented how long laboratory reared *Lygus* nymphs can survive under field conditions and to what extent they can inflict damage. Researchers have already agreed upon the fact that manual removal of floral buds is not directly comparable to damage caused by plant bugs (Sadras 1995, Teague et al. 2001). Therefore, artificial infestations by plant bugs are the best choice in order to evaluate the early-season square loss and compensation ability. Further work on fruit structure preference of *Lygus* bugs and knowledge of feeding duration of bugs to cause actual loss will strengthen research results.

Pre-harvest plant mapping is helpful in understanding the fruiting profile of plants in an individual treatment. Significantly fewer open bolls were present in the 3PP treatment as compared to SC treatment in the pre-bloom study of 2005 (Fig. 2.5). In contrast, more missing bolls were found in the 3PP treatment as compared to the SC treatment in the same study. Considering these results from pre-harvest plant mapping for the pre-bloom 2005 experiment, it can be inferred that there would be a difference in final yield between 3PP and SC treatments. This inference was later substantiated by our final yield data. However, this yield difference may be due to heavier and larger boll size or more number of fruits in secondary positions in bug-treated plants as compared to non-infested plants. We recorded the number of bolls from secondary positions and its contribution to total yield but boll weight and size was not taken into account. About 74% of the harvestable bolls were present in first position followed by 23% and 3% in second and third positions in the pre-bloom 2005 study (Fig. 2.6). In the case of the early-bloom 2005 experiment, the proportion of open bolls in each nodal position was 63%, 30% and 7% for first, second and third position (Fig. 2.13), respectively. Pre-harvest fruit retention data for 2006 studies are not yet available, but similar analyses as for 2005 data will be conducted when they become available.

2.4.3 Yield

Lint yield is the mostly commonly used parameter for determining compensation in cotton for early-season fruit loss due to insect pests. Although work on compensation studies have been conducted for both 2005 and 2006, only the first year's yield data are available for analysis at this time. In pre-bloom study of 2005, there was a significant

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yield reduction (225 kg/ha) in 3PP treatment when compared to the SC treatment (Fig. 2.7). This reduction was primarily due to first position fruit loss on plants in plots augmented with plant bug releases. No significant contribution from second or third position fruits was recorded which could have compensated the yield.

In the 2005 early-bloom study, yield differences between the 3PP and SC treatments were lower than the 2005 pre-bloom study (Fig. 2.14). Again, yield contribution from other than first position bolls was significantly higher in 3PP when compared to the SC treatment. The 1PP treatment was similar to the NC treatment in terms of total yield. There was no significant variation in percent fruit loss between these treatments (1PP and NC). It appears that plants receiving bugs tried to compensate for the loss to some extent either by adding more fruit in secondary positions or by increased the weight of first position bolls.

Based upon the lint yield from the two 2005 experiments, it can be concluded that timing of bug infestations may be crucial for cotton plants being able to compensate for losses. Another possible reason for the compensation difference between the two experiments (pre-bloom and early-bloom) could be the level of input or general field conditions. Plant parameters from these two studies show that plants on the early-bloom study were more vigorous in growth (higher numbers of fruiting nodes, fruiting positions and open bolls) as compared to the pre-bloom experiment. Therefore, it may be speculated that the early bloom test was more likely to show a significant compensation in lint yield compared to the plants in pre-bloom study that were stressed due to wind, temperature and moisture conditions. In the pre-bloom study, higher numbers of first position fruits were lost as a result of the bug releases occurring when the plants were in

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squaring stage. There were very few secondary position fruits present during that time. A major loss in first position fruit in bug released treatments is evident from the yield data for the 2005 pre-bloom study which was not compensated by the addition of more secondary position fruit or vertical growth of the plant. When *Lygus* bugs were released after a few weeks of squaring (early-bloom stage) or just before flowering, there was less damage to first position squares on the plants because more secondary position squares were available. Only a 13% reduction in total lint yield was realized in the 2005 early-bloom study while a 20% reduction was observed in the pre-bloom study. There was no significant difference observed in total lint yield when 1 bug/plant was released in the early-bloom stage of the crop. This indicates that cotton can fully recover the damage caused by 1 *Lygus* bug per plant under the prevailing conditions. Another indication of compensation in the 2005 early-bloom study was the increased lint yield resulting from second and other nodal positions.

Reduction in yield in response to insect injury in early growth stages may vary depending on the extent of fruit loss or the compensation ability of cotton crop. Stewart et al. (2001) studied compensation of cotton to early-bloom square loss by mechanical destruction of squares and found no significant difference in lint yield between control and moderate level (≈ 20 to 50%) of pre-bloom square removal treatments. Overcompensation by cotton for pre-bloom square loss was reported by Montez and Goodell (1994) where they found more yield in the square-removed treatment as compared to their control. An experiment by Teague et al. (2001) which has more resemblance to our study, showed significantly lower yield in bug-injury treatments compared to a protected control. Holman and Oosterhuis (1999) evaluated response of

cotton to pre-bloom square loss from a tarnished plant bug infestation and found decreased yield from first fruiting positions but more yield from second and outer positions in bug-injured treatment as compared to their control treatment.

The most common mechanism for compensation in cotton for early square loss is that the reduction in first position fruits triggers additional secondary or outer position fruits to compensate the overall yield (Baugh et al. 2003, Jones et al 1996). However, this mechanism may not always be true, particularly when resources are limited. In our 2005 pre-bloom study, the experiment was laid out in a field with water limited irrigation. In such a situation, it is not surprising to see cotton not fully compensating for a 30 to 40% square loss in its early growth stage. Plant response to early square loss by plant bugs not only depends on a plant's inherent ability but also on favorable growing condition and prevailing environmental factors (Holman and Oosterhuis 1999), which explains why there is so much variation in plant response reported by various researchers from different cotton growing regions. One other mechanism of compensation is production of heavier fruit in response to square removal in cotton. Jones et al. (1996) reported that early loss of fruiting structures causes the plant to produce more fruit in second or outer positions whereas fruit loss in a later stage of plant growth is associated with the production of heavier or larger bolls to compensate overall yield loss.

2.4.4 Fiber Quality

Fiber quality was not significantly variable among different treatments in pre-bloom and early-bloom studies conducted during 2005. However, a small increase in fiber length and strength was observed in 3PP treatment of the pre-bloom study (Table

2.2). It is not confirmed if this variability is due to the effect of the bug infestation. There is no documented underlying physiological reason which supports elongated or strong fibers from bug-infested plants. No difference in fiber strength and elongation was observed when squares were removed in early squaring stage of cotton crop (Terry 1992, Teague et al. 2001, Holman and Oosterhuis 1999).

2.5 Conclusions

Studies on ability of *Lygus* bug to cause differential fruit loss in cotton and crop's compensatory response in terms of final yield provides valuable information for decision making in pest management. Present research shows that cotton has some level of tolerance for low *Lygus* bug pressure. Growers can take advantage of this information by reducing early season insecticide applications against insect pests. Equivalent yield and no delay in plant maturity after low level of bug infestation were observed from our studies. From two years of research observations, it can be concluded that if proper cultivation practices are adopted, cotton has significant potential for compensating early fruit loss due to this insect pest under Texas High Plains conditions.
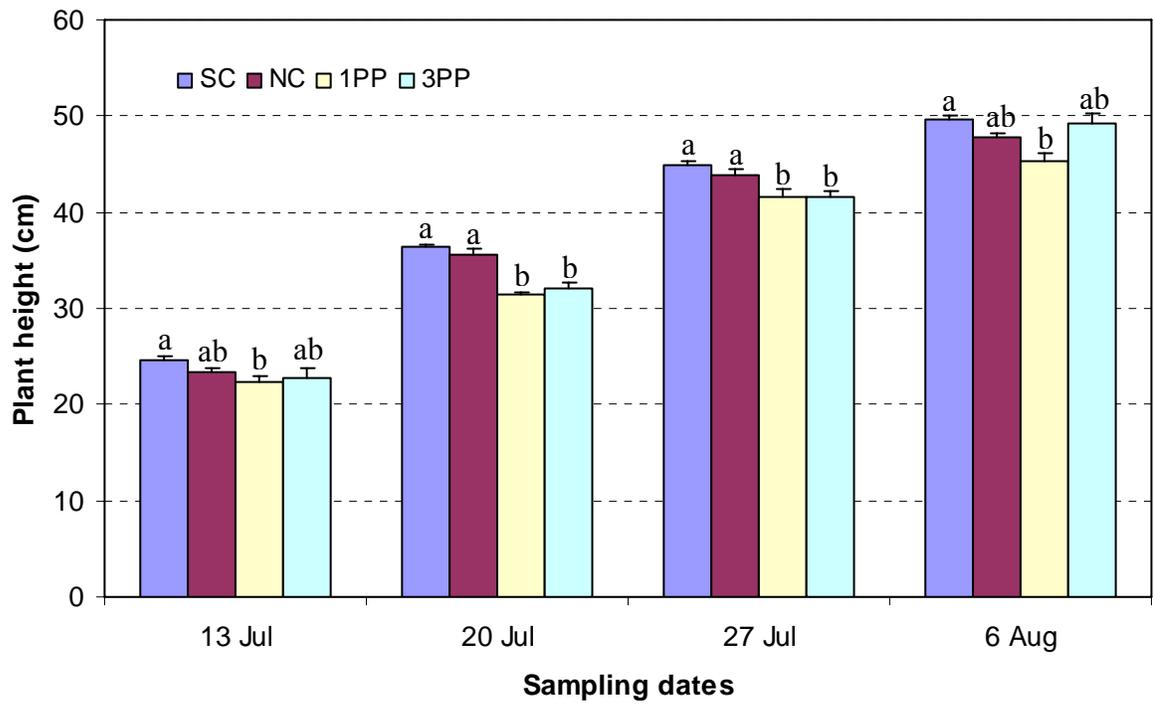
Fig. 2.1 Average plant height during in-season plant mapping: pre-bloom study 2005, Lubbock, TX. Treatments within date followed by the same letter are not statistically significant at P=0.10.
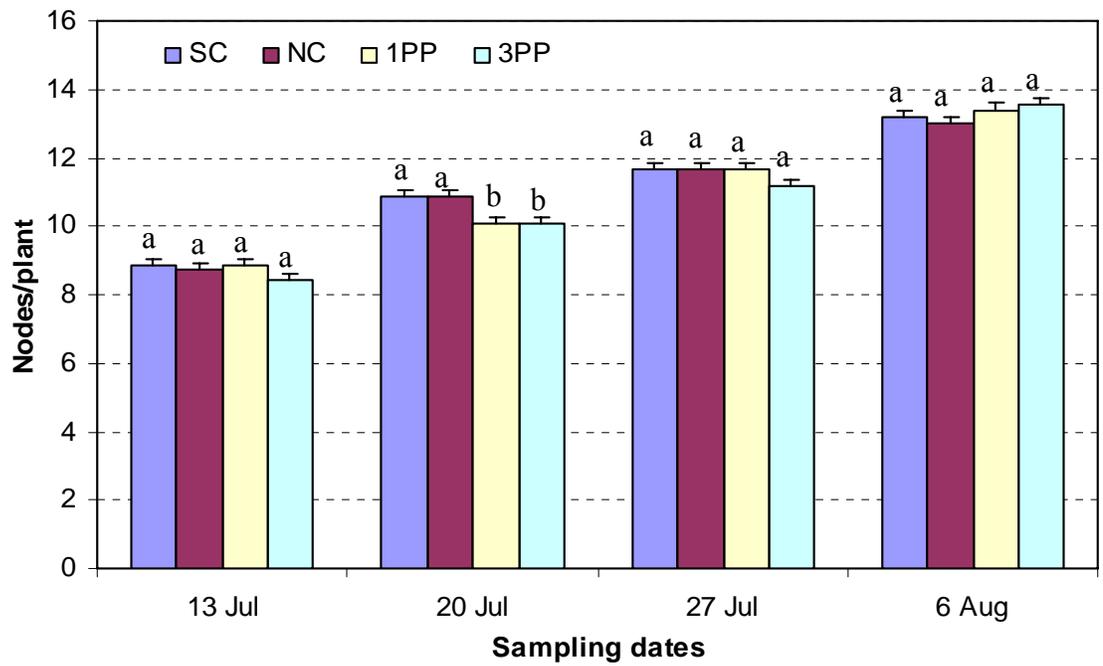
Fig.2.2 Average number of vertical nodes per plant during in-season plant mapping: pre-bloom study 2005, Lubbock, TX. Treatments within date followed by the same letter are not statistically significant at P=0.10.
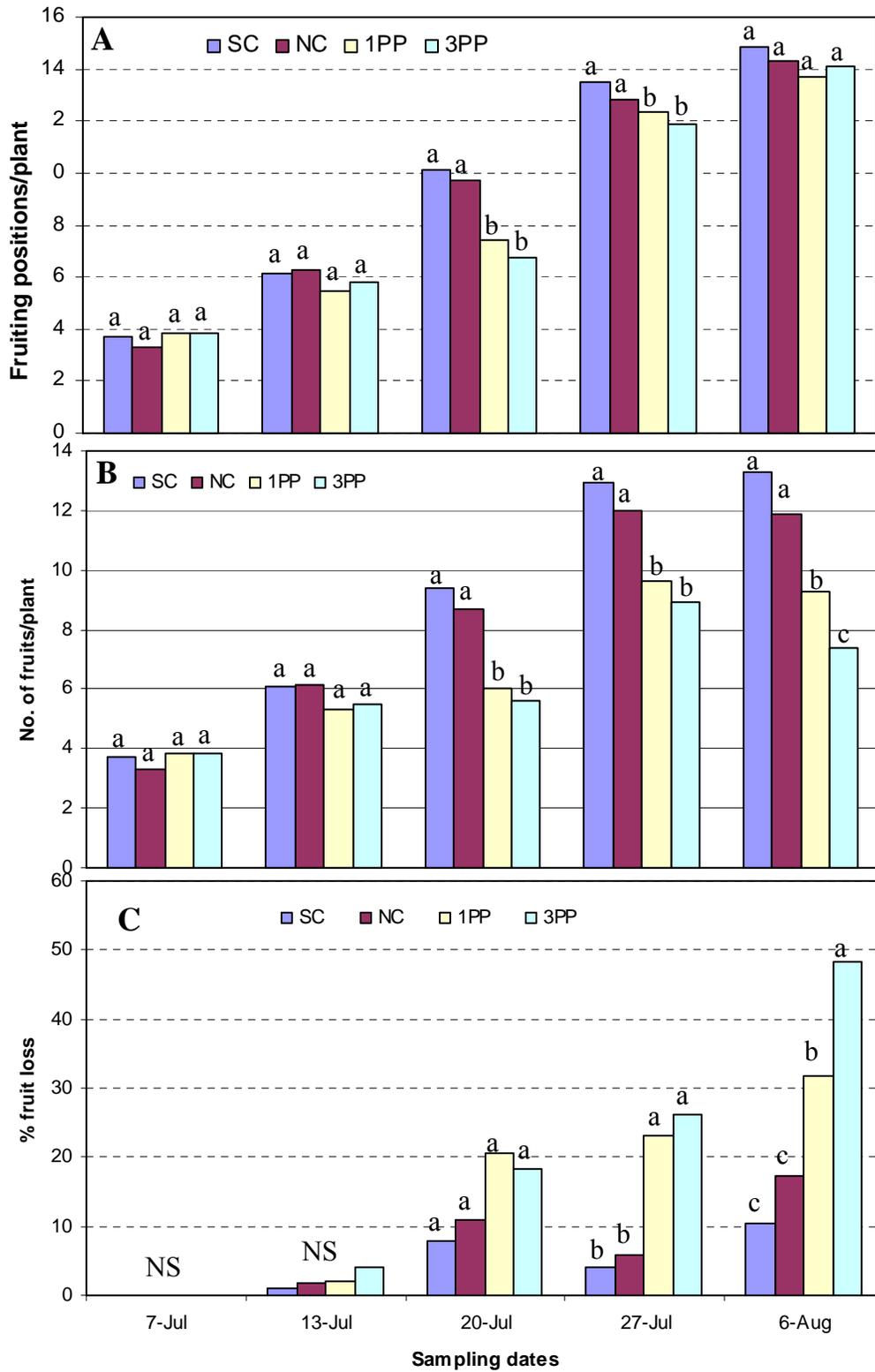
Fig.2.3 Fruit retention during in-season plant mapping: pre-bloom study 2005, Lubbock, TX.
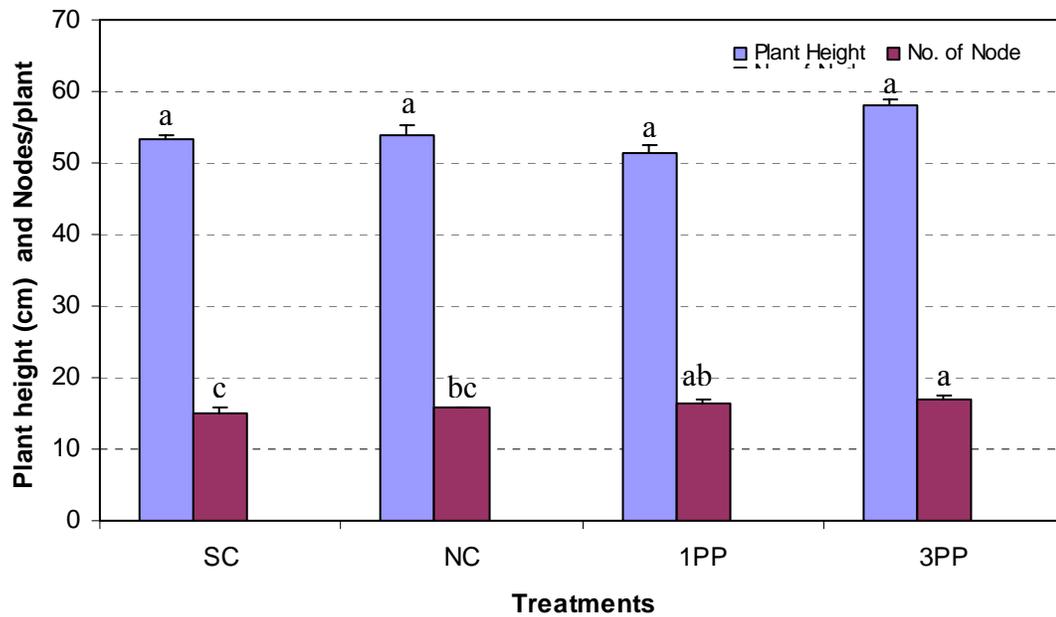
Fig. 2.4 Average plant height and total vertical nodes per plant at pre-harvest plant mapping: pre-bloom study 2005, Lubbock, TX. Treatments followed by the same letter are not statistically significant at P=0.10.
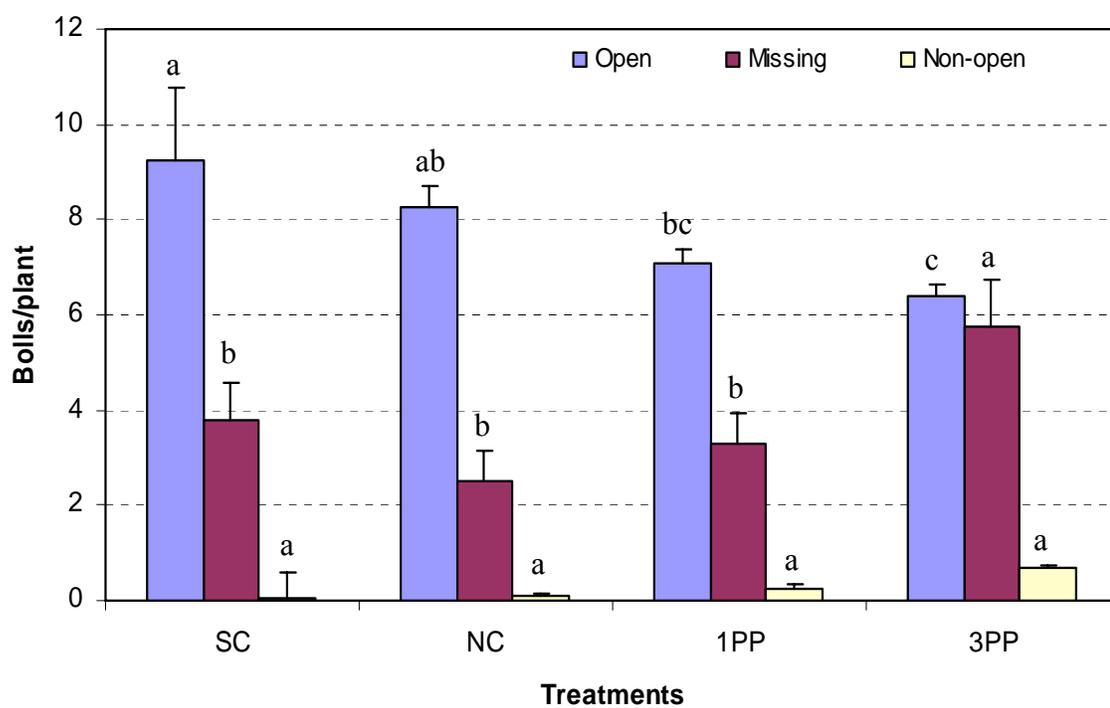
Fig. 2.5 Fruit retention at pre-harvest plant mapping: pre-bloom study 2005, Lubbock, TX. Treatments followed by the same letter are not statistically significant at P=0.10.
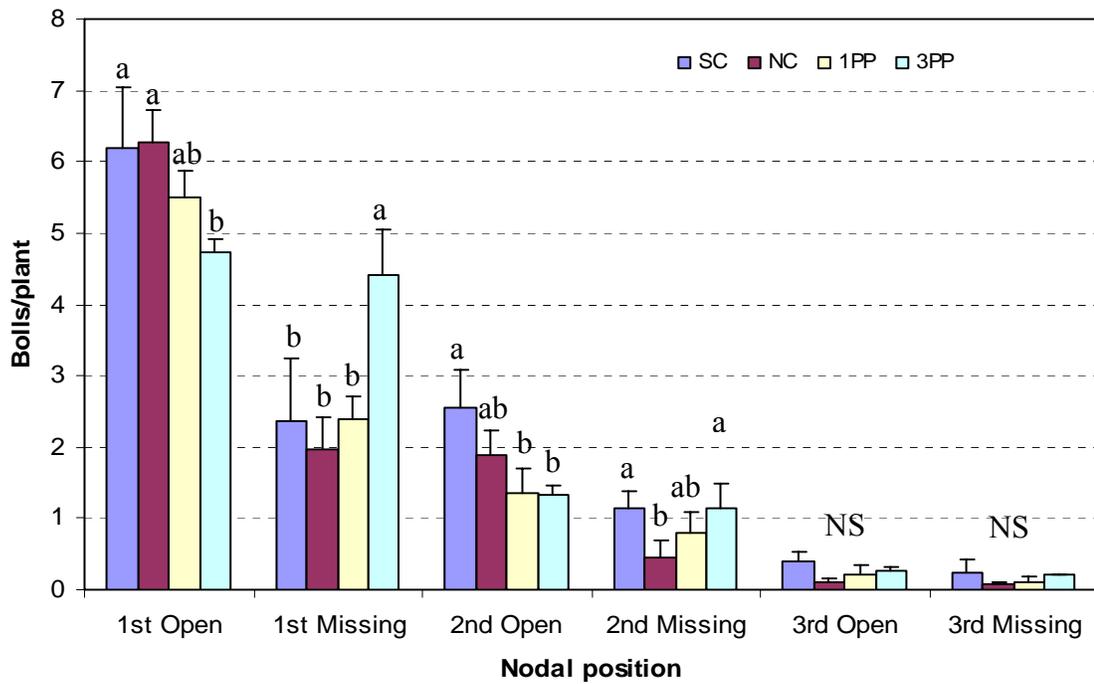
Fig. 2.6 Fruit retention by nodal position at pre-harvest plant mapping: pre-bloom study 2005, Lubbock, TX. Treatments within nodal position followed by the same letter are not statistically significant at P=0.10.
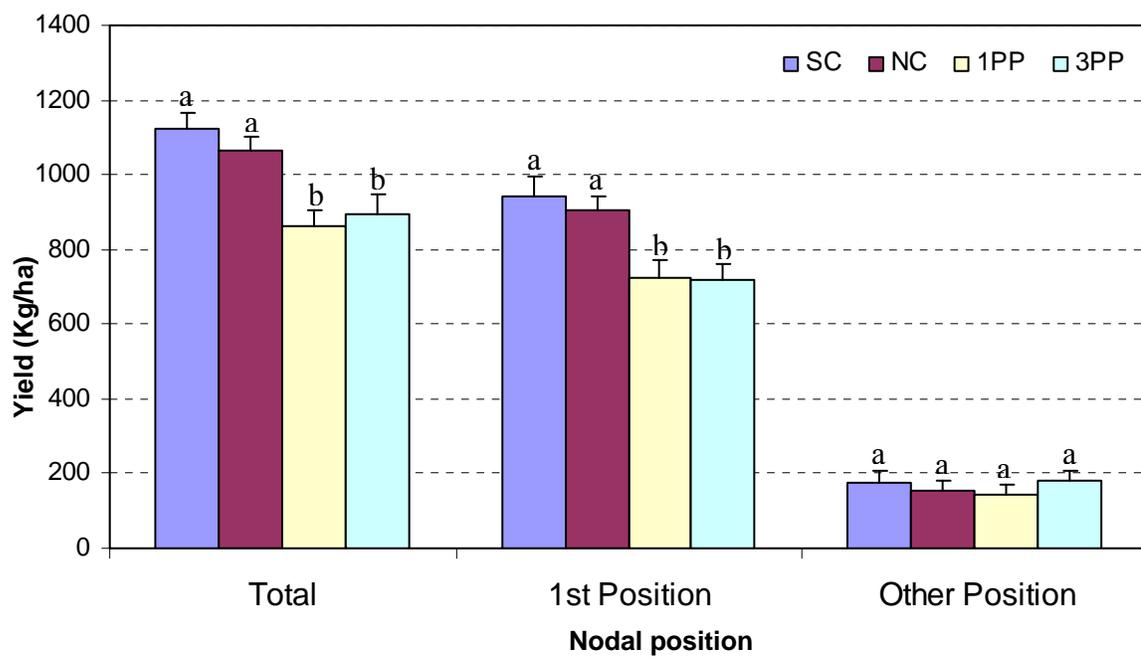
Fig. 2.7 Average lint yield in total and by position: pre-bloom study 2005, Lubbock, TX. Treatments followed by the same letter are not statistically significant at P=0.10.

Fig. 2.8 Average plant height during in-season plant mapping: early-bloom study 2005, Lubbock, TX. Treatments within date followed by the same letter are not statistically significant at P=0.10.

Fig. 2.9   Average number of vertical nodes per plant during in-season plant mapping:
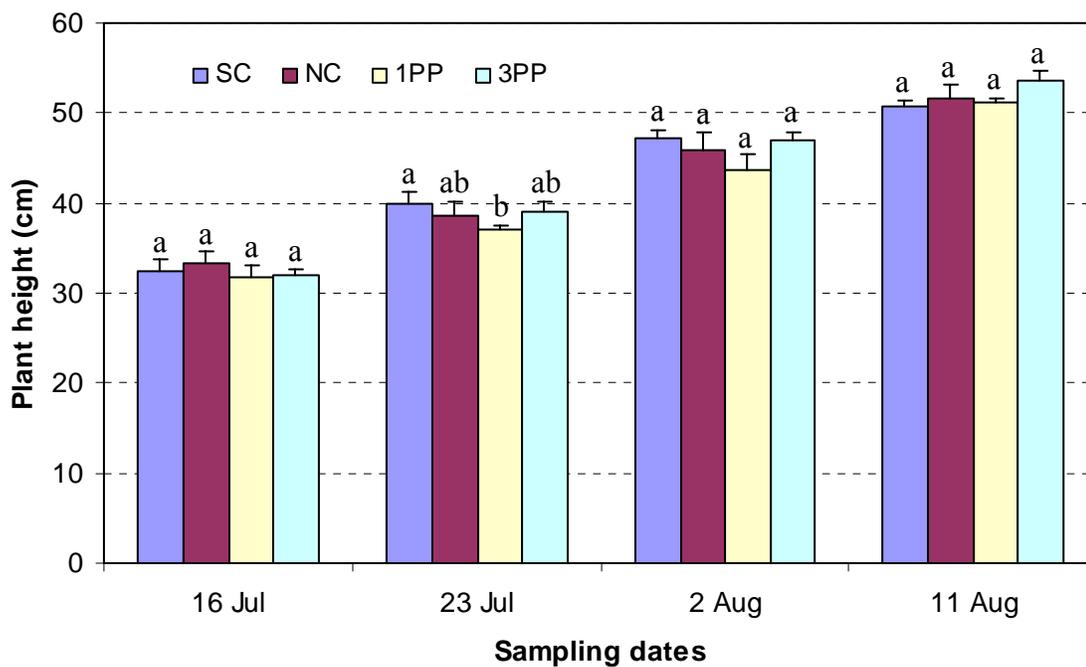early-bloom study 2005, Lubbock, TX. Treatments within date followed by the same
letter are not statistically significant at P=0.10.

Fig. 2.10 Fruit retention during in-season plant mapping: early-bloom study 2005, Lubbock, TX.
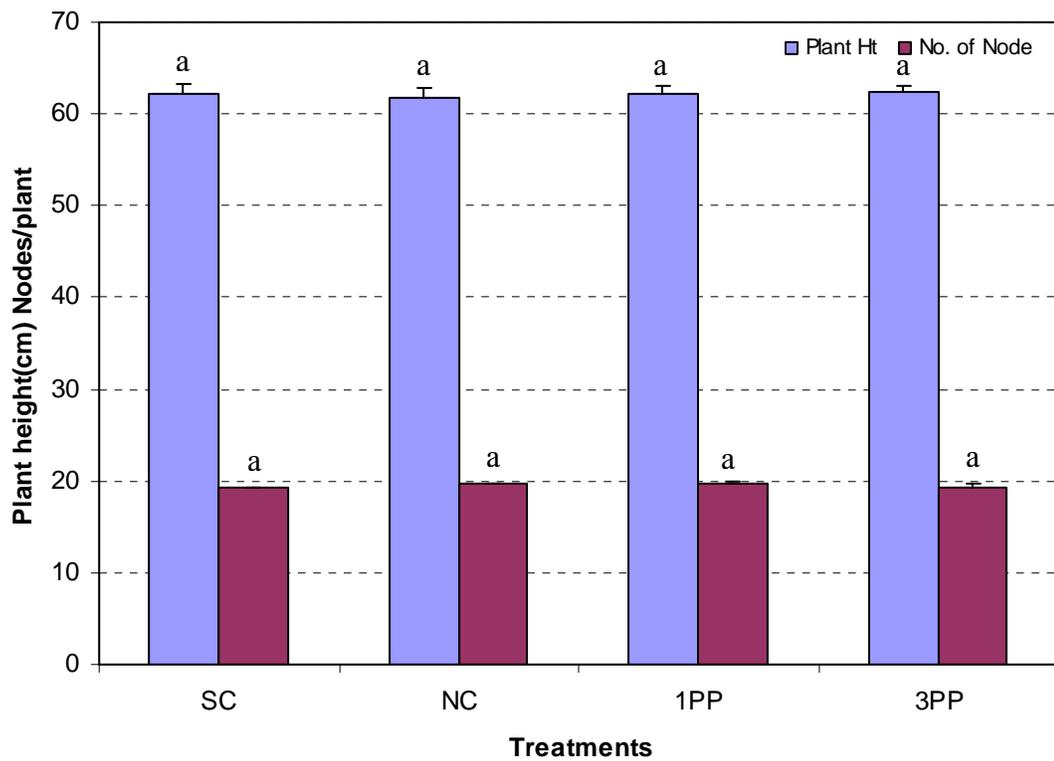
Fig. 2.11 Average plant height and total vertical nodes per plant at pre-harvest plant mapping: early-bloom study 2005, Lubbock, TX. Treatments followed by the same letter are not statistically significant at P=0.10.

Fig. 2.12 Fruit retention at pre-harvest plant mapping: early-bloom study 2005, Lubbock, TX. Treatments followed by the same letter are not statistically significant at P=0.10.
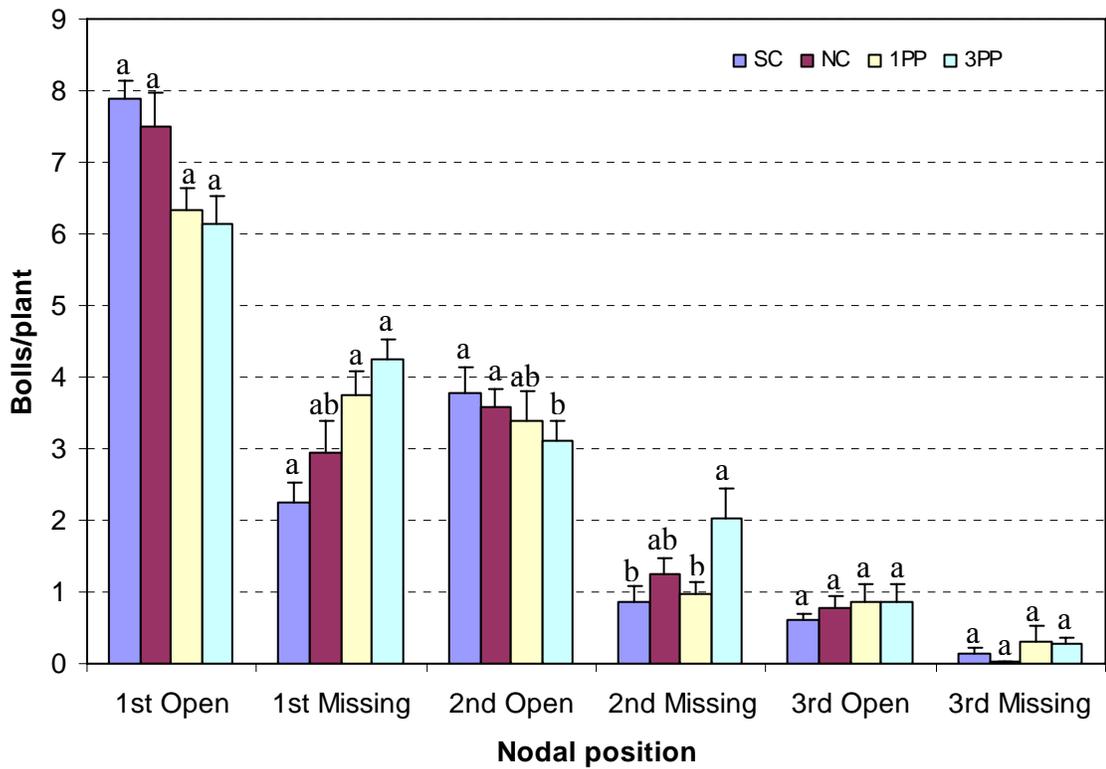
Fig. 2.13 Fruit retention by nodal position at pre-harvest plant mapping: early-bloom study 2005, Lubbock, TX. Treatments within each nodal position followed by the same letter are not statistically significant at P=0.10.
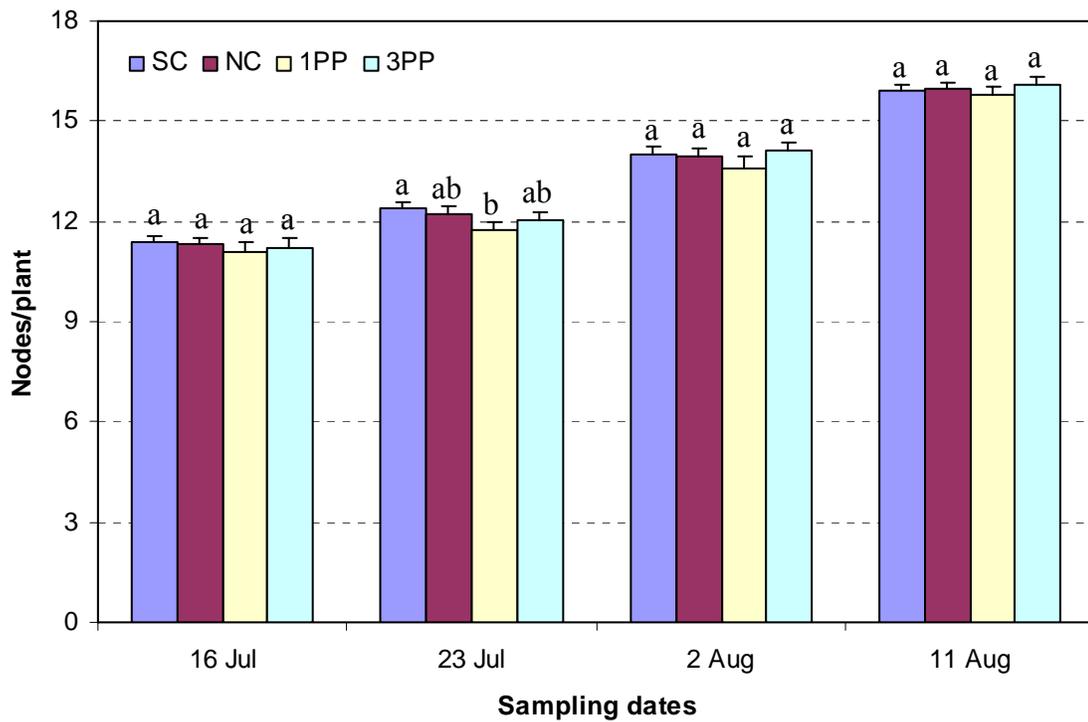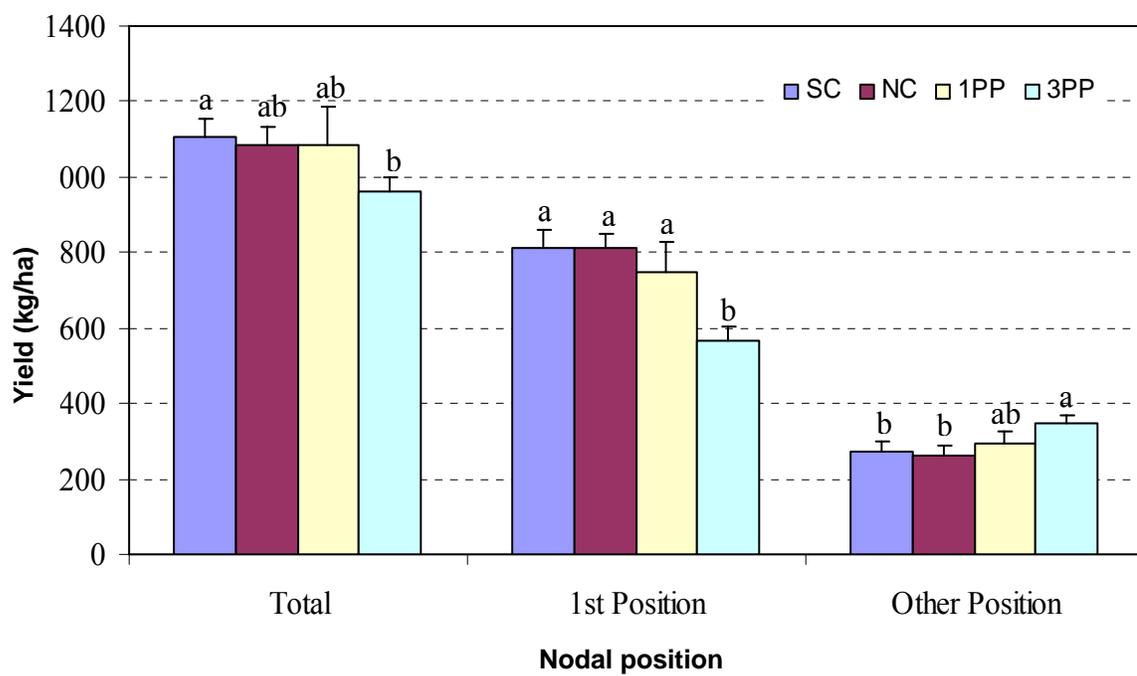
Fig. 2.14 Average lint yield in total and by position: early-bloom study 2005, Lubbock, TX. Treatments followed by the same letter are not statistically significant at P=0.10.
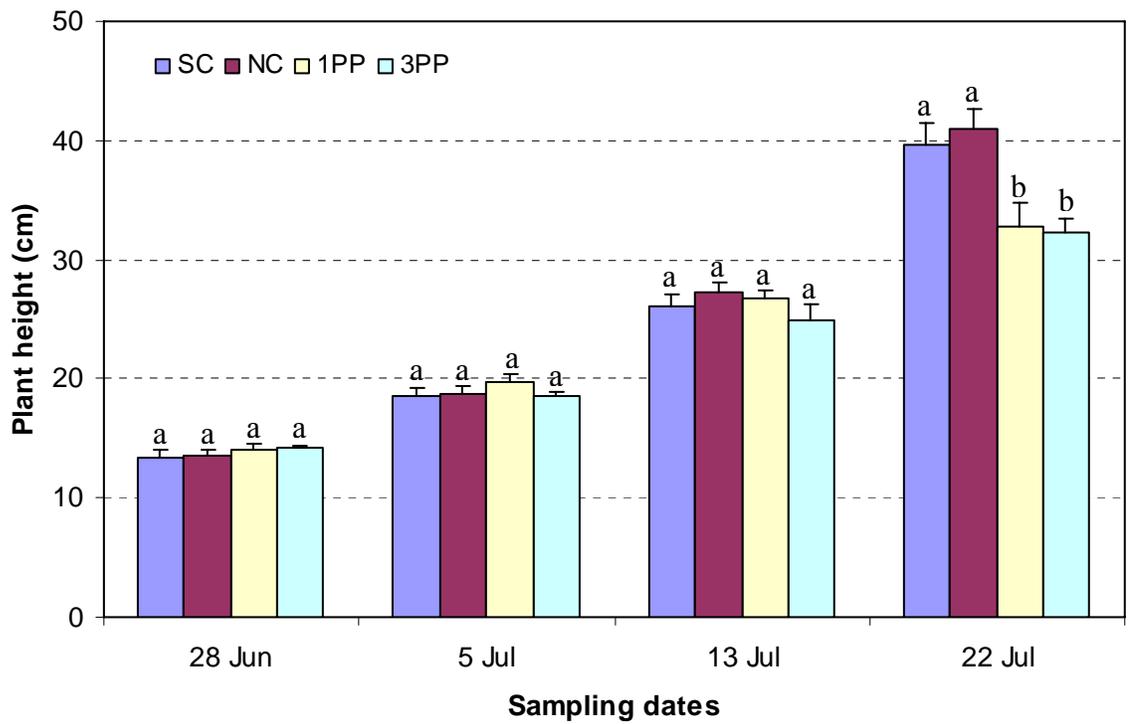
Fig. 2.15 Average plant height during in-season plant mapping: pre-bloom study 2006, Lubbock, TX. Treatments within date followed by the same letter are not statistically significant at P=0.10.
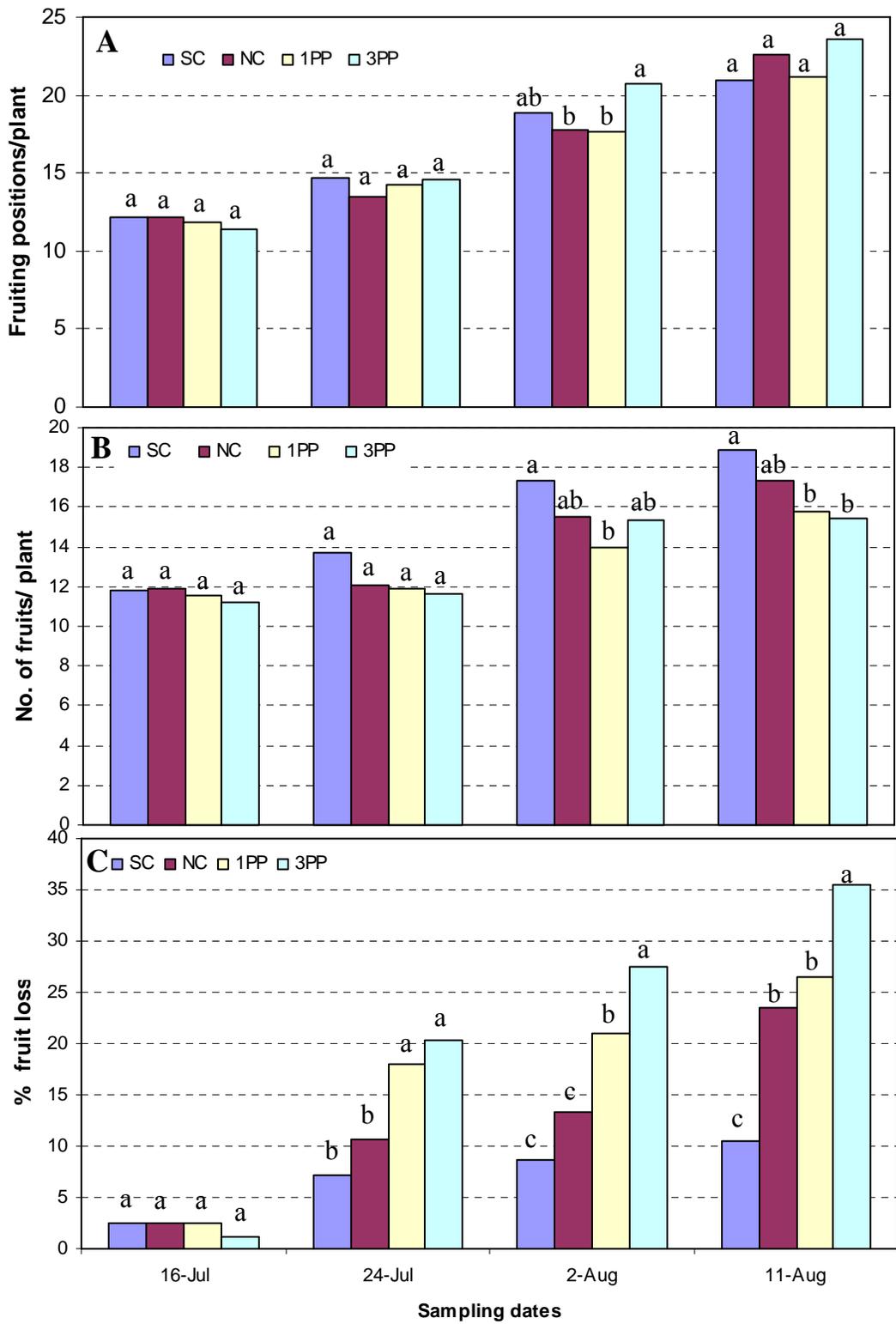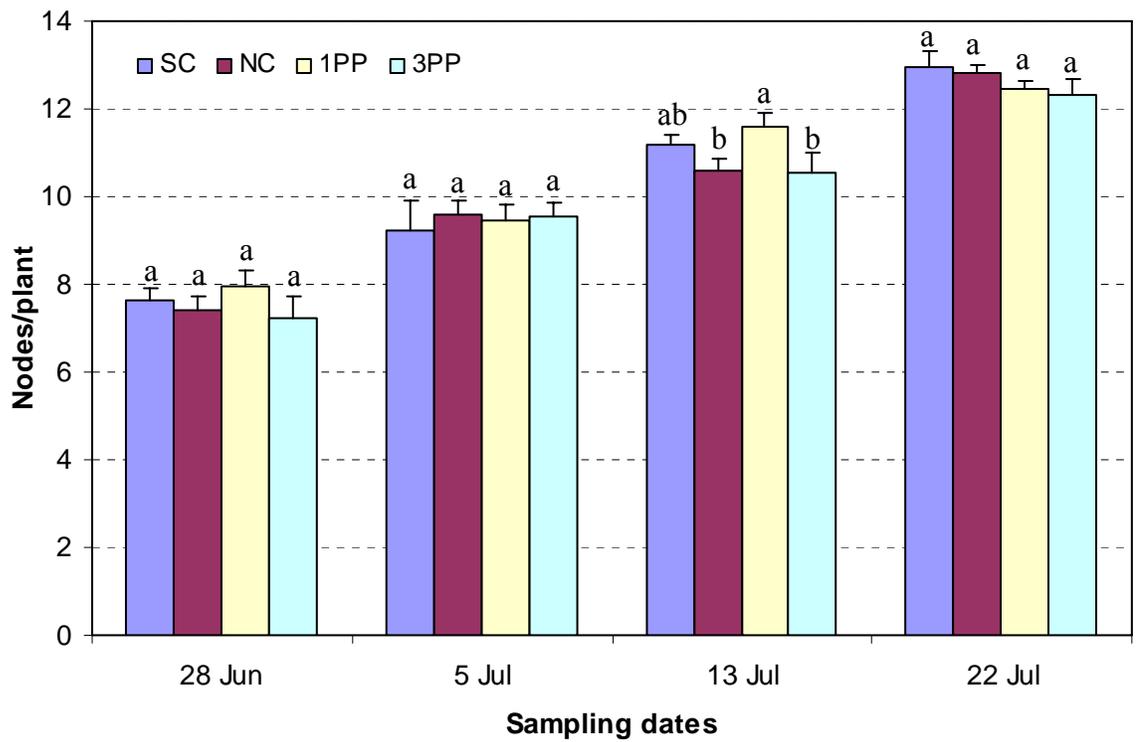
Fig. 2.16 Average number of vertical nodes per plant during in-season plant mapping: pre-bloom study 2006. Lubbock, TX. Treatments within date followed by the same letter are not statistically significant at P=0.10.
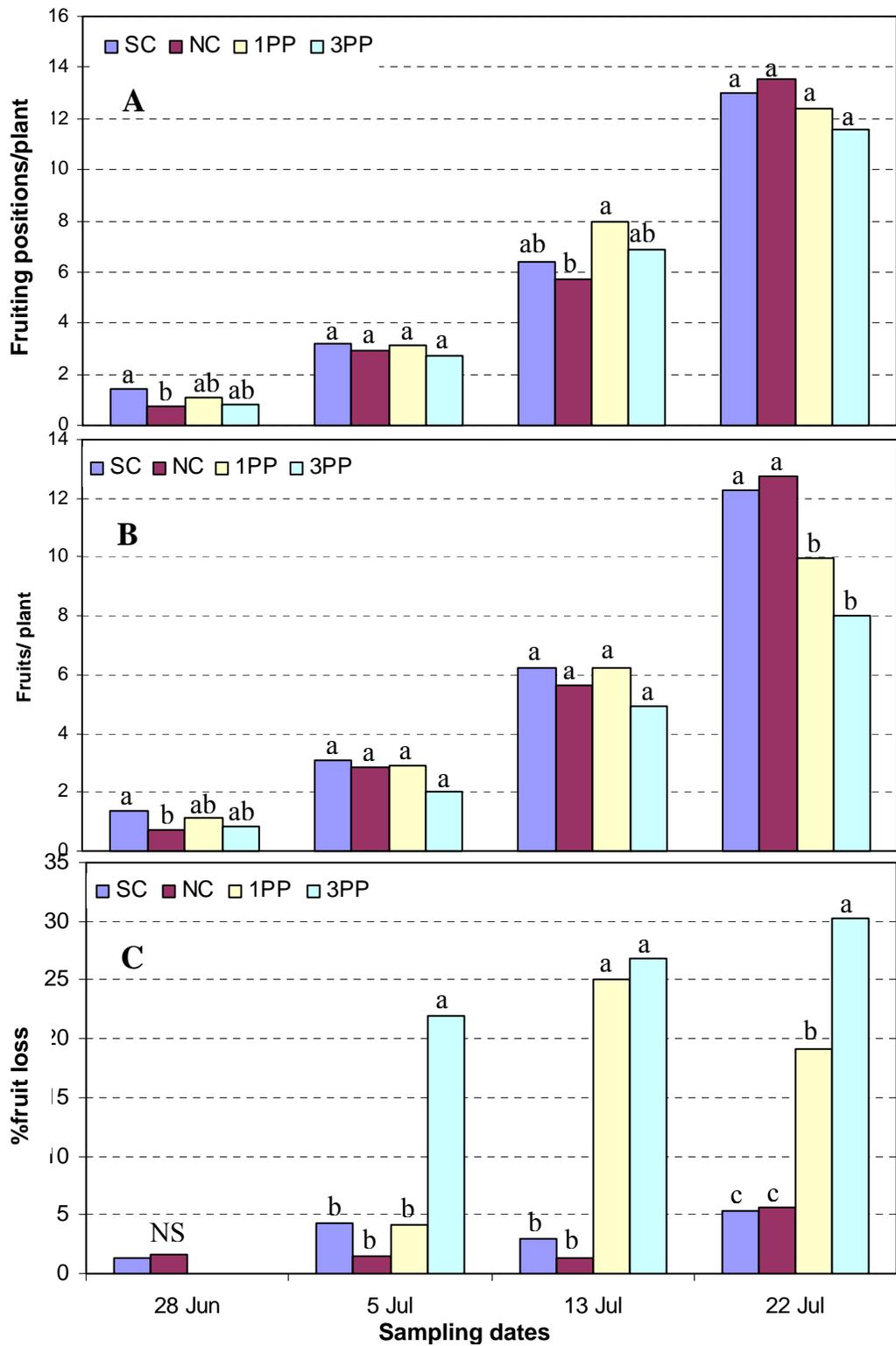
Fig. 2.17 Fruit retention during in-season plant mapping: pre-bloom study 2006, Lubbock, TX.
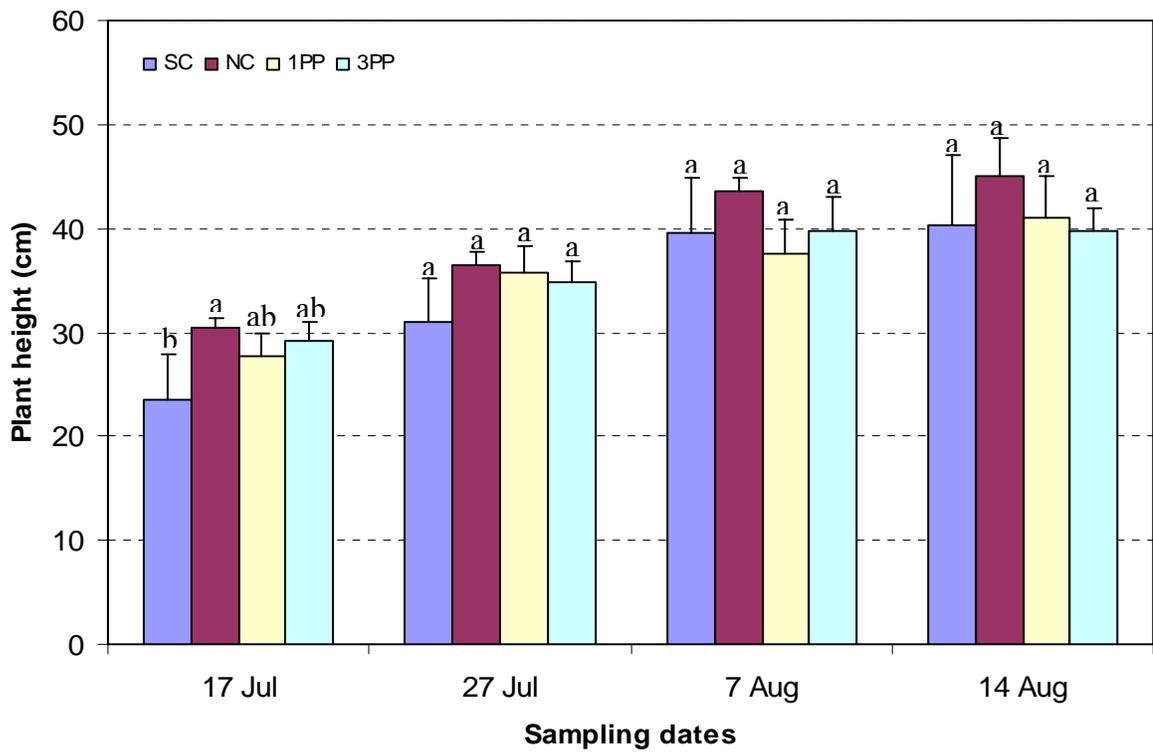
Fig. 2.18 Average plant height during in-season plant mapping: early-bloom study 2006, Lubbock, TX. Treatments followed by the same letter are not statistically significant at P=0.10.
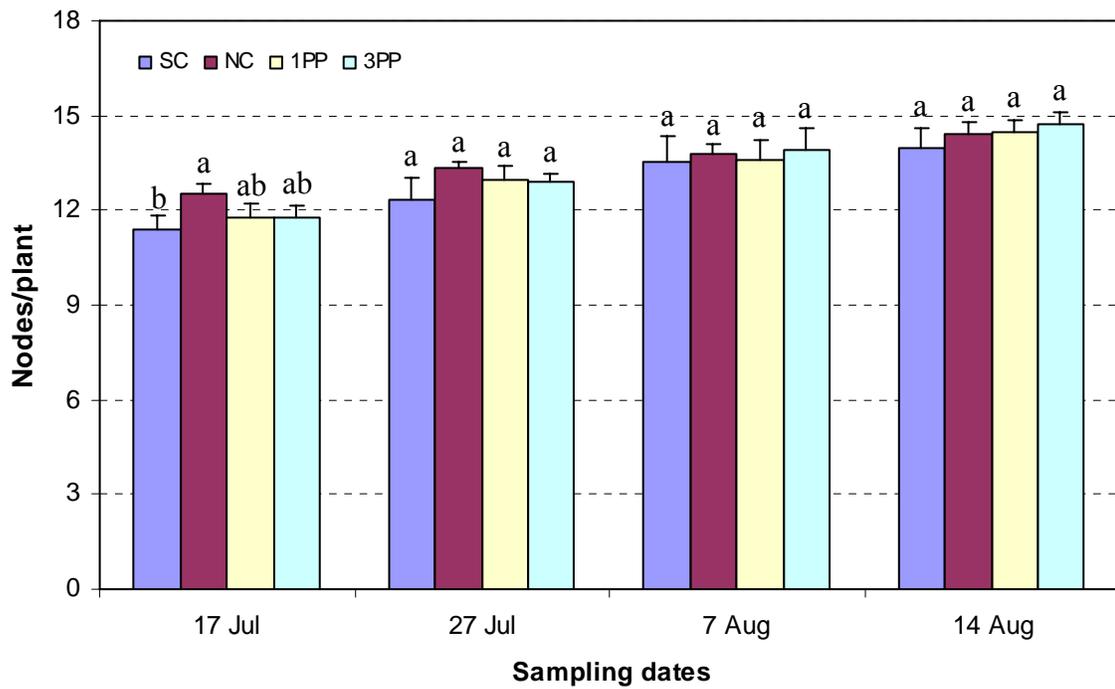
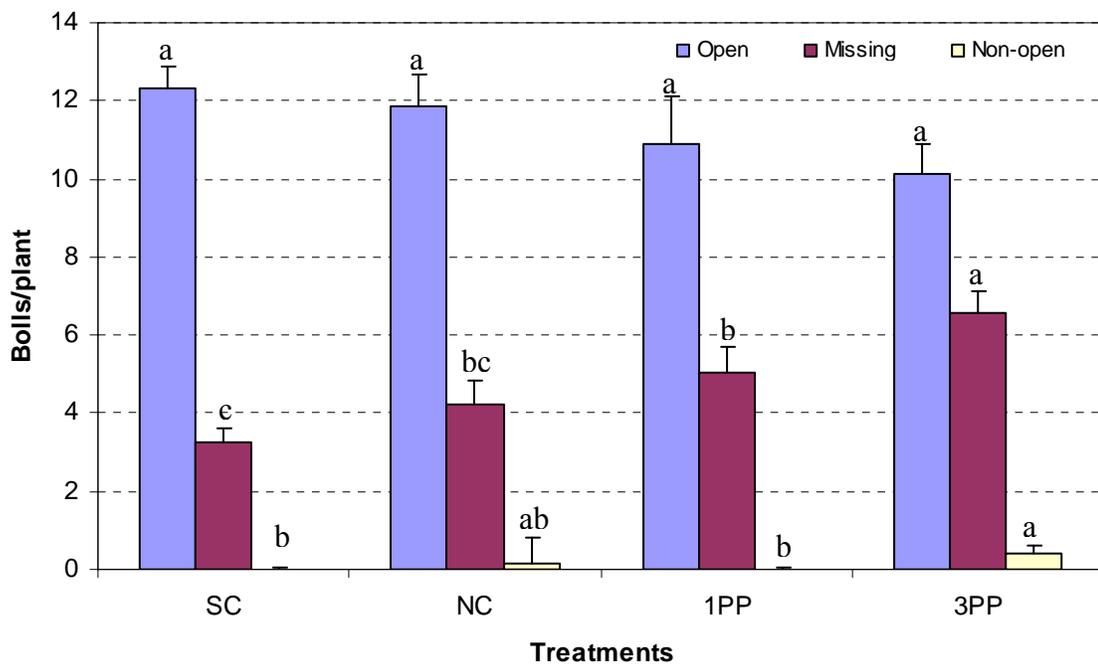Fig. 2.19 Average number of vertical nodes per plant during in-season plant mapping: early-bloom study 2006, Lubbock, TX. Treatments within date followed by the same letter are not statistically significant at P=0.10.
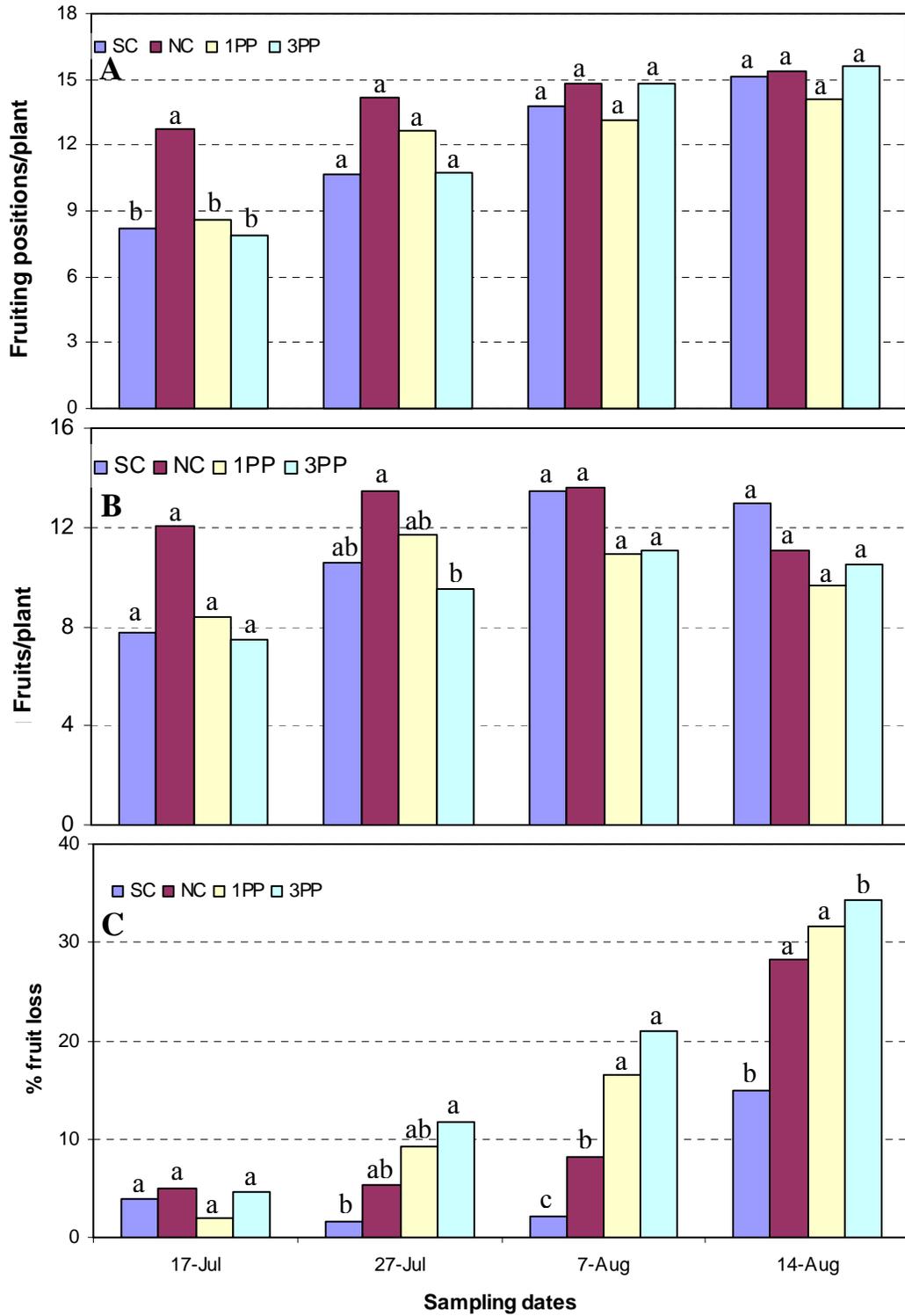
Fig. 2.20 Fruit retention during in-season plant mapping: early-bloom study 2006, Lubbock, TX.

Table 2.1 Field activities during compensation study, 2005 and 2006, Lubbock, TX

Year	Activities	Pre-bloom	Early-bloom
2005	Plant mapping	6 Jul, 13 Jul, 20 Jul, 27 Jul, 6 Aug	16 Jul, 23 Jul, 2 Aug, 11 Aug
	Insect release	7 Jul, 14 Jul, 21 Jul	16 Jul, 23 Jul, 3 Aug
	Insecticide spraying	28 Jun, 5 Jul, 22 Jul, 29 Jul	6 Jul, 13 Jul, 20 Jul, 28 Jul, 4 Aug
2006	Plant mapping	28 Jun, 5 Jul, 13 Jul, 22 Jul	20 Jul, 27 Jul, 7 Aug, 14 Aug
	Insect release	29 Jun, 6 Jul, 13 Jul	24 Jul, 1 Aug, 7 Aug
	Insecticide spraying	23 Jun, 3 Jul, 7 Jul, 23 Jul	27 Jun, 31 Jun, 7 Jul, 16 Jul

Table: 2.2 High-volume instrument (HVI) quality measure (± SE) for cotton lint: 2005, Lubbock, TX.

Year	Treatments	Micronaire	Span length (cm)	Fiber strength (gm/tex)	Fiber elongation (degree)	Uniformity (UI ratio)
Pre-bloom 2005	SC	4.75 ± 0.06 a	2.60 ± 0.03 b	27.37 ± 0.22 b	6.60 ± 0.17 a	82.10 ± 0.33 a
	NC	4.78 ± 0.02 a	2.58 ± 0.0 b	27.40 ± 0.26 b	6.60 ± 0.12 a	82.23 ± 0.23 a
	1PP	4.83 ± 0.03 a	2.58 ± 0.03 b	27.37 ± 0.34 b	6.45 ± 0.17 a	81.93 ± 0.4 a
	3PP	4.80 ± 0.04 a	2.65 ± 0.0 a	28.57 ± 0.41 a	6.45 ± 0.05 a	82.76 ± 0.11 a
		F=1.15; P=0.37	F=4.76; P=0.02	F=5.50; P=0.02	F=0.35; P=0.78	F=1.49; P=0.28
Early-bloom 2005	SC	4.65 ± 0.09 a	2.56 ± 0.0 b	27.60 ± 0.36 a	6.25 ± 0.06 a	82.75 ± 0.25 a
	NC	4.80 ± 0.11 a	2.65 ± 0.0 ab	28.45 ± 0.60 a	6.28 ± 0.12 a	82.53 ± 0.47 a
	1PP	4.75 ± 0.07 a	2.70 ± 0.3 a	28.30 ± 0.51 a	6.30 ± 0.09 a	82.70 ± 0.08 a
	3PP	4.80 ± 0.03 a	2.68 ± 0.0 a	27.93 ± 0.08 a	6.18 ± 0.04 a	82.50 ± 0.51 a
		F=0.37; P=0.77	F=2.93; P=0.09	F=0.22; P=0.88	F=0.71; P=0.57	F=0.07; P=0.97

In all statistical tests df=3,12; Values followed by different letters are significantly different (P<0.10).

Table: 2.3 Fruit intact and loss in each nodal position after three releases of bugs: 2006, Lubbock, TX.

	Treatment	All position	First position	Second position	Third position
Pre-bloom study: 2006					
Fruit intact	SC	12.30a	7.62a (61.9)	4.20a (34.1)	0.45a (3.6)
	NC	12.75a	6.62a (51.92)	4.65a (36.47)	0.47a (3.6)
	1PP	9.97b	6.40b (64.19)	2.85b (28.6)	0.72a (7.2)
	3PP	8.02b	5.32c (66.33)	2.35b (29.3)	0.35a (4.3)
Fruit loss	SC	0.7c (5.3)	0.57c (4.4)	0.1b (0.8)	0.02a (0.1)
	NC	0.8c (6.0)	0.67c (5.0)	0.12b (1.0)	0a (0.0)
	1PP	2.42b (19.5)	1.37b (11.0)	1.02a (8.0)	0.02a (0.5)
	3PP	3.52a (30.6)	2.35a (20.4)	1.07a (9.3)	0.1a (0.9)
Early-bloom study: 2006					
Fruit intact	SC	13.02a	8.55 a (65.6)	2.97a (22.81)	1.20a (9.0)
	NC	11.10a	7.32 ab (65.94)	3.07a (27.65)	0.57a (5.1)
	1PP	9.52a	7.25 ab (76.15)	1.90a (19.9)	0.37a (3.8)
	3PP	10.52a	6.82b (64.82)	2.85a (27.1)	0.80a (7.6)
Fruit loss	SC	2.17b (14.92)	0.80b (5.2)	1.1a (7.2)	0.22a (1.4)
	NC	4.3a (28.26)	2.17a (14.1)	1.82a (11.8)	0.30a (1.9)
	1PP	4.4a (31.58)	2.45a (17.3)	1.85a (13.1)	0.12a (0.8)
	3PP	5.07a (34.27)	2.87a (18.4)	1.67a (10.7)	0.45a (2.8)

Values in parentheses are percentage contribution by each nodal position (fruit intact) and percentage fruit loss (fruit loss). Values followed by different letters are significantly different (P<0.10)

REFERENCES

Baugh, B., J. F. Leser, R. Boman, and T. Deoderlein. 2003. Plant responses to different levels of pre-bloom square removal and its relevance to plant bug management, pp. 1131-1137. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Bednarz, C. W., and P. M. Roberts. 2001. Spatial distribution in cotton following early-season floral bud removal. Crop Sci. 41: 1800-1808.

Belsky, A. J. 1986. Does herbivory benefit plants? A review of the evidence. Amer. Nat. 127: 870-892.

Bergelson, J., and M. J. Crawley. 1992. The effects of grazers on the performance of individuals and populations of scarlet gilia, *Ipomosis aggregata*. Oecologia 90: 435-444.

Bergelson, J., T. Juenger, and M. J. Crawley. 1996. Regrowth following herbivory in *Ipomosis aggregate*: Compensation but not overcompensation. Amer. Nat. 148: 744-755.

Brook, K. D., A. B. Hearn, and C. F. Kelly. 1992a. Responses of cotton, *Gossypium hirsutum* L., to damage by insect pests in Australia: Pest management trials. J. Econ. Entomol. 85: 1356-1367.

Brook, K. D., A. B. Hearn, and C. F. Kelly. 1992b. Responses of cotton, *Gossypium hirsutum* L., to damage by insect pests in Australia: Manual simulation of damage. J. Econ. Entomol. 85: 1368-1377.

Burden, B. J., P. W. Morgan, and W. L. Sterling. 1989. Indole-acetic acid and the ethylene precursor, ACC, in the cotton fleahopper (Hemiptera: Miridae) and their role in cotton square abscission. Ann. Entomol. Soc. Am. 82: 476-480.

Chapin, F.S., III, and S. J. McNaughton. 1989. Lack of compensatory growth under phosphorus deficiency in grazing-adapted grasses from the Serengeti Plains. Oecologia 79: 551-557.

Cook, R. D., and C. W. Kennedy. 2000. Early flower bud loss and mepiquat chloride effect on cotton yield distribution. Crop Sci. 40: 1678-1684.

Crawley, M. J. 1983. Herbivory, the Dynamics of Animal-Plant Interactions. University of California Press, Berkeley, Calif. 437 pp.

Danckwerts, J. E., and A. J. Gordon. 1987. Long-term partitioning, storage, and re-mobilization of ^{14}C assimilated by *Lolium perenne* (cv. Melle). Ann. Bot. 59: 55-66.

Debolt, J. W. 1982. Meridic diet for rearing successive generations of *Lygus hesperus*. Ann. Entomol. Soc. Am. 75:119-122.

Doak, D. 1991. The consequences of herbivory for dwarf fireweed: Different time scales, different morphological scales. Ecol. 72: 1397-1407.

Dunman, E. W., J. C. Clarck, and S. L. Calhoun. 1943. Effect of the removal of squares on yield of upland cotton. J. Econ. Entomol. 36: 896-900.

Fitt, G. P. 1994. Cotton pest management: An Australian perspective. Ann. Rev. Entomol. 39: 543-562.

Hall, W. C. 1958. Physiology and biochemistry of abscission in the cotton plant. Texas Agri. Exp. Stn. Bull. MP-285.

Hanny, B. W., T. C. Cleveland, and W. R. Meredith, Jr. 1977. Effects of tarnished plant bug, (*Lygus lineolaris*), infestation on presquaring cotton (*Gosspium hirsutum*). Environ. Entomol. 6: 460-462.

Harnett, D. C., and W. G. Abrahamson. 1979. Effects of stem gall insects on life-history patterns in *Solidago canadiensis*. Ecol. 72: 1397-1407.

Holman, E. M., and D. M. Oosterhuis. 1999. Cotton photosynthesis and carbon partitioning in response to floral bud loss due to insect damage. Crop Sci. 39: 1347-1351.

Inouye, D. W. 1982. The consequences of herbivory: A mixed blessing for *Jurinea mollis* (Asteraceae). Oikos 39: 269-290.

Islam, Z., and M. J. Crawley. 1983. Compensation and regrowth in ragwort (*Senecio jacobaea*) attacked by cinnabar moth (*Tyria jacobaeae*). J. Ecol. 71: 829-843.

Jones M. A., R. Wells, and D. S. Guthrie. 1996. Cotton response to seasonal patterns of flower removal: I. Yield and fiber quality. Crop Sci. 36: 633-638.

Juenger, T., and J. Bergelson. 1997. Pollen and resource limitation of compensation to herbivory in scarlet gilia, *Ipomosis aggregata.* Ecol. 78: 1684-1695.

Kletter, E., and D. Wallach. 1982. Effect of fruiting form removal on cotton reproductive development. Field Crops Res. 5: 69-84.

Layton, M. B. 2000. Biology and damage of the tarnished plant bug, *Lygus lineolaris*, in cotton. Southwest. Entomol. 23 (suppl.): 7-20.

Lei, T. T., and L. J. Wilson. 2004. Recovery of leaf area through accelerated shoot ontogeny in thrips-damaged cotton seedlings. Ann. of Bot. 94: 179-186.

Lennartsson, T. J., P. Nilsson, and J. Tuomi. 1998. Induction of overcompensation in the field gentian, *Gentianella campestris*. Ecol. 79: 1061-1072.

Mabry, C. M., and P. W. Wayne. 1997. Defoliation of the annual herb *Abutilon theophrasti*: Mechanisms underlying reproductive compensation. Oecologia 111: 225-232.

Marquis, R. J. 1988. Phenological variation in the neotropical understory shrub *Piper arieianum*: Causes and consequences. Ecol. 69: 1552-1565.

McNaughton, S. J. 1979. Grazing as an optimization process: Grass ungulate relationships in the Serengeti. Am. Nat. 113: 691-703.

Meyer, G. A. 1998. Pattern of defoliation and its effect on photosynthesis and growth of goldenrod. Func. Ecol. 12: 260-279.

Montez, G. M., and P. B. Goodell. 1994. Yield compensation in cotton with early season square loss, pp. 916-919. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Paige, K. N., and T. G. Whitham. 1987. Overcompensation in response to mammalian herbivory: The advantage of being eaten. Am. Nat. 129: 407-416.

Rosenheim, J. A., R. W. Lawrence, and P. B. Goodell. 1997. Plant compensation, natural biological control, and herbivory by *Aphis gossyppi* on pre-reproductive cotton: The anatomy of a non-pest. Entomologia Experimentalis et Applicata 85: 45-63.

Rosenthal, J. P., and P. M. Kotanen. 1994. Terrestrial plant tolerance to herbivory. Trends Ecol. Evol. 9: 145-148.

Rosenthal, J. P., and S. C. Welter. 1995. Tolerance to herbivory by a stemboring caterpillar in architecturally distinct maize and wild relatives. Oecologia 102: 146-155.

Prins, A. H., and H. J. Verkaar. 1989. Responses of *Cynoglossum officinale* and *Senecio jacobaea* to various degrees of defoliation. New Phytol. 111: 725-731.

Rude, P. A. 1984. Integrated pest management for cotton. Publication 3305. Div. of Agric. and Nat. Resources, Univ. of Calif.

Sadras, V. O. 1995. Compensatory growth in cotton after loss of reproductive organs. Field Crops Res. 40:1-18.

Sadras, V. O. 1996. Cotton responses to simulated insect damage: Radiation-use efficiency, canopy architecture and leaf nitrogen content as affected by loss of reproductive organs. Field Crops Res. 48:199-208.

Sadras, V. O., and L. J. Wilson. 1998. Recovery of cotton crops after early season damage by thrips (Thysanoptera). Crop Sci. 38: 399-409.

SAS. Statistical Analysis Systems Institute Inc. 2003. Version 9.1, Cary, NC.

Stewart, S. D., and W. L. Sterling. 1988. Dynamics and impact of cotton fruit abscission and survival. Environ. Entomol. 17: 629-635.

Stewart, S. D., and W. L. Sterling. 1989. Susceptibility of cotton fruiting forms to insects, boll rot, and physical stress. J. Econ. Entomol. 82: 593-598.

Stewart, S. D., M. B. Layton, M. R. Williams, D. Ingram, and W. Maily. 2001. Response of cotton to prebloom square loss. J. Econ. Entomol. 94: 388-396.

Strauss, S. Y., and A. A. Agrawal. 1999. The ecology and evolution of plant tolerance to herbivory. Trends Ecol. Evol. 14: 179-185.

Teague, T. G., N. P. Tugwell, and E. J. Villavaso. 2001. Comparison of cotton plant response to square loss following manual removal or tarnished plant bug feeding results from field trials in 2000, pp. 1149-1156. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Teague, T. G., S. Coy., N. P. Tugwell, and E. J. Villavaso. 2002. Comparison of cotton plant response to square loss following manual removal or tarnished plant bug feeding: Results from field trials in 2001. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Terry, L. I. 1992. Effect of early season insecticide use and square removal on fruiting patterns and fiber quality of cotton. J. Econ. Entomol. 85: 1402-1412.

Tiffin, P. 2000. Mechanism of tolerance to herbivore damage: What do we know? Evolutionary Ecol. 14: 523-536.

Trumble, J. T., D. M. Kolondy-Hirsch, and I. P. Ting. 1993. Plant compensation for arthropod herbivory. Ann. Rev. Entomol. 38: 93-119.

Tugwell, N. P., S. C. Young, B. A. Dumas, and J. Phillips. 1976. Plant bugs in cotton: Importance of infestation time, types of cotton injury, and significance of wild hosts near cotton. Ark. Agric. Exp. Stn. Report Series 277.

Ungar E. D., E. Kletter, and A. Genizi. 1992. Conservative response and stress damage interactions in cotton reproductive development. Agron. J. 84: 382-386.

Ungar, E. D., D. Wallach, and E. Kletter. 1987. Cotton responses to bud and boll removal. Agron. J. 79: 491-497.

Van der Heyden, F., and W. D. Stock. 1996. Regrowth of a semiarid shrub following simulated browsing: The role of reserve carbon. Funct. Ecol. 10: 647-653.

Wells, R. 2001. Leaf pigment and canopy photosynthetic response to early flower removal in cotton. Crop Sci. 41: 1522-1529.

Whitham, T. G., J. Maschinski, K. C. Larson, and K. N. Paige. 1991. Plant responses to herbivory: The continuum from negative to positive and underlying physiological mechanisms, pp. 227-256. *In* P. W. Price, T. M. Lewisohn, G. W. Fernandes and W. W. Bensons (eds). Plant-Animal Interactions: Evolutionary Ecology in Tropical and Temperate Regions. John Weily and Sons, New York.

Wilson, A. G. L. 1981. *Heliothis* damage to cotton and concomitant action levels in the Namoi Valley, New South Wales. Prot. Ecol. 3: 311-325.

Wilson, L. T., and A. L. Bishop. 1982. Responses of Deltapine 16 cotton *Gossypium hirsutum* L. to simulated attacks by known populations of *Heliothis* larvae (Lepidoptera: Noctuidae) in a field experiment in Queensland, Australia. Prot. Ecol. 4: 371-380.

Wilson, L. J., V. O. Sadras, S. C. Heimoana, and D. Gibb. 2003. How to succeed by doing nothing: Cotton compensation after simulated early season pest damage. Crop Sci. 43: 2125-2134.

Zink, A. G., and J. A. Rosenheim. 2005. Stage-dependent feeding behavior by western tarnished plant bugs influences flower bud abscission in cotton. Entomologia Experimentalis et Applicata 117: 235-242.

CHAPTER III

HOST PREFERENCE OF *Lygus* BUG TO

SOME SELECTED HOST SPECIES

Abstract

Lygus bug is becoming an important pest of cotton after bollworm in the Texas

High Plains while it is an economic pest of cotton in the Mid-South. *Lygus* can utilize

several crop and many non-crop hosts and the availability and phenological synchrony of

these hosts with cotton may largely determine the resulting intercrop movement of *Lygus*

between cotton and non-cotton hosts. A field study was conducted in the Texas High

Plains in 2005 and 2006 to evaluate the host preference of *Lygus* to cotton and four non-

cotton plant hosts. The four non-cotton hosts and cotton were planted in a randomized

complete block with four replications. The non-cotton hosts included alfalfa (*Medicago*

sativa L.), wild sunflower (*Helianthus annuus* cv. maximallia), Russian thistle (*Salsola*

iberica L.), and Palmer amaranth (*Amaranthus palmeri* L.). Sampling for *Lygus* during

2005 (July to November) and 2006 (June to November) shows that alfalfa and Russian

thistle were the two most preferred hosts out of the five hosts considered. *Lygus*

reproductive activity, measured in terms of nymphal abundance, followed the patterns

observed for adult abundance. That is, Russian thistle and alfalfa supported significantly

higher nymphal abundance compared with the other three hosts examined. In other

words, cotton did not appear to be an attractive host for *Lygus* when Russian thistle and

alfalfa were available in the host mosaic.

3.1 Introduction

Lygus bugs are polyphagous pests of many crops and survive on a large number of non-crop hosts. Among the two most prevalent species of *Lygus*, *L. hesperus* Knight, western tarnished plant bug (WTPB), has about 100 host plant species within 24 plant families (Scott 1977). Whereas, *L. lineolaris* (Palisot de Beauvois), tarnished plant bug (TPB), which is more abundant in the southern states like Louisiana, Mississippi, Alabama, Georgia, Arkansas and some regions of Texas, has about 385 reported host plant species in 55 families (Young 1986). The major plant families for both of these insect species are shown in Table 3.1.

Many preferred wild or crop hosts have been reported from different cotton growing regions. Snodgrass et al. (1984) found the plant family Asteraceae to contain the largest number of hosts which support *L. lineolaris* populations in Arkansas, Louisiana and Mississippi. In California, *L. hesperus* is a major pest of cotton which builds up its spring population in other crops including alfalfa and safflower (*Carthamus tinctorius* L.). After two years of extensive survey in the northern Blackland Prairies of Texas, Womack and Schuster (1987) reported 56 different wild hosts for *L. lineolaris*. They divided these hosts into non-reproductive, reproductive, summer, early-season and late season hosts depending on the presence of *Lygus* and its development on that particular host. The primary hosts supporting *Lygus* populations throughout the year in that region were found to be in the genera *Erigeron*, *Helenium*, *Hymenoxys* and *Conyza*. In another survey report from Yakima Valley and Columbia Basin in Washington, Fye (1980) reported several weed species which continuously support *Lygus* bug populations.

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Among them Russian thistle, kochia (*Kochia scoparia* L.), Palmer amaranth (*Amaranthus retroflex* L.), common ragweed (*Ambrosia artemisiifolia* L.) and common Lambsquarter (*Chenopodium album* L.), were reported to be major reproductive hosts at different times of the year. A 3-year survey conducted in Colorado during the period of 2000-2002 indicate that *Lygus* has several important wild hosts such as wild mustard (*Brassica kaber*), flixweed (*Descurainia sophia*)and tansy mustard (*Descurinia pinnata*) besides alfalfa (Demirel and Cranshaw 2006). Once these weeds senesce (or are destroyed) and alfalfa is mowed, *Lygus* migrate to a nearby crops such as canola and cause significant damage in its early flowering stage.

 Lygus bugs are one of the emerging pest issues in cotton. Following the disappearance of the boll weevil (due to eradication programs) and the introduction of Bt-cotton, pest complexes in the cotton agroecosystem have changed tremendously, so thus the pest management strategies. Previously, a few insecticidal sprays against the Heliothine complex or the boll weevil suppressed other non-targeted secondary pests such as plant bugs (*Lygus* spp.), cotton fleahopper (*Pseudatomoscelis seriatus*), cotton aphid (*Aphis gossypii*) and other sucking pests. But available technology has eliminated most early season insecticidal sprays which not only benefited farmers but also has reduced environmental pollution and provided a better opportunity for ecologically intensive pest management. In such a promising and managed agricultural system, *Lygus* bugs can be of concern in cotton production. Potential of *Lygus* as an emerging pest has already been documented as it has been ranked among the most damaging pests after the bollworm-budworm complex (Williams 2005). In general, *Lygus* develops its populations

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in non-cotton hosts for 1-2 generations and then it moves into cotton due to its unique

host-sequencing ecology. Furthermore, *Lygus* moves out of cotton and seeks non-cotton

overwintering hosts or refugia when cotton terminates or becomes an unacceptable host.

Extensive work has already been done and documented regarding the biology and

behavior of this pest. In late fall, *Lygus* overwinter as adults in dried plant debris, alfalfa

patches or roadside weeds (Sevacherian and Stern 1975). In the early spring, adults

emerging from overwintering habitats locate and spend 1-2 generations on early season

wild hosts before moving to crop hosts such as cotton or alfalfa (Layton 2000). The time

period *Lygus* spend on the spring hosts is critical because the availability and growth

conditions of these alternate hosts will determine the potential population level that

would move to the cultivated crop. Therefore, the importance of alternate hosts is

enormous in managing this pest. Monitoring of weed species near cotton fields can

provide information on the potential invasion of *Lygus* into the cotton (Anderson and

Schuster 1983). Movement of *Lygus* out of preferred weed hosts is determined by the

growth condition, phenology, and availability of weed hosts in nature (Fleischer and

Gaylor 1988). Prevailing weather parameters such as rainfall (Anderson and Schuster

1983) and wind direction or velocity (Butler 1972) can also influence abundance and

movement of *Lygus* between non-cotton hosts and cotton. Therefore, an understanding of

the sequential growth habit of different weed habitats adjacent to a cultivated crop could

help estimate the timing and degree of *Lygus* invasion into the crop. Depending on the

timing and degree of preference of these hosts by *Lygus*, the non-cotton hosts could be

managed by using them as a trap crop or by removing them from the crop surroundings.

The concept of arresting *Lygus* movement though the use of other hosts has been in practice for decades. Alfalfa has been adopted as the crop of choice to trap *Lygus* in the vicinity of cotton fields. A distinct preference by *L. hesperus* to alfalfa over cotton was demonstrated by Sevacherian and Stern (1974). Based on this observation, intercropping of alfalfa along with cotton and strip harvesting of alfalfa (Godfrey and Leigh 1994) are the two most common cultural management practices adopted in California to prevent migration of this pest to nearby cotton. High dispersal ability of *Lygus* in the field poses difficulty in managing this pest in a particular crop at certain point in time. However, the presence of preferred hosts and comparatively higher abundance of *Lygus* in these hosts may suggest an arrestment response (Kareiva 1983). This plant response to *Lygus* can be utilized as a mechanism to trap the pest and keep them out of cotton fields during the most vulnerable stage of the crop (Bancroft 2005). Concept of trap cropping for the *Lygus* bug (*L. rugulipennis*) in Europe is widely used in lettuce agrosystems. Lettuce is a high value cash crop but insecticide treatments are not recommended in the production system due to its use as human food. Pest management researchers in Sweden recommend the use of trap crops including *Melilotus officinalis, Vicia sativa, Trifolium pretense, Medicago sativa* (all are cover crops) and *Artemisia vulgaris* (common wormwood) to protect lettuce. Weed species *Artemisia vulgaris* was found to attract 100 times more *Lygus* than lettuce (Ramert et al. 2001). In northern Italy, the movement of *L. rugulipennis* into lettuce was successful arrested by using alfalfa as trap crop (Accinelli et al. 2005). Mueller and Stern (1973) and Sevacherian et al. (1977) described another trapping technique for *Lygus*, where they used safflower to colonize the bugs and kill

them with an insecticidal application at the proper time. Efforts to interplant alternate non-crop hosts with cotton which not only acts as a trap or nurse crop for *Lygus* but also can be used as a refuge crop for cotton bollworm. Kenaf (*Hibiscus cannabinus* L.), and redroot Palmer amaranth (*Amaranthus retroflexus* L.), are two preferred hosts of the tarnished plant bug and were inter-planted with cotton. Subsequent insecticidal treatment on these intercrops was helpful in reducing TPB dispersal and attack on cotton (Craig 1998, Craig et al. 1999).

Destruction of weed hosts near cotton cultivation can be another approach to prevent *Lygus* populations from breeding and their successive movement. This cultural control method would most likely be successful if the early spring weed hosts can be destroyed to prevent the first generation of *Lygus* from perpetuating and resulting in further dispersal to other hosts. However, it is reported to be virtually impossible to eliminate *Lygus* populations with mechanical destruction or herbicide application on early spring weeds (Stewart and Layton 2000). Due to the mobility of *Lygus* bugs and their polyphagous nature, it is more difficult to manage them in a small area. It should be an area-wide approach to manage *Lygus* in any region. In regions such as the Texas High Plains, where cotton is cultivated so extensively, destruction of weed hosts in a small area may not be a feasible *Lygus* management option. It might be possible to let the preferred weed hosts grow or partially destroy the stands of weeds in the early growing season and then use the remaining plants as a refuge crop. Once cotton is matured or passes the susceptible stage for *Lygus* attack, these weed hosts could be sprayed with insecticides or destroyed. Cook et al. (2005) suggested that weed management in the spring may be

helpful in reducing *Lygus* bug density in cotton. In Washington State, Fye (1980) also reports that weed management can be a feasible cultural practice to prevent *Lygus* from emigrating to other fruit crops.

Considering the possibility of incorporating weed hosts and their importance in the life cycle of *Lygus* bugs, it would be worthwhile to investigate the more preferred host(s) in a region. Every region has its own array of vegetation depending upon the climatic and other geographic variation. In the Texas High Plains region, Barman et al. (2006), furthered the work of Parajulee (2006), Carroll et al. (2005) and Parajulee et al. (2003) by evaluating the preferences (based upon presence and evidence of reproduction) of naturally occurring *Lygus* to cotton, alfalfa and numerous prevalent weed hosts in an attempt to identify the few key host-plant species and the sequencing that supports much of the *Lygus* activity throughout the year.

3.2 Materials and Methods

Four non-cotton host plants that had been identified by previous research (Carroll 2005) to support *Lygus* populations in the Texas High Plains and cotton were planted in a randomized block design with four replications. The study was conducted at the Texas Agricultural Experiment Station farm in Lubbock, TX during 2005 and 2006. The non-cotton hosts included alfalfa (*Medicago sativa* L.), wild sunflower (*Helianthus annuus* cv. maximallia), Russian thistle (*Salsola iberica* L.), and Palmer amaranth (*Amaranthus palmeri* L.). Individual plot were 12 rows (101.6 cm spacing) wide and 18.24 m long. Russian thistle and Palmer amaranth plots were established by transplanting young plants

collected from naturally occurring roadside weed patches, whereas sunflower, cotton and alfalfa seeds were planted directly into the seedbeds of the experimental plots at different planting dates to mimic the natural mosaic of these host plants (Fig. 3.1). Sampling for *Lygus* colonization and reproductive populations began in late July when all host plants attained full foliage growth. Sampling was performed by using a sweep-net or a vacuum sampler and the number of adults and nymphs retrieved by each sampling effort were recorded per plot. Sampling was conducted at weekly intervals until all host plants were terminated or *Lygus* numbers reached undetectable levels. Later, the collected male *Lygus* specimens which had been stored in a freezer were identified to species following Mueller et al. (2003). Alfalfa plots were mowed once (28 September in 2005 and 7 September in 2006) to bring the alfalfa back into a vegetative stage or promote re-growth for the remainder of the sampling period. Data on recovered adults and nymphs during each sampling effort in both the years were averaged and statistical analysis was performed using general linear models procedure and means were separated by least significant difference at P=0.10 (SAS Institute 2003).

<u>3.3 Results and Discussion</u>

3.3.1 Study Year 2005

Lygus bug activity throughout the sampling period (August to November) followed the growth stages of hosts, which varied with the sampling time of a year (Fig. 3.2). Early in the sampling period (August), adults started colonizing on alfalfa and Russian thistle and continued to increase in these two hosts only. Overall, Russian thistle

was the more preferred host over alfalfa during the sampling period except after mid-October, when it started drying. Once alfalfa was mowed near the end of September, numbers of *Lygus* observed in Russian thistle increased (50 *Lygus*/50 sweeps). Later on, when alfalfa was in the new vegetative growth and Russian thistle senesced, higher numbers of adults (48 *Lygus*/50 sweeps) were recovered in alfalfa. Among the other three hosts (Palmer amaranth, sunflower and cotton), only Palmer amaranth showed a detectable level of *Lygus* over the sampling period. Cotton and sunflower did not support any noticeable number of *Lygus* adults when the other three hosts were present.

During 2005, alfalfa was the most preferred host of *Lygus* for *Lygus* reproduction *in situ* followed by Russian thistle (Fig. 3.3). Number of nymphs recovered from alfalfa showed a considerable variation among the sampling dates. Relatively higher numbers of nymphs were found at intervals of about 30-35 days. Three peaks of nymphal abundance were observed within the three months of alfalfa sampling, which were 46, 64 and 45 *Lygus* nymphs per 50 sweeps on 8 August, 14 September and 17 October, respectively. On Russian thistle, the fluctuation in number of nymphs was less variable. Out of nine total sampling dates, five dates had nymphal counts of 20 or more nymphs per 50 sweeps. The other three hosts were less favorable reproductive hosts of *Lygus* as evidenced by near zero nymphal recovery from those hosts.

Seasonal averages of both adults and nymphs recovered from all sampled hosts are shown in Fig. 3.4. Russian thistle (25 adults/50 sweeps) and alfalfa (22 adults/50 sweeps) had similar number of adults, whereas Russian thistle and alfalfa had significantly more *Lygus* compared with Palmer amaranth, sunflower or cotton. The

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presence of nymphs indicated that alfalfa (18 nymphs/50 sweeps) and Russian thistle (15 nymphs/50 sweeps) were better reproductive hosts than other hosts evaluated during 2005.

3.3.2 Study Year 2006

Sampling for adult *Lygus* in five different hosts during late June to September revealed that *Lygus* began colonizing in low numbers (4 adults/50 sweeps) in alfalfa in late June (Fig. 3.5) and continued until near the end of September. Although less attractive than alfalfa in the early to mid-sampling period, Russian thistle was the next host which became attractive to *Lygus* adults in the field while Palmer amaranth, sunflower and cotton attracted very few adults for the entire sampling period. During the later half of September, Russian thistle supported the highest numbers of adults. An extended peak of adult abundance in alfalfa was observed from 11 August (35 adults/50 sweeps) to 18 August (32 adults/50 sweeps), when the crop was in the blooming stage. On 7 September, half of each individual alfalfa plot was mowed to promote re-growth from the senesced stage. Following the mowing, the number of adults found in alfalfa on the next two sampling dates were reduced to 6 and 0 adults/50 sweeps, both of which were lower than the corresponding numbers (9 and 11 adults/50 sweeps) found in Russian thistle. These changes appeared to be due to the movement of adults from alfalfa plots to nearby Russian thistle plots. It is noteworthy that after the mowing of alfalfa, *Lygus* did not appear to move to sunflower, cotton or Palmer amaranth while they selectively moved to Russian thistle.

Abundance of nymphs detected in all the sampled hosts (Fig. 3.6) over the entire sampling period clearly indicated that *Lygus* did not have detectable reproduction in three hosts (cotton, sunflower and Palmer amaranth). During most of the 2006 sampling period, alfalfa was the most favored host for *Lygus* population growth but Russian thistle also contributed to *Lygus* reproduction particularly in the late sampling period. Two peak sampling dates among the total ten sampling efforts stood out based upon the higher number of nymphs in alfalfa, which occurred on 7 July (35 nymphs/50 sweeps) and 11 August (70 nymphs/50 sweeps). Russian thistle contributed less to the support of *Lygus* reproduction as compared to alfalfa in 2006. Abundance of nymphs in Russian thistle varied from 2-10 nymphs/50 sweeps over the sampling period. Once alfalfa began to senesce (late August), the number of nymphs reduced drastically and the host was no longer favorable for reproduction. As compared to alfalfa, Russian thistle lived longer and supported a less fluctuating abundance of adults as well as nymphs through the end of September.

Overall, alfalfa supported the highest seasonal average number of both adults and nymphs compared with other hosts evaluated (Fig. 3.7). The average number of adults in alfalfa was 11.6 bugs as compared with 4.2 bugs per 50 sweeps in Russian thistle. Similarly, the number of nymphs were also higher in alfalfa (14.8 nymphs/50 sweeps) compared with Russian thistle (5.4 nymphs/50 sweeps). The seasonal averages of adults for the other three hosts were much lower than in both alfalfa and Russian thistle, whereas the seasonal averages of nymphs for these habitats were in all cases at or near zero.

The collected *Lygus* bugs during 2005 and 2006 were subjected to initial species identification. Combined over all five host plants and all sampling dates, *Lygus* complex consisted of 97% *L. hesperus*, 2% *L. elisus* and 1% *L. lineolaris* (Fig. 3.8). Species composition did not vary greatly between host plant species. Natural predominance of *L. hesperus* in Texas High Plains is in corroboration with previous reports from the region.

3.4 Discussion

Results from this 2-year host preference study shows that alfalfa and Russian thistle are two primary hosts for attracting and holding *Lygus* under field conditions in the Texas High Plains. However, their abundance varies with the weed/crop growth stages, growth conditions and time of the year. Based upon the previous research of others, it is well known that alfalfa is the most attractive host for *Lygus* in different cotton growing regions of the United States (Stern et al. 1967, Stern 1969, Sevacherian and Stern 1974). Our results in finding Russian thistle as another attractive host corroborates with previous research by Fye (1980) and Clancy (1968) who reported this weed to be a potential host by harboring high numbers of *Lygus* bugs in Washington and California, respectively. Carroll et al. (2005) also reported Russian thistle as one of the dominant weed hosts for *Lygus* bugs in Texas High Plains area. The blooming stage was the most attractive stage of alfalfa for *Lygus* adults. During 2005, sampling during the second half of August that coincided with alfalfa blooming showed considerably higher numbers of *Lygus* in alfalfa compared with other phenological stages (Fig. 3.2). New lush vegetation following mowing of alfalfa can also be attractive to *Lygus* adults as was evident from the 2005

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study. Similarly, the highest numbers of adult *Lygus* in alfalfa were found during the

blooming stage of the crop (11 and 18 August) during 2006 (Fig. 3.5). Another

significant observation was the movement of *Lygus* from alfalfa after mowing of the

upper portion of the crop. After the mowing, the surviving *Lygus* bugs either remained in

the uncut portion of the crop or moved to nearby Russian thistle plots. Our observations

clearly indicated that they did not prefer to move to sunflower or Palmer amaranth or

cotton when Russian thistle was available in the host mosaic. Although, Palmer amaranth

was not found as the most attractive host of *Lygus* in our study, Stewart and Khoury

(1976) reported Palmer amaranth as a primary source of *L. lineolaris* in Canada to infest

celery.

Cotton did not appear to be a preferred host for *Lygus*, at least in the presence of

other hosts such as alfalfa, Russian thistle and Palmer amaranth. We also observed a

general peak of nymphal abundance at 30-35 days intervals, indicating a reproductive

cycle. This information may help in developing management strategies to reduce

numbers or prevent movement from a non-crop host into cotton. More *Lygus* (adults)

were found in Russian thistle than alfalfa during 2005 which was in contrast to our 2006

results where alfalfa was more favored host than Russian thistle. Proportions of adults to

nymphs were also different between the years. The number of nymphs in 2005 was

consistently lower than adults, whereas nymphs outnumbered adults in 2006. This might

be due to the sampling variation between years or a true difference in natural abundance

of the life stages in response to weather conditions.

Rainfall and wind are two important weather conditions which might have direct or indirect influence on observed *Lygus* abundance. Rainfall determines the growth condition of the wild hosts such as different weeds in the field and finally reflects on their attractiveness or suitability to a *Lygus* population. Local rainfall data for the period of January to August in both 2005 and 2006 (which includes our major sampling effort) showed that the first year of our study received twice (30.27 cm) as much rainfall as second year (16.42 cm). This could be a reason for overall low number of *Lygus* during the second year of study. Besides, there was no standard protocol maintained on cultivation practices between years as our plot lay-out and fields were different. It was difficult to bring all the treatments under the same management practices and established with equal care. Abundance of *Lygus* bugs in an area depends on the availability and growth condition of vegetation which in turn is influenced by weather conditions (Snodgrass et al. 1984). Anderson and Schuster (1983) reported from a study conducted in the northern Blacklands region of Texas that the annual rainfall pattern and intensity did have an influence on the number of *Lygus* bugs recovered from different hosts from that area. Sparse rainfall with higher temperatures in a particular year make the weed hosts less favorable and senesce earlier, thereby forcing *Lygus* to move from a more preferred weed host to cotton.

3.4 Conclusions

Studies on host preference of *Lygus* can provide insight to possible management strategies, particularly those involving cultural controls. Weeds are an integral part of the agroecosystem in which diversity and abundance vary with region and weather conditions. Detail study on attractiveness of different weed species for *Lygus* bugs adjacent to cotton fields will help in predicting the degree and timing of potential movement of *Lygus* between weed hosts and cotton. Different intercropping or cultural practices have been adopted where alfalfa is used as trap crop or buffer crop in order to prevent movement of *Lygus* into cotton. In the Texas High Plains where extensive cotton cultivation is not interfaced with alfalfa, other crop or non-crop hosts of *Lygus* should be identified. Identification of preferred hosts which pertain to a region or particular *Lygus* species will have multiple implications in using them as a refuge crop or indicator species for *Lygus* severity.

Table 3.1. Percentage of known plant hosts of *Lygus* reported by family (Goodell 1998).

Plant Family	*L. lineolaris*	*L. hesperus*
Asteraceae	26.17	23.42
Fabaceae	11.01	15.32
Brassicaceae	7.70	6.31
Gramineae	5.23	7.20
Chenopodiaceae	3.31	6.31
Plantaginaceae	1.10	7.21
Rosaceae	5.79	5.00
Others	39.69	29.00

Fig. 3.1. Four non-cotton hosts and cotton established in a field to quantify *Lygus* colonization in a multi-crop mosaic, Lubbock, TX.
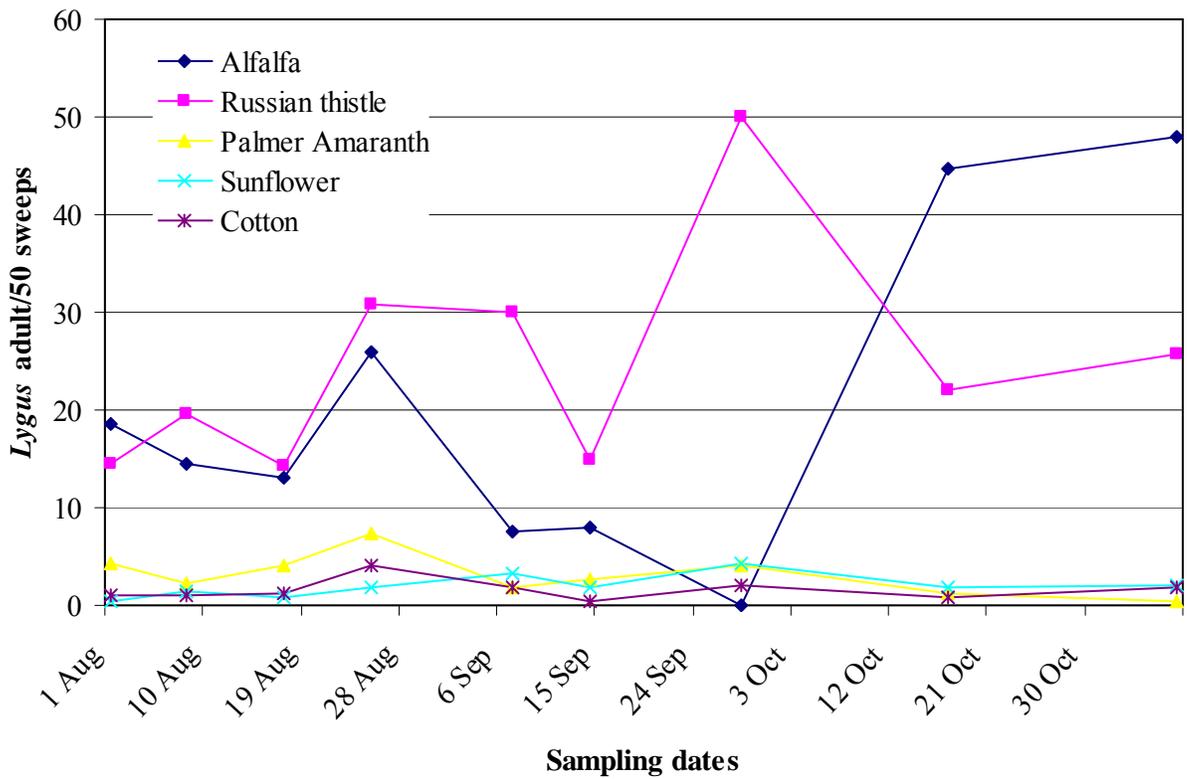
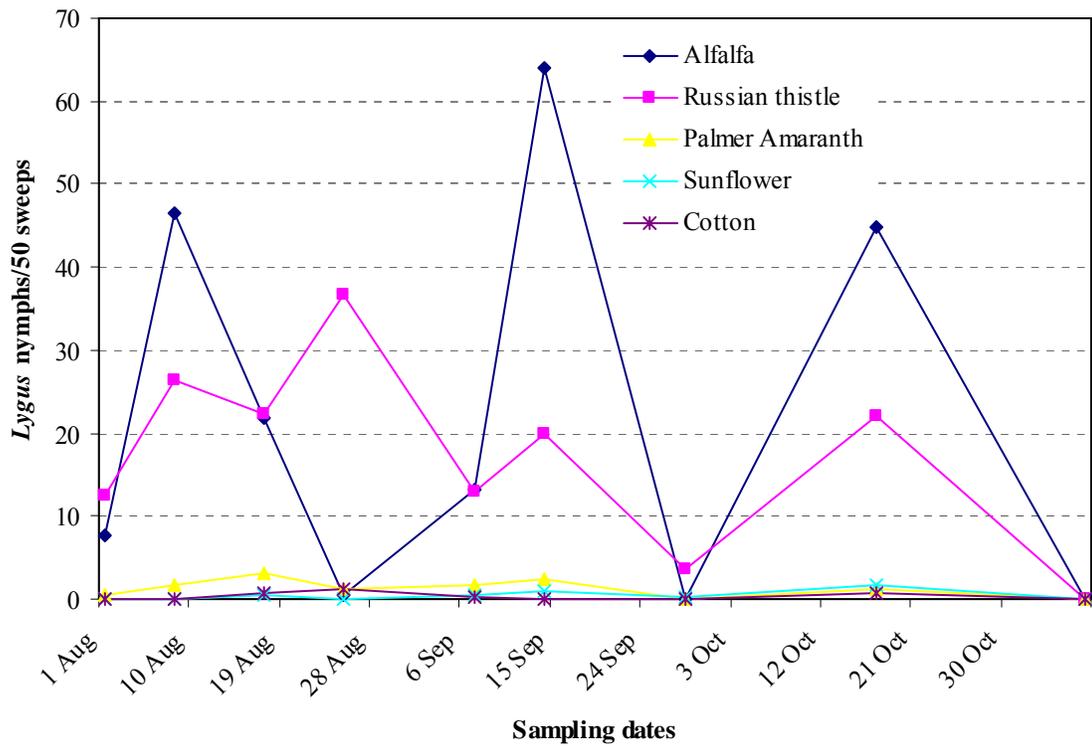Fig. 3.2. Abundance of *Lygus* adults in different hosts during the sampling periods of 2005, Lubbock, TX.

Fig. 3.3. Abundance of *Lygus* nymphs in different hosts during the sampling periods of 2005, Lubbock, TX.
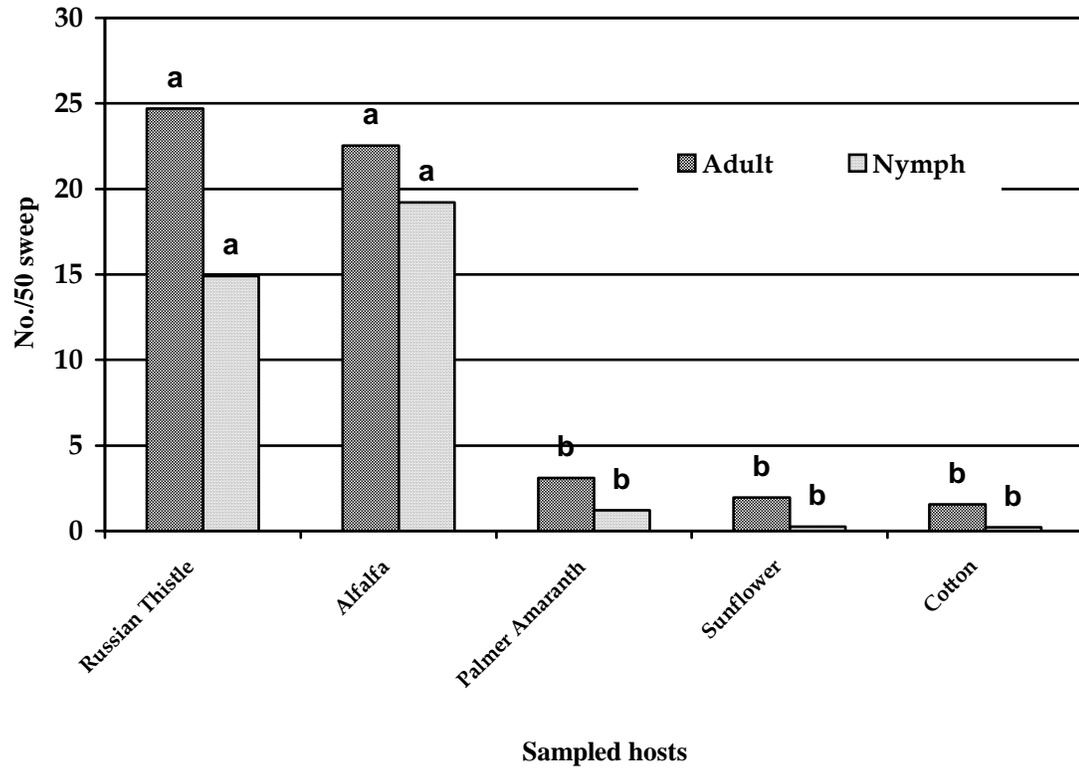
Fig. 3.4 Seasonal abundance of *Lygus* adults and nymphs in different hosts during 2005, Lubbock, TX. Treatments followed by same letters within adult or within nymph are not statistically significant.
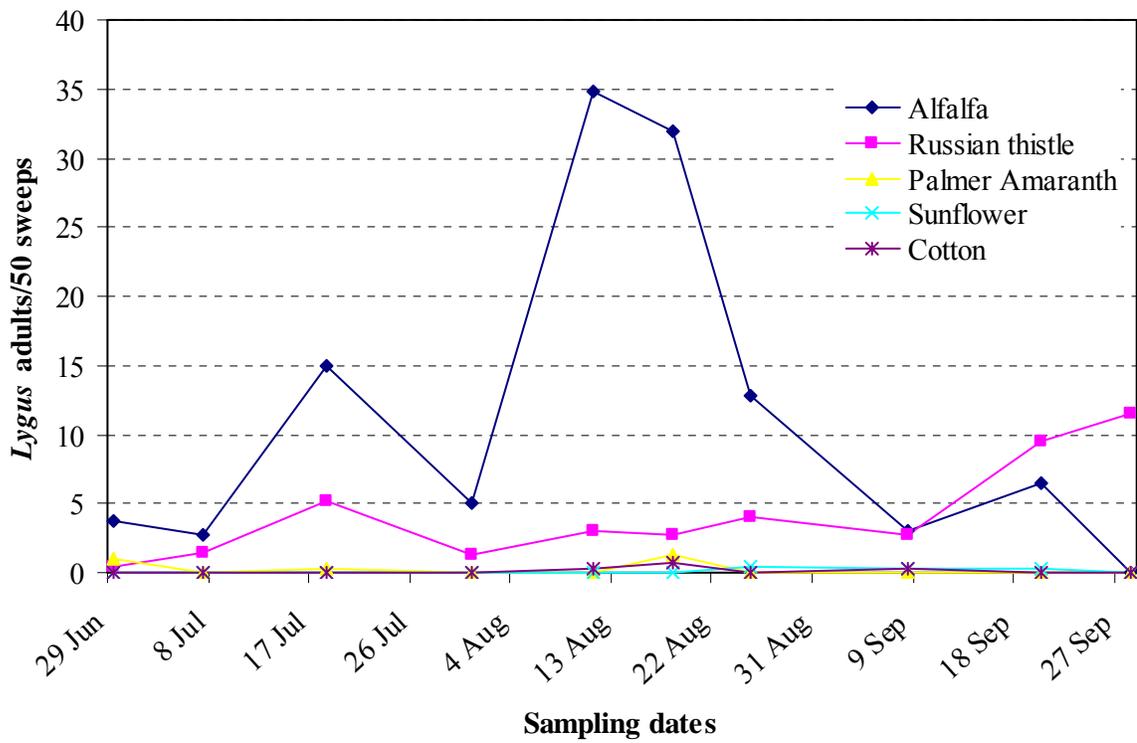
Fig. 3.5 Abundance of *Lygus* adults during the sampling periods of 2006, Lubbock, TX.
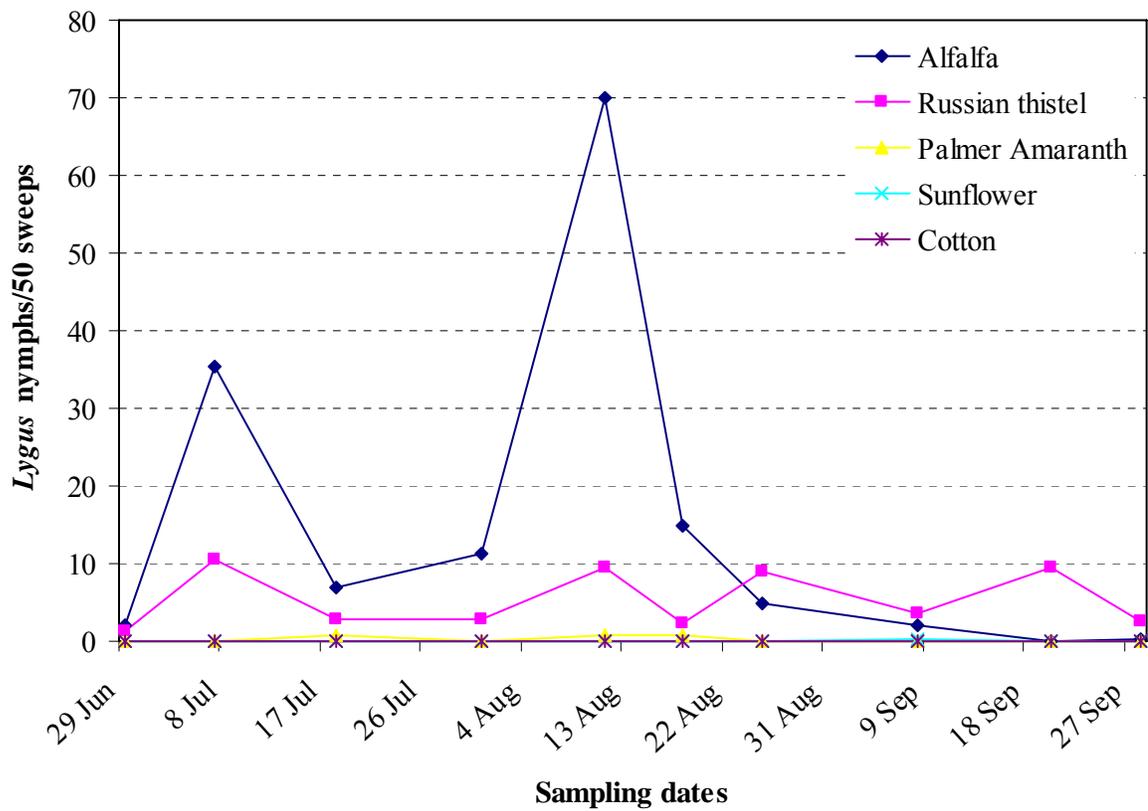
Fig. 3.6 Abundance of *Lygus* nymphs during the sampling period of 2006, Lubbock, TX.
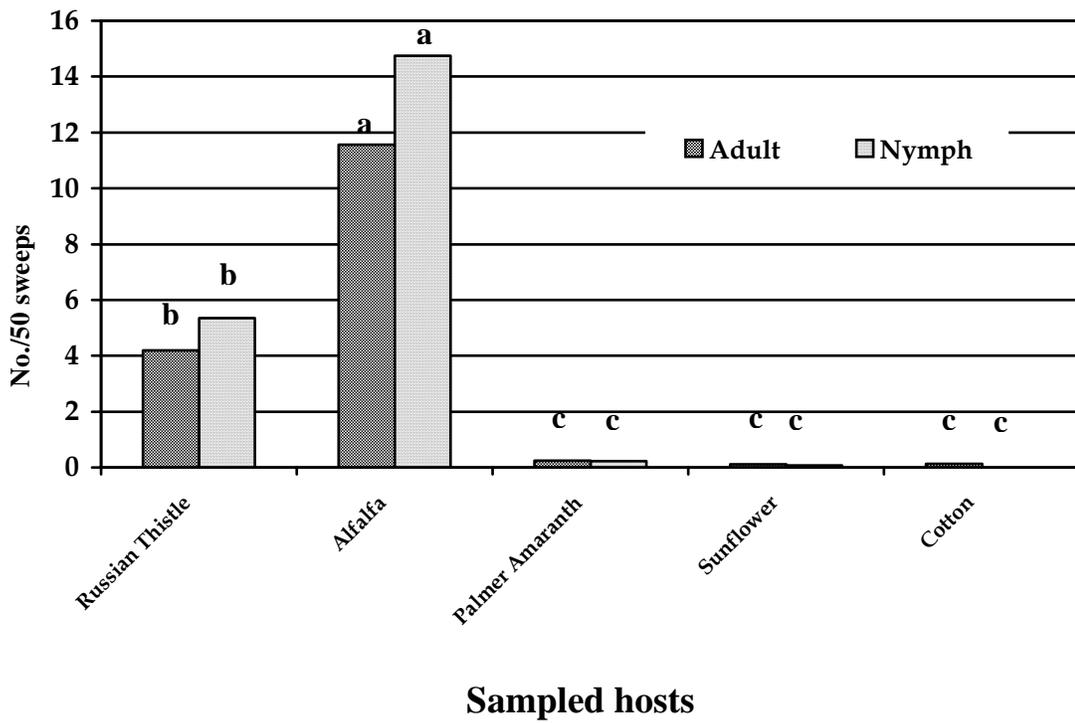
Fig. 3.7. Seasonal average of *Lygus* adults and nymphs during 2006, Lubbock, TX.
Treatments followed by same letters within adult or within nymph are not statistically
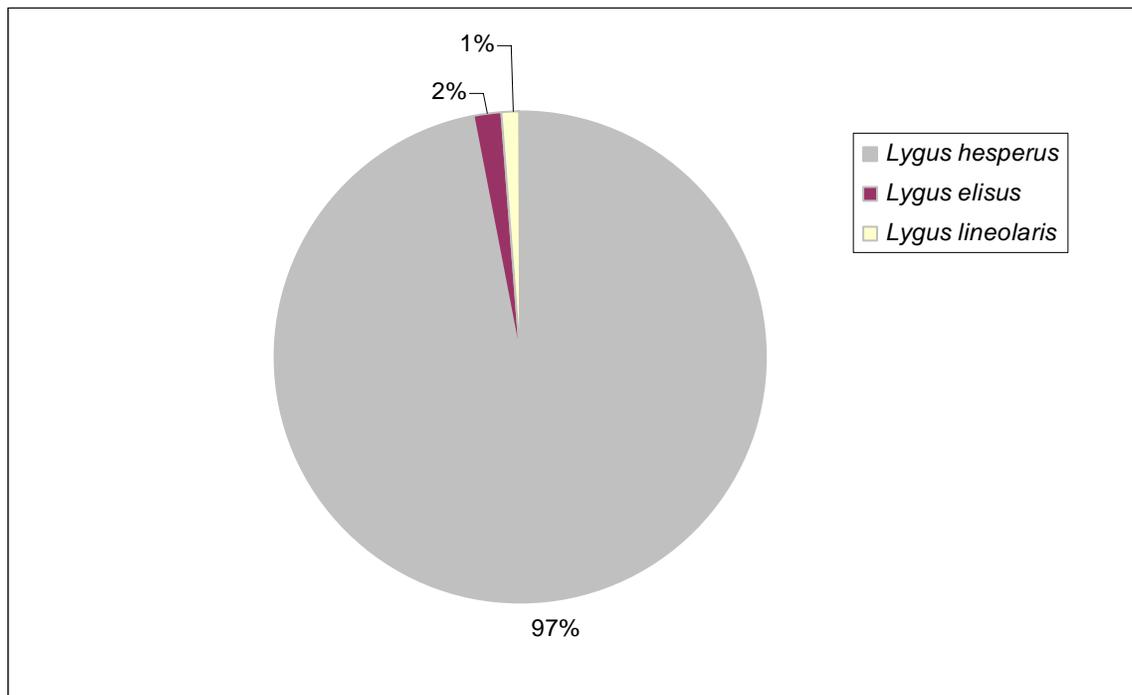significant.

Fig. 3.8. Species dominance of *Lygus* collected during 2005 and 2006, Lubbock, TX.

REFERENCES

Accinelli, G., A. Lanzoni, F. Ramilli, D. Dradi, and G. Burgio. 2005. Trap crop: An agroecological approach to the management of *Lygus rugulipennis* on lettuce. Bull. Insectology 58: 9-14.

Anderson, R. A., and M. F. Schuster. 1983. Phenology of the tarnished plant bug on natural host plants in relation to populations in cotton. Southwest. Entomol. 8: 131-136.

Bancroft, J. S. 2005. Dispersal and abundance of *Lygus hesperus* in field crops. Environ. Entomol. 34: 1517-1523.

Barman, A. K., M. N. Parajulee, S. C. Carroll, and R. B. Shrestha. 2006. Evaluation of host preference of *Lygus hesperus*, pp. 1443-1446. Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Butler, G. D., Jr. 1972. Flight times of *Lygus hesperus*. Environ. Entomol. 65: 1299-1230.

Carroll, S. C., M. N. Parajulee, and M. D. Arnold. 2005. *Lygus* survey in Texas High Plains: Species composition and host-plant sequencing, pp. 1754-1761. Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Cook, D. R., R. W. Costello, E. Burris, B. R. Leonard, and D. R. Burns. 2005. Effects of field margin vegetation management on tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) densities in cotton, *Gossypium hirsutum* (L.). International Symposium on Ecology and Management of *Lygus* Plant Bugs, Ottawa, Canada, January 30-February 3, 2005.

Craig, C. C., Jr. 1998. Development of trap crop for *Lygus lineolaris* (Heteroptera: Miridae) and a refuge for production of *Heliothis virescens* (Lepidoptera: Noctuidae) susceptible to cotton expressing insecticidal proteins. M.S. Thesis, Mississippi State University, Starkville, MS.

Craig, C. C., Jr., S. D. Stewart, R. G. Luttrell, J. Robbins, and G. L. Snodgrass. 1999. Use of alternate hosts as a trap crop for tarnished plant bug and a refuge for Bt-susceptible tobacco budworms, pp. 1056-1061. Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Demirel, N., and W. Cranshaw. 2006. Surveys of *Lygus* spp. and their movement on cultivated crops and non-cultivated habits throughout growing season on Colorado. Pakistan J. Biol. Sci. 9: 197-200.

Fleischer, S. J., and M. J. Gaylor. 1988. *Lygus lineolaris* (Heteroptera: Miridae) population dynamics: Nymphal development, life table, and Leslie matrices on selected weeds and cotton. Environ. Entomol. 17: 246-253.

Fye, R. E. 1980. Weed sources of *Lygus* bugs in the Yakima Valley and Columbia Basin in Washington. J. Econ. Entomol. 73: 469-473.

Godfrey, L. D., and T. F. Leigh. 1994. Alfalfa harvest strategy effect on *Lygus* bug (Hemiptera: Miridae) and insect predator population density: Imprecations for use as a trap crop in cotton. Environ. Entomol. 23: 1106-1118.

Goodell, P. B. 1998. Biology, ecology, and host plants of *Lygus lineolaris* and *Lygus hesperus*, pp. 949-951. Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Kareiva, P. 1983. Influence of vegetation texture on herbivore populations: Resource concentration and herbivore movement, pp. 259-290. R. F. Denno and M. S. McClure (eds.), Variable Plants and Herbivores in Natural and Managed Systems. Academic Press, New York.

Layton, M. B. 2000. Biology and damage of the tarnished plant bug, *Lygus lineolaris*, in cotton. Southwest. Entomol. 23 (suppl.): 7-20.

Mueller, A. J., and V. M. Stern. 1973. Timing of pesticide treatments on safflower to prevent *Lygus* from dispersing to cotton. J. Econ. Entomol. 67: 77-80.

Mueller, S. C., C. G. Summers, and P. B. Goodell. 2003. A field key to the most common *Lygus* species found in the Agronomic crops of the Central Valley of California. ANR Publication 8104.

Parajulee, M. N. 2006. Sampling *Lygus* bugs in west Texas, pp. 1597-1608. Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Parajulee, M. N., M. D. Arnold, S. C. Carroll, A. M. Cranmer, R. B. Shrestha, and P. L. Bommireddy. 2003. *Lygus* abundance on wild hosts: A survey across the Texas High Plains, pp. 970-973. Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Ramert, B., S. Hellqvist, B. Ekbom, and J. E. Banks. 2001. Assessment of trap crops for *Lygus* spp. in lettuce. Int. J. Pest Manage. 47: 273-276.

SAS Institue. 2003. Statistical Analysis Systems Institute Inc. Version 9.1, Cary, NC.

Scott, D. R. 1977. An annotated list of host plants for *Lygus hesperus* Knight. Bull. Entomol. Soc. Amer. 23:19-22.

Sevacherian, V., and V. M. Stern. 1974. Host plant preference of *Lygus* bugs in alfalfa-interplanted cotton fields. Environ. Entomol. 3: 761-766.

Sevacherian, V., and V.M. Stern. 1975. Movement of *Lygus* bugs between alfalfa and cotton. Environ. Entomol. 4:163-165.

Sevacherian, V., V. M. Stern, and A. J. Mueller. 1977. Heat accumulation for timing *Lygus* control measures in a safflower-cotton complex. J. Econ. Entomol. 70: 399-402.

Snodgrass, G. L., W. P. Scott, and J. W. Smith. 1984. Host plants and seasonal distribution of the tarnished plant bug (Hemiptera: Miridae) in the Delta of Arkansas, Louisiana, and Mississippi. Environ Entomol. 13: 110-116.

Stern, V.M. 1969. Interplanting alfalfa in cotton to control *Lygus* bugs and other pests. Proceedings, Tall Timber Conference on Ecological Animal Control by Habitat Management. No. 1: 55-69.

Stern, V. R., R. Van den Bosch, T. F. Leigh, O. D. McCutcheon, W. R. Sallee, C. E. Houston, and M. J. Garber. 1967. *Lygus* control by strip cutting alfalfa. UC Agricultural Extension Service. AXT-241. pp. 13.

Stewart, S. D., and M. B. Layton. 2000. Cultural controls for the management of *Lygus* populations in cotton. Southwest. Entomol. 23 (suppl.): 83-95.

Williams, M. R. 2005. Cotton insect losses estimates-2004, pp. 1105-1160. Proceedings, Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Womack, C. L., and M. F. Schuster. 1987. Host plants of tarnished plant bug (Heteroptera: Miridae) in the northern Blackland Prairies of Texas. Environ. Entomol. 16: 1266-1272.

Young, O. P. 1986. Host plants for tarnished plant bug, *L. lineolaris* (Heteroptera: Miridae). Ann. Entomol. Soc. Am. 79: 747-762.

CHAPTER IV

SUMMARY AND FUTURE RESEARCH

Behavioral response of *Lygus* bug was studied for their interaction with the cotton crop and preference for different hosts under field conditions. In response to damage due to *Lygus*, cotton plants attempt to compensate for losses and this response may vary from region to region and depending on growing conditions. This study was conducted at the Texas Agricultural Experiment Research Station at Lubbock, TX during 2005 and 2006 and results are presented in Chapter II in this thesis. Augmentative release of two levels of *Lygus* bugs (1 bug per plant and 3 bugs per plant) caused various levels of fruit loss in cotton. This variability accounts for differences in the number of *Lygus* released and crop growth stage at which they were released. During 2005, three consecutive releases of 1 bug and 3 bugs per plant at pre-bloom stage of cotton caused 31 and 48% fruit loss and at the early-bloom stage the loss was 26 and 36%, respectively. Percent fruit loss during 2006 was 19 and 30% (pre-bloom) and 31 and 34% (early bloom) for 1 bug and 3 bugs per plant, respectively. From two years of fruit loss data, it was evident that percent fruit loss of cotton did not correspond with number of bug numbers or the crop growth stages. This indicates that there are other variables (i.e., plant's inherent quality, weather parameters, soil fertility, cultivation practice and presence of other pests and predators) that influence the ensuing loss in the cotton crop and its ability to compensate from this loss. The sprayed and un-sprayed controls are two treatments which give an estimate of background fruit loss when augmentative releases of *Lygus* are excluded. In our

experiment, fruit loss in the sprayed control treatment was significantly lower, indicating that the releases of *Lygus* bugs caused considerable fruit losses. As an effect of *Lygus* bug infestation, plant height and number of main stem nodes did not increase significantly. Pre-harvest plant mapping data indicated that there was no delay in crop maturity due to *Lygus* infestation as evidenced by an insignificant number of non-harvestable bolls in bug-augmented plots compared to control plots. Cotton crop could not fully compensate for crop loss caused by both levels of bug treatment (1 and 3 bugs per plant) when releases were made in pre-bloom stage and the loss was about 227 kg/ha. Interestingly, fruit loss caused by 1 bug per plant treatment at the early-bloom stage of cotton was compensated fully as the yield in 1PP was equivalent to that in the control treatment. In general, fruit loss during early growth stages of cotton is compensated by addition of more fruits in horizontal positions at later growth stages. We also experienced a similar mechanism of crop compensation in the early-bloom, 2005 experiment. Treatment with 3 bugs per plant had significantly less yield from first nodal (vertical) positions but the second and other position yield contribution was higher in this treatment than any other treatments. This indicates that the crop tried to compensate through adding more fruits in secondary position as a response to early fruit loss.

Outcome of this research has practical implications in cotton insect pest management, particularly the *Lygus* bug. A primary concern for early infestation of *Lygus* bug in cotton is the delayed maturity. So, under the prevailing conditions of the Texas High Plains there was no observable delay in maturity from our study. It is still arguable which stage of cotton is more susceptible to *Lygus* infestation and to what extent we can

depend on the compensation ability of cotton so that there is no economic loss in final yield. What would be the consequences if a farmer decided to tolerate the early fruit loss by *Lygus* and do not use insecticides? Certainly, his action will result in better natural enemy colonization and lower the cost of insecticide applications. But how much yield will be lost or compensated for the harvest. Studies on compensation ability of cotton can also generate the threshold information for *Lygus* infestation in this crop. This information will provide growers guidance in deciding whether the field needs to be treated. Another component of present study was to evaluate the relationship between the number of *Lygus* bugs released and resultant fruit loss. In general, a higher level of insect infestation caused higher number of fruit loss. However, there was no proportional relationship between these two factors. In our study, use of 1 bug per plant was beyond the recommended threshold level for *Lygus* (20 *Lygus*/100 sweeps in two consecutive dates) for the Texas High Plains. However, in this situation the cotton crop also exhibited an ability to compensate for early fruit loss without having a need for insecticide intervention. This indicates that farmers can tolerate low levels of *Lygus* bug pressure without incurring an economic loss. To recommend anything farther, it would be necessary to investigate this phenomenon with multiple years of experiment on *Lygus* bug and cotton crop interaction on a regional basis. Detail experiments on a plant's physiological changes in response to insect attack and possible mechanism of compensatory ability of cotton plant will be helpful in selecting a particular cultivar. In conducting experiments for compensation response of cotton, optimum irrigation, soil fertility, cultivar and planting dates are some important factors that need to be considered.

The second aspect of *Lygus* behavior evaluated in this thesis was a potential host preference that can have a considerable impact in cultural control programs on a regional basis. Studies at the Texas Agricultural Experiment Station, Lubbock, TX during 2005 and 2006 clearly showed that Russian thistle could be a very important host for *Lygus* next to alfalfa when compared to Palmer amaranth and sunflower. Russian thistle is a highly prevalent weed in the Texas High Plains area, and remains in and around fields from late spring until late fall. It remains attractive until senescence and both adult and nymph were recovered on the first week of November. During the sampling period, even in the most susceptible stage of cotton (squaring and early flowering stage) *Lygus* did not move to the crop when other hosts such as alfalfa and Russian thistle were available. This indicates that *Lygus* threat to cotton in the Texas High Plains is much less when other non-cotton hosts such as alfalfa and Russian thistle are present. Unlike California and Arizona, where cotton is grown in the vicinity of alfalfa seed cultivation, Texas High Plains cotton is mostly contiguous through a large area. Therefore, there is less risk of *Lygus* pressure in cotton at any growth stage, provided other alternate hosts are present. Russian thistle can be a good indicator host of possible *Lygus* invasion into cotton and also possibly serve as a "sink" for *Lygus*. Growth of weed hosts is dependent on rainfall patterns and temperature during the growing season. A scanty rainfall pattern and high summer temperatures are likely to cause early senescence of weeds and this might cause movement of harboring *Lygus* bugs into cotton, especially when adjacent cotton is irrigated. Close monitoring of *Lygus* bug activity in nearby weed hosts can help

producers and crop managers develop more ecologically sound management options for this pest.

Predominance of *Lygus hesperus* among different species in the region was clearly evident from the samples collected during the study. Future study should be planned in examining the different factors underlying the attractiveness of these hosts to *Lygus* bug. Among several factors, plants' olfactory and visual cues are of primary importance in the process of host selection by any phytophagous insects. Laboratory studies with olfactometers can be used to observe the response of *Lygus* bugs to various plants/plant parts as well as further chemical extraction from these favored hosts may lead to developing noble behavioral tools for insect pest management.

CHAPTER V

BIOGRAPHY

Apurba K Barman was born on 15 August 1976. He is the eldest son of Mrs. Binapani Barman and Mr. Nagendra Nath Barman who presently live in Guwahati, India. He has two siblings who are continuing their education in India. Apurba received his undergraduate and M.S. (Entomology) degrees from Assam Agricultural University, India, and then worked for two years as a Senior Research Fellow at the Indian Agricultural Research Institute, New Delhi, India. He began a master's degree program at the Texas Tech University Department of Plant and Soil Science in summer 2004 and earned an M.S. (Entomology) degree in December 2006. In continuation of his pursuit for a career in entomology, Apurba has joined a Ph.D. program in Entomology at Texas A&M University Department of Entomology, College Station, Texas. While at Texas Tech University, Apurba received several awards and academic recognitions including West Texas Agricultural Institute Scholarship, Texas Tech University and Departmental fellowships, and Beltwide Cotton Conference Award for Outstanding Graduate Student Presentation (second place). Apurba has a long term goal of contributing to the science of entomology in the areas of research and academics at the university setting.