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Principles and Practices of Integrated Pest Management on Cotton in the Lower Rio Grande Valley of Texas

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1. Introduction

Sustainable agriculture is ecologically sound, economically viable, socially just, and humane. These four goals for sustainability can be applied to all aspects of any agricultural system, from production and marketing, to processing and consumption. Integrated Pest Management (IPM) may be considered a key component of a sustainable agriculture system. This publication reviews recent advances in the development of IPM programs for cotton in the Lower Rio Grande Valley of Texas. We describe annual losses caused by arthropod pests in general and by specific key insect pests, briefly showed sampling of insect populations and cotton growth stages, which importance of the proper timing of scouting procedures and treatments; and economic threshold harmfulness (ETH) for optimizing control and minimizing risk from insects. We describe effectiveness of cotton insecticides; transgenically modified cotton; microbial insecticides; native, most widely-distributed and augmentative releases of beneficial insects; and cultural control techniques for cotton insects. We also show cotton diseases and weed controls. IPM is a process that considers all control options in the proportion shown in the model of a pyramid, and it can be used to demonstrate how growers might productively construct their pest management programs.

2. What is IPM

Integrated Pest Management (IPM) has been defined as a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks (ND IPM Homepage, Texas Pest Management Association); IPM has also been defined as a knowledge-based, decision–making process that anticipates limits and eliminates or prevents pest problems, ideally before they have become established. IPM typically combines several strategies to achieve long-term solutions. IPM programs include education, proper waste management, structural repair, maintenance, biological and mechanical control techniques, and pesticide application when necessary (www.PestControlCanada.com). IPM is a pest management strategy that focuses on long-term prevention or suppression of pest problems through a combination of techniques such as 1) monitoring for pest presence and establishing treatment threshold levels, 2) using nonchemical practices to make the habitat less conducive to pest development; improving sanitation; and 3) employing mechanical and physical controls. Pesticides that pose the least possible hazard and are effective in a manner that minimizes risk to people, property, and the environment are used only after careful monitoring indicates they are needed, according to established guidelines and treatment thresholds (California Department of Pesticide Regulation, cdprweb@cdpr.ca.gov). IPM employs approaches, methods, and disciplines to minimize environmental impact, minimize risks, and optimize benefits. An expansion of the IPM concept is the process of Integrated Crop Management (ICM), which includes other agricultural decision-making tasks such as fertilizer and soil water management. An ICM program would include an IPM component to deal with pest management decisions plus address remaining issues applicable to the total crop production process (Ohio Pest Management & Survey Program, http://ohioline.osu.edu/icm-fact/fc-01.html). Thus, IPM is a system of pest management decisions based on ecological, economic, and sociological values.

2.1 Pest management practices and set of IPM principles

It may be classified according to the approach or the method used to deal with a pest problem. In terms of approach, pest management practices may be designed to prevent, suppress, or eradicate problems. Pest management practices are grouped under four categories: biological, chemical, cultural and mechanical, and legal. IPM approaches and methods are used to minimize environmental contamination, minimize risk from harmful organisms, and optimize benefits. It is a systems approach to pest management that utilizes decision making procedures based on either quantitative or qualitative observations of the pest problem and the related host or habitat (Ohio Pest Management & Survey Program, http://ohioline.osu.edu/icm-fact/fc-01.html).

The U.S. Environmental Protection Agency (EPA) has developed a useful set of IPM principles. *Acceptable pest levels* occur when pest population (s) are present but occur at densities too low to cause economic damage. Controls are applied only if pest densities increase to *action thresholds* for that particular crop. *Preventive cultural practices* involve selecting the best varieties for local growing conditions, together with plant quarantine, cultural techniques, and plant sanitation. *Monitoring plant growth* and densities of key and secondary pest species (commonly referred to as *scouting*) is a cornerstone of IPM. *Mechanical controls* include a variety traps, vacuuming, and tillage to disrupt survival and reproduction by various pest species. *Biological controls* involve the use of predators, parasitoids and pathogens to maintain pest populations at densities lower than would occur in their absence (and hopefully at subeconomic levels). *Chemical controls* which involve use of synthetic pesticides only as required and often only at specific times in a pest life cycle (Bennett et al., 2005)

Therefore, setting up an IPM program and designing a monitoring plan for a given crop should be based on the phenology of the plant and population densities of key and secondary pests.

2.1.1 Cotton production and insect diversity

Cotton production in the U. S. occurs on 30,000 farms and covers an average of 14.4 million acres (5.8 m ha) with a mean yield of 683.3 lb of lint per acre (766 kg/ha) (for 2004-2006)

(Williams, 2007). Cotton generates $6.2 billion in cash for farmers, and the total business revenue for the U.S. cotton industry is estimated at $40.2 billion per year. Texas ranks first in cotton production in the U.S., averaging 6.0 million acres (2.4 m ha) and generates $1.6 billion in cash for farmers, thus providing a total economic impact of $5.2 billion (Statistical Highlights of United States Agriculture, 2007; Agricultural Statistics, 2008). In the Lower Rio Grande Valley (LRGV) of Texas, an average of 220,000 acres (88,710 ha) of cotton were planted each year during 2004-2006 and generated an estimated $63.8 million in crop production (Lower Rio Grande Valley Cotton Blue Book, 2006)

Cotton production in the LRGV is challenged with a diversity of pests, and links the North American cotton states with those of Mexico and other South American cotton-producing areas. The most notable pest of Texas cotton production is the boll weevil (BW), *Anthonomus grandis grandis* Boheman, which entered the U.S. near Brownsville, Cameron Co, TX, during the 1890's. Other noted pests of cotton that emerged during the progression of cotton production in the LRGV were numerous lepidopterans (bollworm, *Heliothis zea* (Boddie); tobacco budworm, *Heliothis virescens* (Fabricius); beet armyworm, *Spodoptera exigua* (Hübner); cabbage looper, *Trichoplusia ni* (Hübner); black cutworm, *Agrotis insilon* (Hufnagel); fall armyworm, *Spodoptera frugiperda* (J. E. Smith); pink bollworm, *Pectinophora gossypiella* (Saunders); yellowstriped armyworm, *Spodoptera ornithogalli* (Guenée); and the leaf perforator, *Bucculatrix thurberiella* Busck); the plant sucking cotton aphid, *Aphis gossypii* Glover; stinkbugs; cotton fleahoppers, *Pseudatomoscelis seriatus* (Reuter); whiteflies, *Bemisia tabaci* (Gennadius) biotype B and *Trialeurodes abutilonea* (Haldeman); spider mite, *Tetranychus* spp.; thrips, *Thrips* spp.; cotton leafminer, *Stigmella gossyppi* (Forbes & Leonard); the verde plant bug, *Creontiades signatus* (Distant); Texas leaf cutting ant, *Atta texana*; and lubber grasshopper, *Brachystola magna* (Girard) (Cotton insects and mites: Characterization and management, 1996; French et al., 2006; Armstrong et al., 2007; Castro et al., 2007; Lei et al., 2009; Greenberg et al., 2009a and 2009b)

2.1.2 Cotton losses due to pests

A diversity of harmful organisms challenges the profitable production of agricultural crops and if left unmanaged, can result in significant losses. Estimates of crop losses vary widely by location and by year, but those are about one-third of potential global agricultural production in the form of food and fiber. Total annual losses in the world are estimated at about U.S. $300 billion (FAO, 2005). Average yield loss range from 30 to 40% and are generally much higher in many tropical and subtropical countries.

Cotton is the most important fiber crop in the world and is grown in almost all tropical and subtropical countries. Cotton production is especially threatened by insect attacks (Homoptera, Lepidoptera, Thysanoptera, Coleoptera) and by weed competition during the early stages of development. Pathogens may be harmful in some areas and years. Only recently have viruses reached pest status in South Asia and some states of the U.S. The estimates of the potential worldwide losses of animal pests and weeds averaged 37 and 36%, respectively. Pathogens and viruses added about 9% to total potential loss. The proportional contribution of crop protection in cotton production areas varied from 0.37 in West Africa to 0.65 in Australia where the intensity in cotton production is very high. Despite the actual measures, about 29% of attainable production is lost to pests (Oerke, 2006).

In the U.S. arthropod pests reduced overall cotton yield by $ 406.2 million (the mean for 2004-2006), in Texas - $ 99.3 million, and in the LRGV - $ 5.6 million (Williams 2005-2007) (Table 1).

Insect	Rank by % loss	Bales lost	Rank by % loss	Bales lost	Rank by % loss	Bales lost
	USA		Texas		LRGV of Texas	
Bollworm/Budworm	1	229,186	2	78,826	1	39,063
Lygus	2	171,478	6	10,314	0	0
Thrips	3	145,040	3	65,062	6	1,563
Fleahopper	4	119,745	1	108,057	2	26,042
Aphids	5	80,418	4	61,162	3	5,208
Stinkbugs	6	68,823	5	13,186	0	0
Spider mites	7	60,720	10	2,917	9	163
Bemisia tabaci	8	14,817	8	3,926	4	3,906
Fall armyworm	9	12,071	7	5,404	7	456
Boll weevil	10	3,190	9	3,190	5	3,190
Beet armyworm	11	1,104	12	229	8	228
Cutworms	12	1,100	0	0	0	0
Saltmarsh Caterpillars	13	237	0	0	0	0
Pink bollworm	14	232	13	28	0	0
Grasshopper	15	131	0	0	0	0
Loopers	16	144	0	0	0	0
Green Mirid	17	0	11	685	0	0
Total lost: bales*		908,436		352,985		79,818

*One bale of lint = 200kg
Source: Williams, 2007.

Table 1. Cotton losses in the United States due to insects.

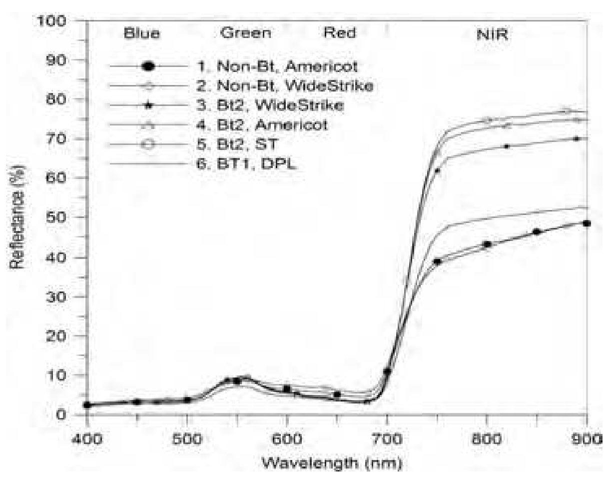
2.1.3 Sampling insect populations

IPM is a process of pest monitoring and sampling to determine the status of a pest, and, when control actions are needed, all control options are considered. Field observation (scouting) is a vital component of cotton insect control. Fields should be checked at least once and preferably twice a week to estimate the species present, the type of damage, and the level of damage which has occurred up to that point in time. Scouting should also include monitoring plant growth, fruiting, weeds, diseases, beneficial insect activity, and the effects of prior pest suppression practices. The number of samples required depends on the field (plot) size and variability. Several different sampling methods are used in IPM programs. Visual observations of plants (generally ranges from 25-100 plants;

preferred method is to examine 5 consecutive plants in 10-20 representative locations within a field); sweep net (5 sweeps per sample, and at least 20 samples per treatment); beat bucket (3-5 plants per bucket, and at least 20 samples per treatment); drop cloth (the standard length – three feet long [=0.9144 m], used if row spacing is 30 inches [=0.762 m] or wider; a minimum of 4-6 drop cloth samples should be taken per field); colored sticky traps; and pheromone traps. Some of the sampling methods are shown in Fig.1. Methods of identification and sampling procedures for cotton insect pests and beneficial are available in some sources (Steyskal et al., 1986; Cotton scouting manual, 1988; Bohmfalk et al., 2002; Spark & Norman, 2003; Greenberg et al., 2005). Scouting is not a suppression tool, but is essential in formulating management decisions. The cost of controlling insects is one of the larger items of the crop production budget, ranging from $70 to over $100 per acre (from $173 to over $247 per ha) (Pest management strategic plan for cotton in the midsouth, 2003).

Modified beat bucket method

Remote sensing technology



Yellow color sticky traps

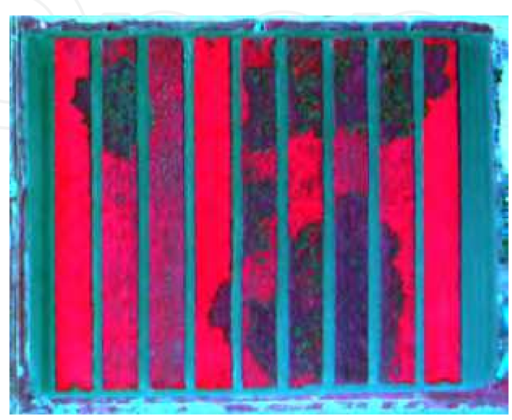


Fig. 1. Examples of sampling methods used in cotton IPM programs.

Knowledge of growth stages is important to the proper timing of scouting procedures and treatments (Table 2).

Developmental period	Calendar days		Accumulated heat units, DD60's	
	Avg.	Range	Avg.	Range
Planting to emergence	7	5-10	43	15-71
Emergence of:				
First true leaf	8	7-9	74	53-96
Six true leaf	25	23-27	239	161-320
Pinhead square	29	27-30	269	192-351
1/3 grown square	43	35-48	400	264-536
Square initiation to bloom	23	20-25	496	382-609
Bloom to: peak bloom	18	14-21	693	525-861
Full grown boll	23	20-25	751	588-912
Open boll	47	40-55	1059	1014-1105

Source: Lower Rio Grande Valley of Texas, Cotton Blue Book, 2006-2008).

Table 2. Cotton development by calendar days and heat units. Accumulated heat units, DD60's measures are in Fahrenheit (F°). Conversion degrees Fahrenheit to Centigrade (C°): C°= F° - (32*5/9).

2.1.4 Economical threshold of harmfulness

Control is needed when a pest population reaches an economic threshold (Table 3) or treatment level at which further increases would result in excessive yield or quality losses. This level is one of the most important indices in IPM for optimizing control and minimizing risk from insects.

Suppression activities are initiated when insect pest populations reach treatment thresholds which are designed to prevent pest population levels from reaching the Economic Injury Level (EIL) when economic losses begin to occur (value of the crop loss exceeds the cost of control).

Insects	Season	Economical Threshold of Harmfulness (ETH)
Boll weevil	Early Mid and Late	40 overwintered boll weevils per acre, 15-20% damage squares from squaring to peak bloom
Thrips	From 50% emergence to 3-4 true leaves	The average number of thrips counted per plant is equal to the number of true leaves at the time of inspection
Fleahoppers (FH)	All	1st-3rd weeks of squaring - 15-25 nymphs and adults per 100 terminals. After 1st bloom – treatment is rarely justified.
Aphids	All	≥50 aphids per leaf
Whiteflies	All	When ≥40% of the 5th node leaves are infested with 3 or more adults
Plant Bugs (*Creontiades* spp.)	During the first 4 to 5 weeks of fruiting	15-25 bugs per 100 sweeps
Spider Mites	All	When 50% of the plants show noticeable reddened leaf damage
Bollworm	Before bloom After boll formation	≥ 30 % of the green squares examined are worm damaged and small larvae are present 10 worms ≤ ¼-inch in length per 100 plants and 10% damage fruit for Non-Bt cottons; or 10 worms >1/4-inch in length per 100 plants with 5% damaged fruit
Beet Armyworm	All	When leaf feeding and small larvae counts exceeded 16-24 larvae per 100 plants and at least 10% of plants examined are infested; when feeding on squares, blooms, or bolls the threshold needs to be 8-12 larvae larger than ¼ inch per 100 plants
Fall Armyworm	Before first bloom	30% of the green squares are damaged
	Bolls are presented	15-25% small larvae are present per 100 plant terminals and 10-15% of squares or bolls are worm damaged

Inch =2.54 cm
Source: Norman & Sparks, 2003; Castro et al., 2007.

Table 3. Economic thresholds for some major cotton insects on cotton in the Lower Rio Grande Valley of Texas.

2.2 Insect control by synthetic chemicals

Synthetic chemicals continue to be the main tool for insect control. The total cost of pesticides applied for pest control is valued at $10 billion annually (Sharma & Ortiz 2000). Conventionally grown cotton uses more insecticides than any other single crop and epitomizes the worst effects of chemically dependent agriculture. Each year, cotton producers around the world use nearly $2.6 billion worth of pesticides, more than 10% of the world's pesticides and nearly 25% of the world's insecticides (http://www.panna.org/

files/conventionalCotton.dv.html). On agricultural crops in the U.S., about 74.1 million kg of insecticides is used. Over half of this amount is applied to cotton fields, corresponding roughly to 7.3 kg/ha of AI per hectare (Gianessi & Reigner 2006). In Texas, the direct insect management treatment cost is $115.6/ha; and, in the LRGV of Texas, the direct cost is $168.9 per hectare (Williams 2005-2007). Insecticides recommended for use on cotton are described in Table 4. Statewide, 46% of insecticides are applied aerially, 46% with ground equipment, and 8% by irrigation. Farmers perform 51% of pesticide application themselves (Lower Rio Grande Valley Cotton Blue Book, 2006-2008). Hollow cone spray nozzles are recommended for insecticide applications because they provide better foliar coverage than flat-fan or flood-jet nozzles. A straight spray boom with two nozzles per row is required for adequate coverage.

2.3 Changes in Texas cotton IPM during recent years

During recent years, there have been significant changes in Texas cotton IPM, and this system continues to evolve rapidly. These changes are occurring because of three major factors: boll weevil (BW) eradication; new and more target-specific insecticides used; and the development and use of transgenic Bt-cotton. The BW is currently the most important key pest of cotton in the LRGV of Texas where it has caused extensive damage since its appearance in 1892. Control of BW is through multiple applications of synthetic insecticides. In 1995, during the initial BW eradication program, farmers in the LRGV lost 13.5 million kg of cotton lint worth $150 million. This loss of 15% of the harvest was due to extensive ULV malathion spraying, mostly by plane, that led to massive secondary pest outbreaks of the beet armyworm (BAW) and areawide natural enemy disruption (http://www.panna.org/files/ conventionalCotton.dv.html; Summy et al., 1996). The BW eradication program in the LRGV was initiated for the second time during 2005. The second attempt at BW eradication did not trigger major secondary pest outbreaks because was initiated in the fall and reduced the heavy malathion use before the following the spring planting of cotton; improved pesticide application techniques (mostly ground rigs, helicopters versus airplane, treatments only edge strip of the fields); preventive activity; availability of target-specific pesticides for lepidopterans. Progress in the U.S. BW eradication effort where BW was successfully eradicated has resulted in a sharp decrease in the number of insecticide applications. The reduction in foliar sprays has also had an indirect effect in reducing outbreaks of secondary pests, such as cotton aphids and beet armyworm.

Cotton IPM in the LRGV of Texas has also improved due to: target specific insecticides such as Tracer and Steward for lepidopterans, (Leonard, 2006); cotton seed treatments with the systemic insecticides Gaucho Grande and Cruiser, which protect cotton from sucking insect damage for 30 days after planting (Greenberg et al., 2009, Zhank et al., 2011); reducing the application rate of insecticides without reducing efficacy of the program, for example, the malathion rate was reduced from 16-oz/ac to 12-oz/ac when oil was added as an adjuvant (Texas Boll Weevil Eradication Foundation, 2011); combination of applications for maintaining and preserving beneficial insects, lessening the environmental impacts, such as early-season spraying of cotton for overwintering BW and fleahoppers; pre-harvest application of the insecticides Karate or Guthion at half-rate with the cotton defoliant Def [synergistic effects] (Greenberg et al., 2004; 2007); termination of insecticide treatments based upon crop maturity; and improved pesticide application techniques (correct nozzle placement, nozzle type, and nozzle pressure) (Leonard et al., 2006; Lopez et al., 2008).

Class	Common name	Brand name	Recommended target pests
OP	Acephate (0.5-1.0)*	Orthene® 90S (generics)	Thrips, cutworms, *Greontiadis* plant bugs, fleahoppers, cutworm, fall armyworm
OP	Dicrotophos (0.25-0.5)	Bidrin	Thrips, plant bugs, fleahoppers, stinkbugs, aphids, boll weevil
OP	Dimethoate (0.11-0.22)	Dimethoate (generics)	Thrips, fleahopper, and *Greontiadis* plant bugs
OP	Malathion (0.61-0.92)	Fufanon ULV9.9	Boll weevil
OP	Methamidophos (0.7-2.2)	Monitor	Thrips, plant bugs, fleahoppers, whiteflies
C	Oxamyl (0.25)	Vydate® 2L	Boll weevil, plant bugs, fleahoppers
C	Methomyl (0.45)	Lannate®2.4LV	Aphids, beet armyworm, fall armyworm, fleahoppers
C	Thiodicarb (0.6-0.9)	Larvin ®3.2	Boll worm, beet armyworm, fall armyworm, tobacco budworm, loopers
CN	Imidacloprid (0.05)	Provado®1.6F	Plant bugs, fleahoppers, aphids, whiteflies
CN	Acetamiprid (0.025-0.05)	Intruder®70WP	Aphids, whiteflies, fleahoppers
CN	Thiamethoxam (0.03-0.06)	Centric® 40WG	Plant bugs, aphids, whiteflies, fleahoppers
IGR	Methoxyfenozid (0.06-0.16)	Intrepid®2F	Beet armyworm, fall armyworm, loopers
OC	Dicofol (0.75-1.5)	Kelthane® MF	Spider mites
P	Bifenthrin (0.37)	Capture or Discipline	Bollworms, fall armyworm, aphids, plant bugs
P	Cyfluthrin (0.01-0.06)	Baythroid® 2E	Cutworm, stinkbug, bollworms, boll weevil, whiteflies
P	Cyhalothrin (0.01-0.04)	Karate-Z	Cutworm, stinkbug, bollworms, boll weevil
P	Deltamelthrin (0.04-0.2)	Decis	Cutworm, stinkbug, bollworms, whiteflies, thrips
	Spiromesifen (0.094-0.25)	Oberon® 2SC	Whiteflies, spider mites
	Plant Growth Regulation	Ethephon (Prep) Mepiquart Clorade	Modified plant growth
	Defoliants	Def, Dropp, Ginstar	For early harvest

*In parentheses – rate AI lb/ac; 1 pound (lb) =0.4536 kg; 1 ac= 0.4047 ha; OP –organophosphate; C –carbamate; CN –chloro-nicotinyl; IGR –insect growth regulator; OC –organochlorine; P –pyrethroid
Source: The Pesticide Manual, 2003.

Table 4. Insecticides recommended for use on cotton in U.S.

2.3.1 Changes in the sucking bug complex – Stinkbugs, plant bugs and the cotton fleahopper

The sucking bug pests of cotton (suborder Heteroptera) have been elevated in pest status within the cotton growing regions of the United States over the past decade. Some of the most notable heteropterans are: tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois); western tarnished plant bug, *Lygus hesperus* Knight; the stinkbug complex (Pentatomidae); and the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter). This transition from being considered secondary pests and now elevated to key pest status has also coincidentally followed the functional eradication of the boll weevil from the southeastern and southern cotton belt regions. (Grefenstette and El-Lissy, 2008).

Other reasons often mentioned for increases in bugs infesting cotton with the progression of BW eradication is the adoption of varieties containing the Bt endotoxins that were being released in conjunction with eradication efforts. Over time, the number of BW was reduced, coinciding with a reduction in number of ULV malathion applications within a season, which may have been suppressing the bugs. Because lepidopteran pests were the key target at the time, Bt cotton varieties significantly reduced these pests, and, at the same time, safer, more target-specific insecticides were in development and being applied under full label. These three factors - the progress of BW eradication and the reduction of ULV malathion, the adoption of cotton varieties with BT, and the use of target-specific insecticides for control of lepidopteran pests are most often cited as the reason for changes in shift from lepidopteran management to sucking bug attacking cotton (Layton, 2000; Greene & Capps, 2003).

Some of the cotton growing regions of Texas are in the process of actively eradicating the BW from the LRGV in south Texas and the Winter Garden area (WGA) south and west of San Antonio, near Uvalde. However, the intensity of problems with the sucking bug complex and economic losses they cause varies by production region. For example, the tarnished plant bug, *L. lineolaris* (Palisot de Beavois) has increased in pest status in the southern and mid-south cotton regions following BW eradication (Layton, 2000), and has developed resistance to a wide variety of insecticides (Snodgrass, 1996; 2008). Not all bug complexes have increased or are related to BW eradication. California and Arizona had perennial problems with *L. hesperus* and *L. elisus* Van Duzee (Heteroptera: Miridae) in alfalfa and cotton before and after BW was eradicated from the cotton producing regions of these 2 states (Leigh et al., 1985; Zink & Rosenheim, 2005). Cotton damage from tarnished plant bugs results from feeding on cotton squares (flower buds), with the most significant impact when fruit abscises or drops to the ground (Tugwell et al., 1976). Further to the west in Arizona and California, the western tarnished plant bug causes similar feeding injury to cotton (Leigh T. et al., 1996).

For the last few years, the verde plant bug, *Creontiades signatus* Distant, has been reported infesting cotton grown in the LRGV and the Lower-Coastal Bend regions of south Texas, causing injury to developing lint and seed inside cotton bolls (Armstrong et al., 2009 a, 2010). The verde plant bug has increased in pest status since the initiation of the second attempt to eradicate the BW in the LRGV (2005) and from 1999 to the present in the Upper and Lower Coastal Bend production areas (Texas Boll Weevil Eradication Foundation, 2011). Feeding injury from the verde plant bug is similar to that caused by lygus bugs, but it has thus far been considered a late season pest, injuring and causing abscission in bolls <315 heat units (DD) from anthesis. Molecular and taxonomic work identified *C. signatus* as being native to the Gulf Coast of the U.S. and Mexico (Coleman et al., 2008). Reasons for increases in the densities of this new plant bug pest of south Texas can only be speculated. Some factors that may account for these increases the significant recent increase in the acres of soybean, *Glycine max* (L.) Merr., planted in the LRGV. *C. signatus* can reproduce on soybean and within the seed-head of grain sorghum, *Sorghum bicolor* (L.) Moench. Moreover, several weedy species also serve as reproductive hosts. Cotton may not be the most highly preferred host of the verde plant bug, but the bug survives on the cotton plant and has a preference for oviposition on the petioles of cotton leaves similar to other *Lygus* species (Armsrong & Coleman, 2009, Armstrong et. al, 2009 b, c).

The stinkbugs attacking cotton can be varied and complex. The most frequently encountered species are the southern green stinkbug, *Nezara viridula* (L.), the green stinkbug, *Acrosternum hilare* (Say), and the brown stinkbug, *Euschistus servus* (Say) (Hemiptera: Pentatomidae). These three species are considered the primary targets for a significant number of insecticide applications applied to cotton (Williams, 2008), most notably in the mid-south and southern cotton regions and have also been associated with elevated pest status following BW eradication (Green et al., 1999; Turnipseed et al., 2004; Willrich et al., 2004). However, in Texas, the diversity of species seems to be broader from central Texas to the Lower-Gulf Coast region south of Corpus Christi, and includes the rice stinkbug (RSB), *Oebalus pugnax* (F.); in the LRGV, Winter Garden area, and in far west Texas, there is the Conchuela stinkbug, *Chlorochroa ligata* (Say) (Muegge, 2002). Stinkbugs of all species and localities are noted for being more injurious to small to medium size cotton bolls, and, on a comparative basis, can cause more injury by lacerating thicker boll tissue, resulting in greater injury to the tissues, seed, and lint (Greene et al., 1999; Musser et al., 2009).

The most consistent early season true-bug pest of cotton in the state of Texas is the cotton fleahopper, which prefers feeding on small, primordial squares developing in the upper terminal of plants (Stewart & Sterling, 1989). When injured, the small squares abscise from the plant. However, the cotton plant is noted for compensation, and if management practices are instigated or populations decrease before the EIL is reached, losses due to fleahopper feeding injury may be negligible (Sterling, 1984). The length of the growing season is often associated with compensatory gain because of the delayed fruit set. The historical relationship between the severities of cotton fleahopper infestations with the progress of BW eradication, in the state of Texas is difficult to make, as severe fleahopper outbreaks have been noted before, during, and after an area has been functionally eradicated. The High Plains of Texas was declared functionally eradicated in 2003, but cotton fleahopper populations are as much a threat now as they were before eradication. In south Texas, cotton fleahoppers are still considered a significant pest, and BW eradication has not yet been fully realized.

With the more recent changes in the pest status of heteropteran pests of cotton, there is a greater realization of the pests' feeding injury and association with incidence of boll rot. Cotton fleahopper feeding injury to cotton squares and bolls is important because the wounds allow bacterial and fungal pathogens to enter and invade the interior of the forming fruit. Environmental conditions in the cotton field, mostly in the form of temperature, humidity, and moisture, can prevent or promote the growth of the boll rotting pathogens.

Economic thresholds established for most sucking pests are generally based on direct feeding injury and do not include boll rot as a yield-limiting factor. Square and boll rot may promote the delayed abscission of cotton fruit due to the production of ethylene by the rotting and degradation of fruiting tissue (Duffey & Powell, 1979). Cotton bolls do not normally sustain extensive damage from cotton fleahopper, due to the fact that their mouthparts (stylets) are not long enough to penetrate the wall of the boll. Boll rot pathogens have, however, been associated with direct transmission of common plant pathogen and cottonseed-rotting bacteria, *Pantoea ananatis* (Bell et al., 2006; Bell et al., 2010). The stinkbugs and plant bugs possess stylets that are long and broad enough to cause physical damage from insertion and laceration of the tissue, injection of digestive enzymes, and the ingestion of the enzymatic soup. This subsequently causes loss of boll, lint, and seed tissue, and provides an entry for pathogens that collectively may cause boll rot (Medrano et al., 2009). Even if the cotton fruit, including bolls, does not abscise, the quality and quantity of lint will be reduced.

2.3.2 Improving management options for the integrated approach to control bug pests

The plant bugs as a group have, in the past, been targeted for the discovery of host plant resistance traits that could be integrated into traditional cotton breeding programs. Host plant resistance of the cotton fleahopper and plant bugs have been studied extensively during the last four decades. The three main sources of host plant resistance identified were relatively high gossypol levels (Lukefahr, 1975), smooth (rather than hirsute) genotypes (Lukefahr, 1970), and production of nectar. No active cotton breeding programs have continued with any forms of resistance since Lidell et al. (1986) screened for glabourous, pilose, and nactariless traits. Many of these same traits were screened in cotton for the lygus bugs (Gannaway & Rummel, 1994; Tingey & Pellemer, 1977; Jenkins & Wilson, 1996). No information is available for host plant resistance for stinkbugs in cotton. Treatment thresholds for insecticide applications for these bugs have been provided in several extension-based publications that list the bug pests and insecticides used for their control. Little research-based economic injury levels (EIL) have been provided for the green plant bug, which has, thus far, been considered a late season pest. Late-season injury levels for the green plant bug, based on boll damage parameters such as boll size (diameter) and age from tagged white-blooms, has been reported by Armstrong et al. (2009c, 2010). Early season infestations occurring during the pre-bloom period have not been observed in south Texas. Economic thresholds could improve if the dynamics of confounding factors, such as the relationship of boll rot and injury levels based on bug pest densities are studied. The overwintering biology and ecology of plant bugs and stinkbugs and the means to monitor movement into the agricultural crops would be of significant use for management of stinkbugs.

2.4 Control Lepidopteran by using transgenically modified cotton

Transgenically modified cotton that expresses an insecticidal protein derived from *B. thuringiensis* Berlinger is revolutionizing global agriculture (Head et al., 2005). In 1996, it was introduced as transgenic cotton, Bollgard® (Monsanto Co., St. Louis, MO) encoding the Cry 1Ac insect toxin protein (Layton, 1997); in 2002, Bollgard II® (Monsanto Co., St. Louis, MO), which produced the Cry1Ac and Cry2Ab endotoxins (Sherrick et al., 2003); Dow

AgroSciences, LLC (Indianapolis, IN) introduced their pyramided-gene technology into the market in 2004 as Widestrike™, which produced two Bt endotoxins, Cry1Ac and Cry1Fa (Adamczyk and Gore, 2004). VipCot is new transgenic cotton. The active Bt toxin is Vip 3A, which is an exotoxin produced during vegetative stages of Bt growth (Mascarenhas et al., 2003). In the first year of commercial availability in the United States, Bollgard cotton was planted on 850,000 hectares or 15% of the total cotton area, and, by 2007, expanded to about 2.9 million hectares, or 65.8% of U.S. cotton area. However, adoption of Bt cotton has varied greatly across growing regions in the U.S., and other countries, depending on the availability of suitable varieties and, more importantly, the particular combination of pest control problems. Bollgard cotton varieties have been rapidly accepted by farmers in areas where tobacco budworm-bollworm complex (BBWC) is the primary pest problem, particularly when resistance to chemical pesticides is high. There are many factors which can affect changes in expressing the amount of stacked endotoxins. Individual lepidopteran species vary in their susceptibility to Bt proteins (Luttrell & Mink, 1999), and efficacy can be affected by protein expression levels in different plant structures (Adamczyk et al., 2008) and among different varieties (Adamczyk and Gore, 2004). Differences in susceptibility can also occur based on the geographic location of populations (Luttrell et al., 1999). The LRGV of Texas is dominated by beet armyworm, bollworm, and fall armyworm, and suitable Bt varieties have not been readily available for more rapid increase in the adoption of Bt technology.

Microbial insecticides are environmentally friendly and highly selective. Transgenic plants reduce the need for conventional insecticides, providing benefits for human health and the environment. For example, in U.S. cotton, the average number of insecticide applications used against tobacco budworm [*Heliothis virescens* (Fabricius)]-bollworm [*Helicoverpa zea* (Boddie)] complex decreased from 5.6 in 1990-1995 to 0.63 in 2005-2009 (from Proceedings of Beltwide Cotton Conferences).

Year	Bt cotton, ha	% Bt cotton of total planted	Hectares Bt sprayed	Average number applications
USA				
2005	2,994,086	51.8	1,234,855	0.54
2006	3,439,604	57.2	1,603,722	0.59
2007	2,877,114	65.8	895,232	0.50
Texas				
2005	546,898	22.6	75,061	0.78
2006	669,891	27.2	37,823	0.44
2007	929,654	47.5	22,657	0.44
LRGV of Texas				
2005	3,474	4.7	0	0
2006	2,285	5.8	0	0
2007	8,097	20.0	0	0

Source: (Williams, 2006-2008).

Table 5. Bt cotton area.

Carpenter & Ginanessi (2001) estimated that the average annual reduction in use of pesticides on cotton in the U.S. has been approximately 1,000 tons of AI . Traxler et al. (2003) estimated that the benefits gained from the introduction of Bt cotton fluctuates from year to year but averaged $215 million. The adoption of transgenic Bt-cotton is described in Table 5.

Bt types, traits, and varieties mostly used in the LRGV of Texas for the last five years (2005-2010) are shown in Table 6.

Bt type	Bt trait	Variety	Bt endotoxins	Owner of Bt trait	Owner of variety
None	Non-Bt	DPL 5415RR	None	None	Delta & Pineland
Single	Bollgard	NuCotn 33B	Cry1Ac	Monsanto	Delta & Pineland (Monsanto)
Dual	Bollgard II	DPL424 BGII/RR	Cry1Ac + Cry2Ab	Monsanto	Delta & Pineland
Dual	WideStrike	Phy485 WRF	Cry1Ac + Cry2F	Dow Agroscience	Dow Agroscience

Source: Greenberg & Adamczyk, 2010.

Table 6. Bt cottons used in the LRGV of Texas.

During the 2005-2007 seasons, the average percentage of leaf damage on non-Bt trait varieties was 1.5-fold greater than on Bollgard varieties. Leaf damage was 3.6-fold less on Bollgard II and WideStrike-trait varieties than on non-Bt cotton, and 2.4-fold less than on Bollgard-trait varieties (F = 18.8, df = 3, 36, P = 0.001, 2005; F = 15.6, df = 3, 36, P = 0.001, 2006; and F = 10.2, df = 3, 36, P = 0.009, 2007) (Fig. 2). The same trend was observed for the

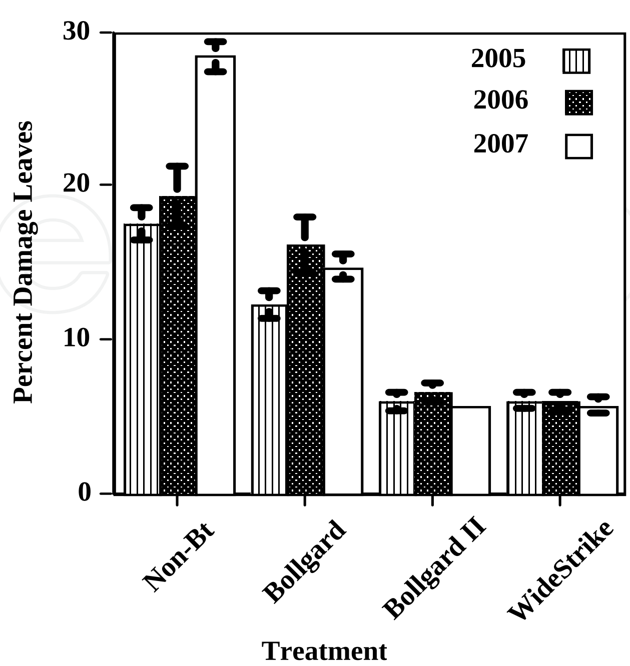


Fig. 2. Percent damage.

proportion of consumed leaves. On non-Bt cotton varieties, the index was 1.6-fold greater than on Bollgard varieties and 2.4-fold greater than on Bollgard II and WideStrike varieties. The proportion of consumed leaves on Bollgard was 1.5-fold greater than on Bollgard II or WideStrike cotton (F = 23.3, df = 3, 36, P = 0.001, 2005; F = 25.8, df = 3, 36, P = 0.002, 2006; F = 23.1, df = 3, 36, P = 0.001, 2007) (Fig. 3). The differences of leaf damage between varieties containing dual Bt endotoxins (Bollgard II and WideStrike) during the cotton-growing seasons were not significant (t = 0.440; P = 0.668) except at the end of the season (110 days of age). The damage to WideStrike cotton (Phy 485 WRF) was 1.4-fold greater than to the Bollgard II variety (ST 4357 BG2RF) (t = 4.332; P = 0.001).

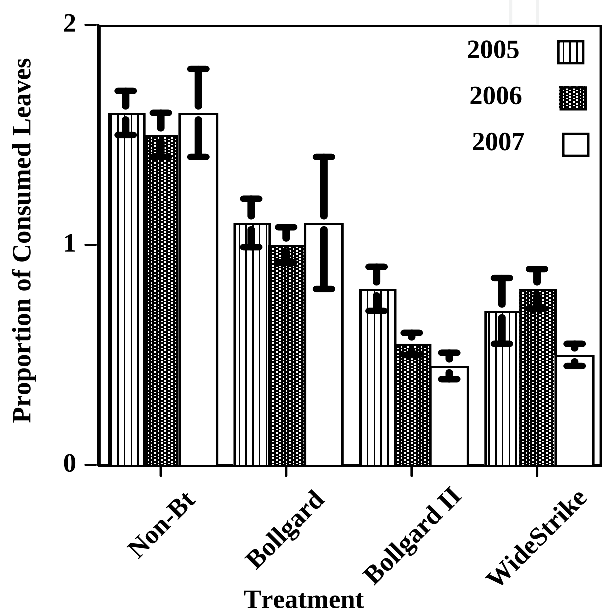


Fig. 3. Proportion of consumed leaves on different Bt trait of cotton.

The seasonal average of damage to fruit on the plant (88.5% attributed to bollworm and, to a lesser extent, beet armyworm) on non-Bt cotton (15.2%) was about 4.6-fold greater than on WideStrike (3.3%), 3.8-fold greater than Bollgard II (4.0%), and 1.7-fold greater than Bollgard (9.0%) (F = 8.9, df = 3, 31, P = 0.001). Damage by noctuids on abscised cotton fruit was 39.0% for non-Bt, 28.5% for Bollgard, 12.6% for Bollgard II, and 8.5% for WideStrike cottons (F = 17.8; df = 3, 16; P = 0.001). In non-Bt cotton, live larvae were 6.2-fold greater than on WideStrike, 4.5-fold greater than on Bollgard II, and only 1.7-fold greater than on Bollgard (F = 11.7; df = 3, 16; P = 0.001). Live larvae in fallen fruit were 92.6% bollworm and 7.4% beet armyworm (Greenberg & Adamczyk, 2010).

Bt cotton has proven itself to be a useful tool in BW eradication zones in minimizing risk of outbreaks of lepidopteran, secondary pest problems; and augmenting activity of beneficial insects.

2.5 Biorational and botanical insecticides

Some registered and produced biorational and botanical insecticides are shown in Tables 7 and 8.

Country	Product name	Based on	Target Insects
U.S.	DiPel DF or ES, Condor, Javelin WG	*Bacillus thuringiensis*	Noctuids
U.S.	Mycotrol	*Beauveria bassiana*	Sucking insects
U.S.	Naturalis	*Beauveria bassiana*	Sucking insects
U.S.	BioBlast	*Metarhizium anisopliae*	Thrips, mites, Coleoptera
U.S.-Europe	PFR-97TM	*Paecilomyces fumosoroseus*	Whiteflies, thrips
U.S.	Spinosad (SpinTor)	*Saccharopolyspora spinosa*	Noctuids, thrips

Source: The Biopesticides Manual, 2001.

Table 7. Registered and produced biorational pesticides.

Common name	Produced	Azadirachtin	Target insects
Neemix™	W.R. Grace & Co. -Conn., Columbia, MD	0.25%	Noctuids, aphids
Neemix®4.5	Certis USA, L.L.C.	4.5	Noctuids, aphids, whiteflies, thrips
Ecozin EC	Amvac, USA, CA	3.0	Noctuids, whiteflies
Agroneem	AgroLogistic Systems, Inc., CA	0.15	Noctuids

Source: Isman, 1999.

Table 8. Registered and produced botanical insecticides.

The effectiveness of some biopesticides based on *B .bassiana* and *M. anisoplia* against sucking insects is not significantly different from synthetic insecticides (Table 9), but *B. thuringiensis* showed satisfactory results against lepidopteran pests (Table 10).

Pesticides	Rate	Mortality, %			
		Young *Bemisia tabaci*	Old *Bemisia tabaci*	*Aphis gossypii*	*Thrips* spp.
B.bassiana	2gr/L	98.8 ± 0.6a	97.6 ± 1.4a	96.4 ± 2.1a	90.4 ± 1.8a
M. anisoplia	5gr/L	90.4 ± 4.8a	91.4 ± 3.1a	91.6 ± 3.6a	98.6 ± 0.8a
Neemix	41.3gr/L	41.6 ± 10.4b	26.0 ± 6.7d	72.1 ± 9.7b	51.4 ± 4.2c
Azadirect	32.3gr/L	68.0 ± 10.2b	64.6 ± 2.5c	90.4 ± 6.5a	46.7 ± 1.8c
QRD	1.3gr/gal	82.1 ± 5.5a	80.3 ± 5.5a	92.4 ±2.7a	69.1 ± 7.7b
Insecticides:					
Fulfil	0.4gr/L	-	-	100a	-
Oberon	0.2gr/L	98.9 ± 0.8a	95.9 ± 3.3a	-	-
Control (H_2O)		6.2 ± 2.0c	1.8 ± 0.8e	4.6 ± 2.0c	1.4 ± 0.9d

Source: Greenberg, unpublished data.

Table 9. Effects of different biorational and botanical pesticides on sucking insects (Greenberg, unpublished data).

Insect Larvae	Pesticides	Mortality, %
Fall armyworm	Spinosad (SpinTor), 12-150 g a.i. per ha	72.3 ± 1.6
Complex (Fall and beet armyworms, bollworm)	Spinosad, 1st spray; DiPel, 2nd spray, 100-300 g a. i. per ha	76.2 ± 3.8
Beet armyworm	DiPel	65.3 ± 3.6
Bollworm	Spinosad	71.3 ± 5.8
Bollworm	DiPel	61.3 ±2.1

Source: Greenberg, unpublished data.

Table 10. Effectiveness of biorational pesticides against lepidopteran.

Three commercial neem-based insecticides, Agroneem, Ecozin, and Neemix, were evaluated for oviposition deterrence of beet armyworm. In controls, the proportion of eggs laid on cotton leaves by beet armyworm was from 2.5 to 9.3-fold higher than neem-based treatments. Neem-based insecticides also deterred feeding by beet armyworm larvae. In controls, the mean percentage of cotton leaves eaten by first instars per day were 3-fold; third instars, 5-fold; and fifth instars,9.3-fold higher than in neem-based treatments, respectively (P<0.001). Agroneem, Ecozin, and Neemix caused 78, 77, and 72% beet armyworm egg mortality after direct contact with neem-based insecticides, respectively, while in non-treated controls, only 7.4 % mortality. Survival of beet armyworm larvae fed for 7 days on cotton leaves treated with neem-based insecticides was reduced to 33, 60, and 61% for Ecozin, Agroneem, and Neemix, respectively, compared with 93% in the non-treated controls (P=0.015) (Greenberg et al., 2005). Neem-based insecticides could control other lepidopteran, also (Isman, 1999, Ma et al., 2000, Saxena & Rembold, 1984).

2.6 Beneficial insects

Beneficial insects in conventional cotton under BW eradication or intensive pressure of synthetic insecticides can control about 10-15% of harmful insects. Native, most widely-distributed beneficial insects in the LRGV of Texas are described in Table 11.

Beneficial Insects	Target insects
Minute pirate bug, *Orius tristicolor* (White)	Aphids, thrips, whiteflies, mites, and moth eggs and small larvae
Bigeyed bug, *Geocoris uliginosus* (Say)	Mites, whiteflies, thrips, plant bug *Creontiades*, fleahoppers, and moth eggs
Lady beetles, *Hippodamia convergens* (Guerin-Meneville)	Aphids, moth eggs and small larvae
Green lacewings, *Chrysopa rufilabris* (Burmeister)	Immature feed on aphids, spider mites, whiteflies,
Syrphid fly larva	Aphids
Spider, *Hibana futilis* (Banks)	Fleahoppers, *Pseudomatoscelis seritatus* (Reuter), plant bug, *Creontiades signatus* (Distant)
Encarsia pergandiella Howard	Parasites on whiteflies nymphs
Trichogramma spp.	Egg parasite
Bracon spp.	Larva parasite mostly of lepidopteran

Source: Based on Extension Entomologists of LRGV of Texas and authors observations.

Table 11. Native, most widely-distributed beneficial insects in the LRGV of Texas.

We estimated that native parasitoids can control whiteflies in organic cotton (95-100%); sustainable agriculture cotton (80-90 %); Bt cotton (50-60%); conventional cotton (25-30%); and under BW eradication (0-5%).

One of potentially effective strategy for early-season suppression BW involves periodic augmentation an ecto-parasitoid of BW larvae such as *Catolaccus grantis* (Burks) (Summy et al., 1994)

Parasitism of boll weevils by *Catolaccus grandis* in release sites

Site	Date	Percent parasitism
Monte Alto	04.28.93	80.0
	05.05.93	52.8
	0.5.12.93	76.4
	05.19.93	78.3
	05.26.93	74.9
	06.02.93	85.2
Weslaco	05.24.94	83.3
	0.6.02.94	69.2
	06.09.94	62.5
	06.16.94	50.0

Boll weevil used : 3rd instar larva and pupa
Parasites released : Monte Alto - 1,000; Weslaco – 500 females / ac / wk

Source: Summy et al., 1994.

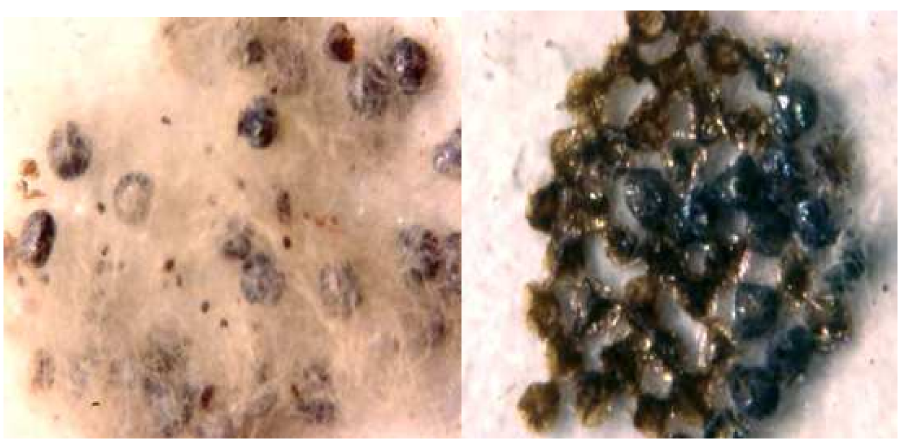
Fig. 4. Parasitism of boll weevil larvae by *C. grandis.*

The alternative to chemical control can be propagation and augmentative releases *Trichogramma* spp., an egg parasite of numerous lepidopteran species. *Trichogramma pretiosum* Riley and *T. minutum* Riley are widely use species in the USA. Some lepidopteran species distributed in LRGV, like as beet armyworm and fall armyworm, deposited hair-covering egg masses and protected a portion of eggs from parasitization. But these eggs punctured by *Trichogramma* and rapidly desiccated. The percentage of desiccated eggs tended to increase the total host mortality induced by *Trichogramma* compared with those on bollworm eggs (Greenberg et al., 1998) (Table 12, Fig. 5)

Treatment	Percentage					
	Parasitized eggs		Desiccated eggs		Total mortality	
	BAW	BWTreat	BAW	BW	BAW	BW
T. pretiosum	44.8±4.3	90.3±1.7	24.9±2.1	5.5±1.2	69.7±5.6	95.9±0.5
T. minutum	51.6±3.7	88.9±1.6	29.3±2.2	6.5±1.6	80.9±3.3	95.3±1.6
Control	0	0	5.8±1.2	4.4±1.7	5.8±1.2	4.4±1.7

Source: Greenberg et al., 1998.

Table 12. Effectiveness of *Trichogramma* spp. against noctuids on cotton.



a **a**

b

Fig. 5. *Trichogramma* parasitized beet armyworm (a) and bollworm (b) eggs.

3. Cultural control in IPM system

Among the important alternatives to insecticides in cotton are cultural control techniques. Different tillage systems are one of the most important cultural control tools. Conservation tillage has found some acceptance among growers because it reduces soil erosion, conserves soil moisture, and substantially lowers cost of field operations compared to conventionally tilled systems. In the LRGV, 30% of cotton acreage is under conservation tillage. Water availability for irrigation has become a major concern for south Texas. In this case, conservation tillage can be a valuable tool for improving soil moisture. Our results demonstrated that different tillage practices had indirect potentially positive or negative effects on pest and beneficial populations in cotton. The effects are influenced by both abiotic and biotic factors which can be created or manipulated by conventional (cv) and conservation (cs) tillage systems. Tillage operations modify soil habitats where some insect pests and beneficial insects reside during at least part of their life cycles. These modifications can alter survival and development of both soil and foliage-inhabiting insects.

Conventional tillage in dryland cotton increased water stress, causing plants to shed squares and bolls, and allocated more resources into vegetative growth. The conservation tillage cotton responded by fruiting at a higher rate. Increased plant height and number of leaves in conventional tillage provided significantly more light interception and shading of the soil surface between rows. Temperatures in conservation tillage rows were higher than in conventional tillage fields by about 15ºC and resulted in increased mortality of insects in fallen fruit (Greenberg et al., 2004, 2010).

Boll Weevil: In dryland cotton, the average number of boll weevils per plant during the 2001 cotton growing season was 2.3-fold (P=0.011) and, in 2002, - 3.5-fold (P=0.019) higher in conventional versus conservation tillage fields (Greenberg et al., 2003).

Aphids: On seedling cotton, numbers of aphids were higher in conventional tillage plots. In late spring and early summer, aphids primarily migrated to conservation tillage cotton where there was higher soil moisture and RH, and plants were more succulent and attractive to aphids than in conventional tillage.

Bollworm and Tobacco Budworm, Beet Armyworm. Fruit fallen on the ground were infested with larvae at 15.7 % higher in conventional than in conservation plots. Numbers of live larvae in infested fruit were 4.7-fold higher in conventional versus conservation tillage plots (69.3% vs. 14.7%). The number of larvae per plant was 5.9-fold higher in conventional than conservation tillage.

Cutworm. Higher infestation densities and plant damage have been observed in conservation tillage fields on seedling cotton (18.3% damaged plants in conservation tillage and 2.7 % in conventional tillage). Conservation tillage promotes the development of weeds that serve as oviposition sites for adults and alternative plant hosts for larval development (Greenberg et al., 2010).

4. Cotton diseases

A plant disease occurs when there is an interaction between a plant host, a pathogen, and the environment. When a virulent pathogen is dispersed onto a susceptible host and the environmental conditions are suitable, then a plant disease develops and symptoms become evident.

Seedling Disease Complex. Seedling disease is caused by a complex of soil fungi which may occur separately or in combinations. These fungi are *Pythium* sp., *Fusarium* sp., *Rhizoctonia solani*, and *Thielaviopsis basicola*. Symptoms include decay of the seed before germination, decay of the seedling before emergence, girdling of the emerged seedling at or near the soil surface, and rotting of root tips. Crop rotation, quality of the seed, timely planting, and the use of fungicides like Captain, Maxim, Nu-Flow ND, Nu-flow M, Vitavax, and Baytan can reduce losses to seedling diseases and are registered for commercial seed and soil treatments (Allen et al., 2010).

Root Rot. This disease, caused by the fungus, *Phymatotrichum omnivorum,* generally becomes evident during the early summer. It causes rapid wilting, followed by death of the plants within a few days. Leaves shrivel, turn brown and die, but they remain attached to the plant. The disease kills plants in circular areas ranging from a few square yards to an acre or more in size. Dead plants will remain standing in the field but can be easily pulled from the soil. Control procedures include: 1) altering the growing environment in the root zone by applying soil amendments to increase organic matter and reducing soil PH by using the chelated element sulfur and in organic trace elements zinc and iron; 2) using winter cover *Brassicae* plants as a cultural control for disease suppression; 3) fumigating infested planting holes will usually only delay the onset of disease in non-infested plants; and 4) applying sulfur in trenches 4 to 6 inches wide and 4 to 6 feet deep around the outside of the drip line of infested plants to prevent the spread of root rot. Incidence and control of cotton root rot is observed with color-infrared imagery by using remote sensing equipment (Matocha et al., 2008, 2009).

Boll Rot. This disease is prevalent in high moisture and heavy plant densities. If excessive stalk growth has occurred, one may encounter boll rot problems. Reducing some of the leaf tissue with the selective use of defoliants may be a practical answer. Good weed and insect management will decrease incidence of boll rot (Allen et al., 2010).

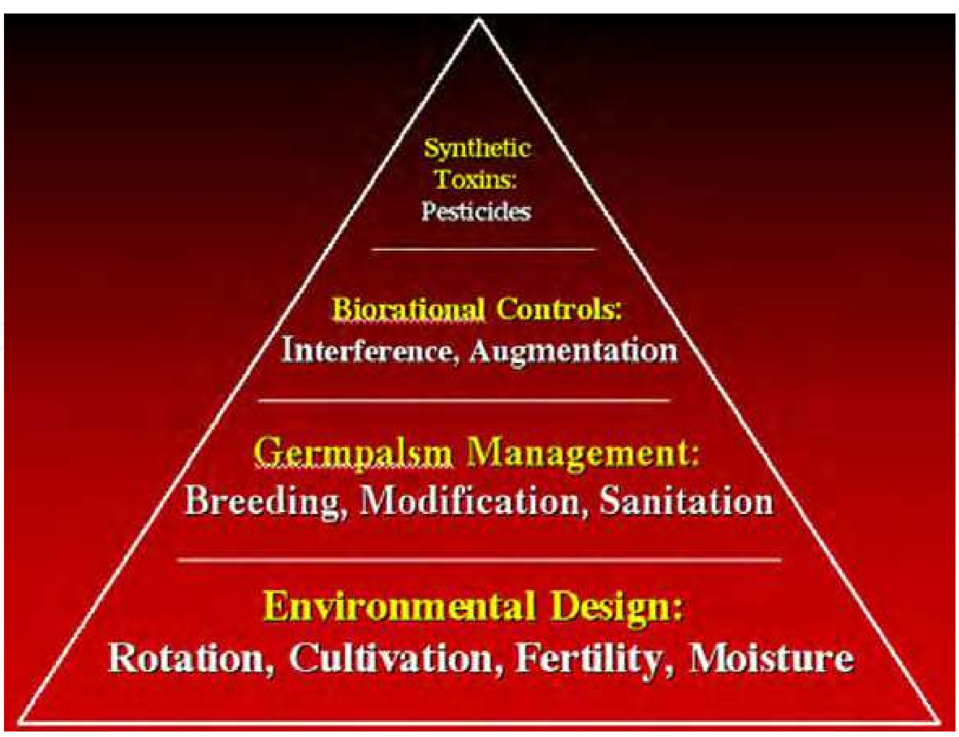
Nematodes. The nematode *Rotylenchus reniformis* Linford & Oliveria is a major problem confronting cotton production in the LRGV of Texas. Root-knot nematode, *Meloidogyne incognita* (Kofoid & White), is prevalent in sandy or sandy clay loam soils. Larvae feed on the root plants causing swellings (galls) on them. Control practices for nematodes include crop rotation and chemical control with nematicides or soil fumigants (Robinson et al., 2008).

5. Weed control

The main winter and spring weeds in cotton are common purslane (*Portulaca oleracea* L.), pigweed (*Amaranthus palmeri* Wats.), wild sunflower (*Helianthus annuus* L.), and Johnsongrass[*Sorghum halepense* (L.) Persoon]. Control is by use of a conventional tillage system, winter cover crops, and selective herbicides. Black oat (*Avena strigosa* Schreb.) and hairy vetch (*Vicia villosa* Roth) suppressed winter weeds to the same extent or more than did winter tillage in no-cover plots. In the spring, soil incorporated black oats cover was slightly more beneficial to cotton than incorporated hairy vetch, but neither cover controlled spring weeds. Two years of winter cover cropping did not obviate the need for cultivation, and hand-weeding for sustainable spring weed management in cotton in the LRGV of Texas. (Moran & Greenberg, 2008).

6. Conclusion – IPM models

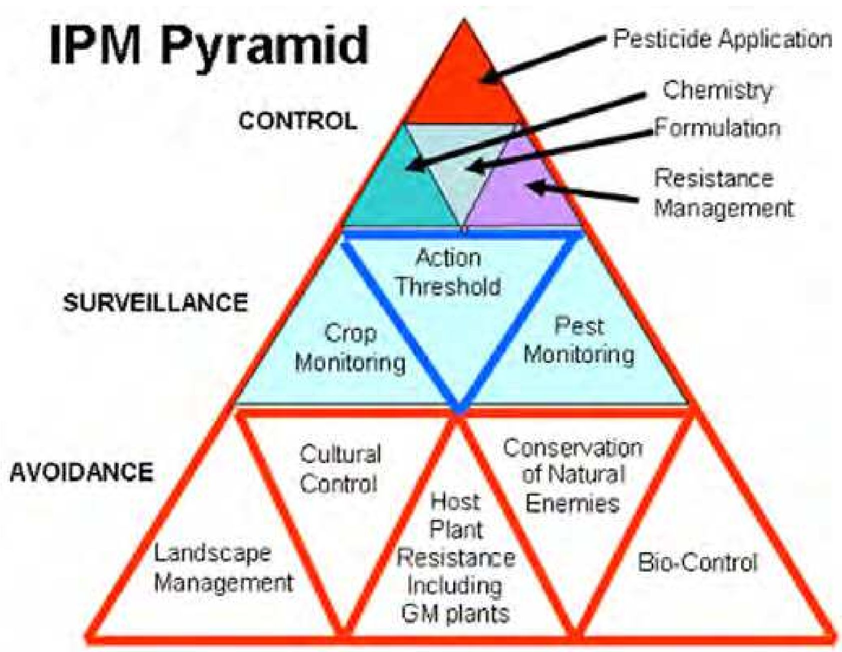
The model of a pyramid can be used to demonstrate how growers might construct their pest management programs. There are different models of pyramids, but they are basically similar. In Fig. 6 (Model #1), the foundation of a sound pest and disease management program in an annual cropping system that begins with cultural practices which alter the environment to promote crop health. These include crop rotations that limit the availability of host material used by plant pathogens, judicious use of tillage to disrupt pest and pathogen life cycles, destruction of weeds, and preparation of seed beds. Management of soil fertility and moisture can also limit plant diseases by minimizing plant stress. Environmental control can regulate in terms of temperature, light, moisture, and soil composition. However, the design of such systems cannot wholly eliminate pest problems. The second layer of defense against pests consists of the quality of crop germplasm. Newer technologies that directly incorporate genes into crop genomes, commonly referred to as genetic modification or genetic engineering, are integrating new traits into crop germplasm. The most-widely distributed are the different insecticidal proteins derived from *Bacillus thuringiensis*. Upon these two layers, growers can further reduce pest pressure by considering both biological and chemical inputs (McSpadden Cardener & Fravel, 2002).



Source: Gardener & Fravel, 2002.

Fig. 6. Model # 1.

High yields of agricultural crops can only be obtained if there is sufficient control of pests. In the mid 20th century, development of chemical pesticides seemed to provide an effective answer, but pests became resistant and, by killing natural beneficial species, resurgence of pest populations occurred. The LRGV played a key role in the acceptance of IPM concept by entomologists. The devastating outbreaks of tobacco budworm (*Heliothis virescens*) in the LRGV of Texas during the late 1960's and early 1970's (and the similar outbreaks of *Heliothis armigera* in Australia during the same period) demonstrated conclusively that unilateral reliance on pesticides for insect control was not sustainable and could lead to economic calamities. This led to the concept of integrated pest management utilizing a range of control tactics in a harmonious way (Fig.7, Model #2 adapted from Naranjo, 2001). The diagram shows the different aspects of IPM – avoidance of pest, then surveillance and finally, if necessary, control using a bio- or chemical pesticide.



Source: Naranjo, 2001.

Fig. 7. Model #2.

In Texas, IPM implies integration of approaches and methods into a pest management system, which takes into consideration that environmental impacts and economic risks have been minimized.

IPM models (Figs. 8, 9) based on conceptions of Extension Entomologists Texas A&M University System and authors of this article. No single pest control method is relied on in IPM systems. Chemical control is used only when needed (in relation to economic thresholds), and it is important to optimize their application. Nozzles need to be selected to optimize the droplet sizes so that the pesticides can be distributed where the pests are located with minimal spray drift. Monitoring (sampling) of the pest is constantly needed. Mere presence of a pest is not a reason to justify action for control.

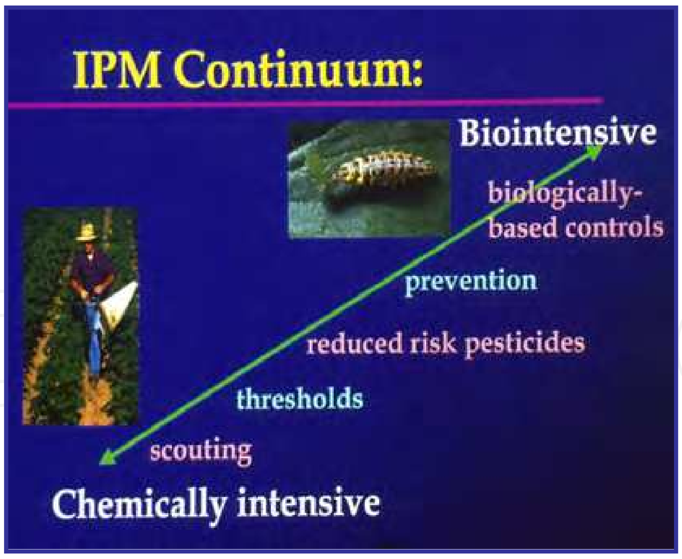


Fig. 8.

Fig. 9.

In the future, IPM is expected to continue to be dominant in agriculture. This will include increased use of reduced-risk pesticides and genetically-engineered crops. Recent surveys of both conventional and organic growers indicate an interest in using biocontrol products (Van Arsdall & Frantz, 2001). The future success of the biological control industry will depend on innovative business management, product marketing, extension education, and research (Mathre et al., 1999). These will contribute substantially to making the 21st century the age of biotechnology by the development of innovative IPM strategies.

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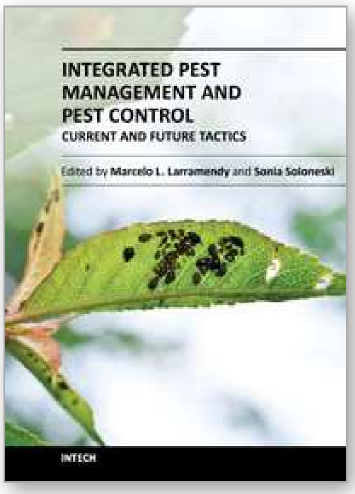

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Integrated Pest Management is an effective and environmentally sensitive approach that relies on a combination of common-sense practices. Its programs use current and comprehensive information on the life cycles of pests and their interactions with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means and with the least possible hazard to people, property, and the environment.

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