RISK ASSSESSMENT: THE OLD WORLD BOLLWORM, *Helicoverpa armigera* (Hubner), (LEPIDOPTERA: NOCUTIDAE)

USDA-APHIS-PPQ-CPHST-PERAL

Section A

Scientific name: ***Helicoverpa armigera*** **(L.)**

Order: Lepidoptera

Family: Noctuidae

Common Name: Old world bollworm

Figure 1. ***Helicoverpa armigera*** **eggs (a), larva (b) and adult (c) (Photos (a) by BASF, (b) and (c) by Courtin R./OPIE 1998).**

Purpose:

The United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS) has developed an Internet accessible list of plant pests (http://www.aphis.usda.gov/ppq/regpestlist). The purpose of the list is to provide trading partners an official USDA-APHIS list of Regulated Plant Pests of concern to the U.S., and to provide focus to APHIS' safeguarding activities including pre-clearance inspection at ports of entry, exotic pest surveys, and eradication activities. Periodically, recommendations are received that propose the addition of new plant pests to this list. This Pest Risk Assessment (PRA) was developed as part of the process for determining whether a plant pest should be added to the Regulated Plant Pest list. The PRA accomplishes this by evaluating the risk to American agriculture, managed and natural ecosystems, should the specified organism be introduced in the U.S. Likely pathways for introduction have been evaluated; however, they were not included in the final evaluation of this organism, since new and unforeseen pathways may develop overnight.

Description:

Eggs: The eggs are approximately 0.2 inches (0.5 cm) long and whitish in color. Over time the eggs darken and are grayish brown prior to hatching (King 1994) (Figure 1a).

Larva: Larva emerge yellowish white and become darker in later instars. Color patterns in the later instars will vary depending on diet. Coloration ranges from bluish green to brownish red. A full grown larva is approximately 1.6 inches (4 cm) long (Figure 1b).

Pupa: The pupa is approximately 0.8 inches (2 cm) long with brownish coloration.

Adult: The adult moth is stout bodied and has a wingspan of 1.6 inches (4 cm). The body is 0.8 inches (2 cm) long. Coloration ranges from greenish yellow to light brown with females being darker than males (Figure 1c).

Life History:

Helicoverpa armigera, the old world bollworm, is a moth belonging to the family Noctuidae. This moth is a major pest threat because the larva can feed on a wide range of economically important crops including cotton, corn, tomato, legumes and tobacco (King 1994, Shanower and Romeis 1999). In addition to feeding on high value crops the old world bollworm is an extremely dangerous pest because: 1) it is extremely fecund, 2) it can sustain itself on over 180 different plant species, 3) it can undergo diapause during adverse conditions and 4) it can migrate over long distances (Manjunath *et al*. 1989, Shanower and Romeis 1999). To make matters worse, the bollworm has evolved a high degree of resistance to organophosphate and pyrethroid insecticides (Armes *et al*. 1996).

Helicoverpa amigera larva are extremely damaging because they prefer to feed and develop on the reproductive structures of crops which are rich in nitrogen (Fitt 1989). These structures are often the part of the crop that is harvested (King 1994). Depending on the crop, bollworm induced damage can range from 50 to 90 percent of the yield (Reed and Pawar 1982, Sehgal and Ujagir 1990).

The life cycle is as follows:

1. Eggs are laid on the reproductive structures of plants and incubate for approximately 3-14 days depending on temperature (Pearson 1958, Shanower and Romeis 1999, Fitt 1991).

2. Newly hatched larva eat the egg sheath and then wander in search of a good site to feed (King 1994). Preferred feeding sites include flowers, buds, bolls and leaves. The number of larval instars and the duration of the larval period will fluctuate depending on the host plant and the temperature (Shanower and Romeis 1999). Typically there are 5-7 instars and a larva period of 12-32 days before pupation occurs (Rajagopal and Channa Basavanna 1982, Reed 1965).

3. Pupation occurs in the ground between 1.2 inches (3 cm) and 7.1 inches (18 cm) (King 1994). The prepupal stage will last for 1-4 days. The pupal period will take 10-14 days if the bollworm is not in diapause (Shanower and Romeis 1999). If in diapause, the pupal period can take several months to complete.

4. Adult moths emerge from just after dark to midnight and crawl onto a plant or vertical substrate where their wings dry (King 1994). Moths feed on nectar, females release sex pheromones and mating occurs approximately 4 days after emergence (Hardwick 1965, Pearson 1958, Ramaswamy 1990).

5. After a pre-oviposition period of 1-4 days, females will begin to oviposit in the reproductive structures of the crop (Fitt, 1990, Jayaraj 1982). Oviposition occurs after dark with females can laying up to 3,000 eggs each (Shanower and Romeis 1999).

The old world bollworm is extremely well adapted to agroecosystems and can exhibit up to 11 generations a year under good conditions (Shanower and Romeis 1999). To compound the problem of control, the bollworm exhibits overlapping generations in the field.

The bollworm has evolved 2 major strategies for adapting to adverse conditions. First, it has excellent migratory abilities and can fly up to 155 miles (250 km) in search of a viable food source (McCaffery *et al*. 1989). Secondly, it has the ability to enter into a facultative diapause when conditions become too hot or cold (King 1994). This allows the bollworm to survive until environmental conditions improve.

Native Distribution:

Continents and Countries where *Helicoverpa amigera* is currently found include: Africa, India, Asia (central and southeastern regions), Japan, the Philippines, the Middle East, Europe, Australia and New Zealand (Pearson 1958, Fitt 1989).

Current distribution in the United States, and history of introduction: None

Projected distribution in the United States if Introduced:

If introduced it is probable that *H. armigera* could establish in every state in the continental U.S. based on habitat and host suitability (**Conservative estimate**). *Helicoverpa armigera* would probably pose the greatest economic threat to the following states: Alabama, Arizona, Arkansas, California, Georgia, Illinois, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Nebraska, New Mexico, North Carolina, Ohio, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Virginia and Wisconsin (Figures 7 and 8).

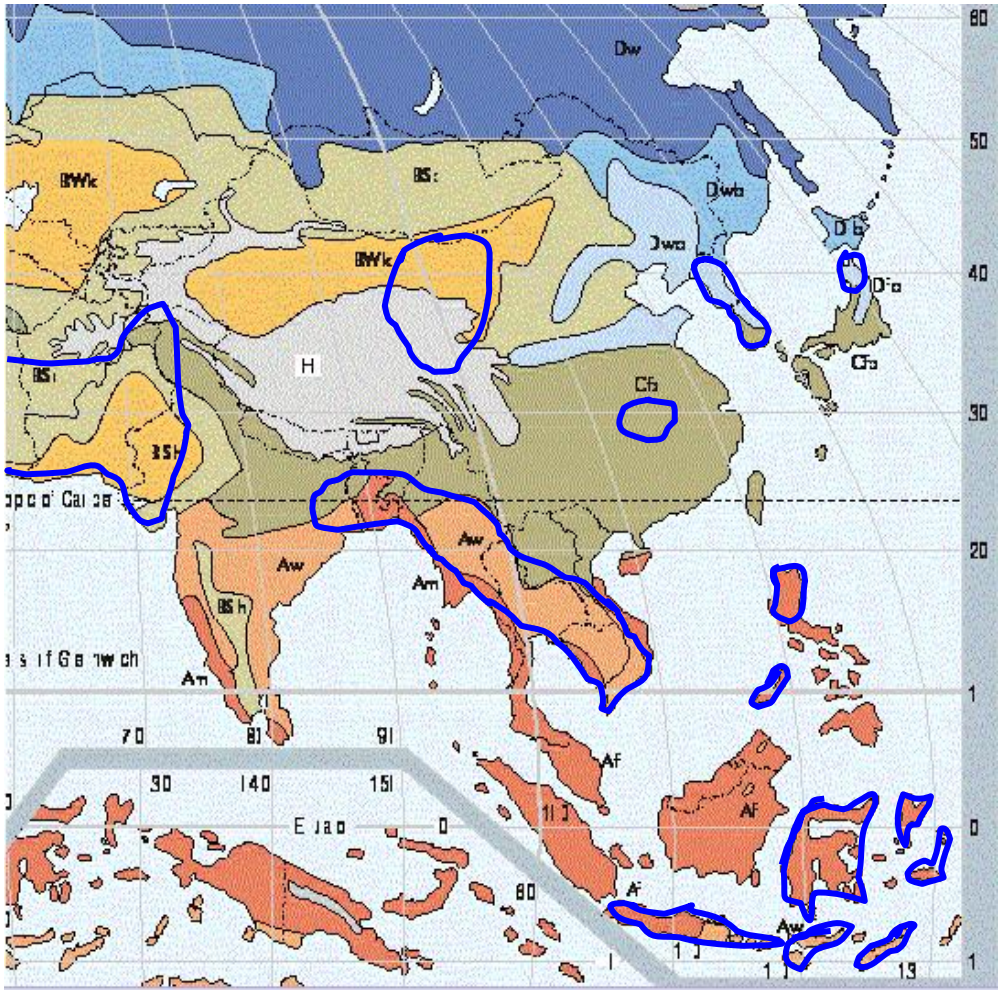

Figure 2. Approximate *H. armigera* distribution in Asia (Crop Protection Compendium 2000).

KOPPEN WORLD CLIMATES (Kimmel 2000)

A.	**HUMID EQUATORIAL CLIMATE**
Af	No dry season
Am	Short dry season
Aw	Dry winter
B.	**DRY CLIMATE (h = hot, k = cold)**
BS	Semiarid
BW	arid
C.	**HUMID TEMPERATE CLIMATE**
Cf	No dry season
Cw	Dry winter
Cs	Dry summer
D.	**HUMID COLD CLIMATE**
Df	No dry season
Dw	Dry winter
E.	**COLD POLAR CLIMATE**
ET	Tundra climate
EF	Icecap Climate
H.	**HIGHLAND AREAS**
	a = hot summer
	b = cool summer
	c = short cool summer
	d = very cold winter

Koppen maps courtesy of Lewis 2000.

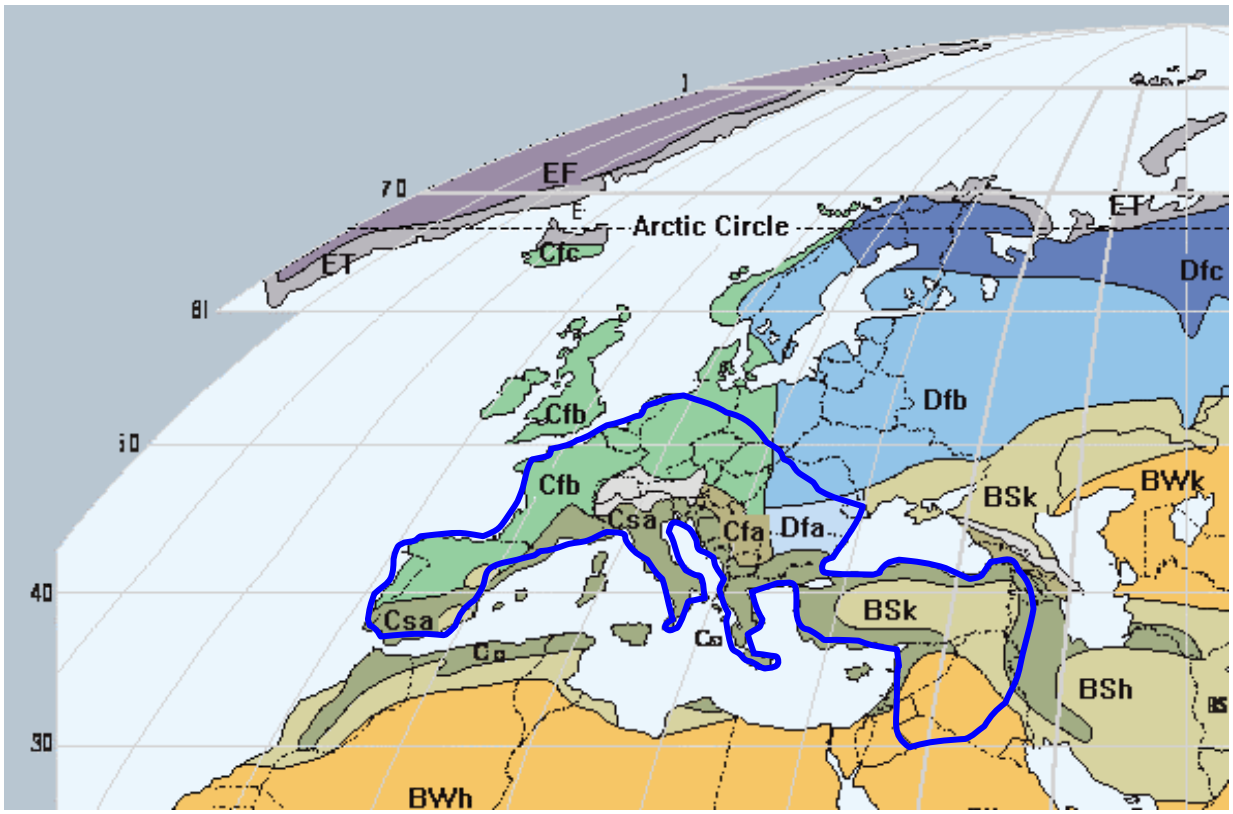

Figure 3. Approximate *H. armigera* distribution in Europe and the Middle East (Crop Protection Compendium 2000).

KOPPEN WORLD CLIMATES (Kimmel 2000)

A.	**HUMID EQUATORIAL CLIMATE**
Af	No dry season
Am	Short dry season
Aw	Dry winter
B.	**DRY CLIMATE (h = hot, k = cold)**
BS	Semiarid
BW	arid
C.	**HUMID TEMPERATE CLIMATE**
Cf	No dry season
Cw	Dry winter
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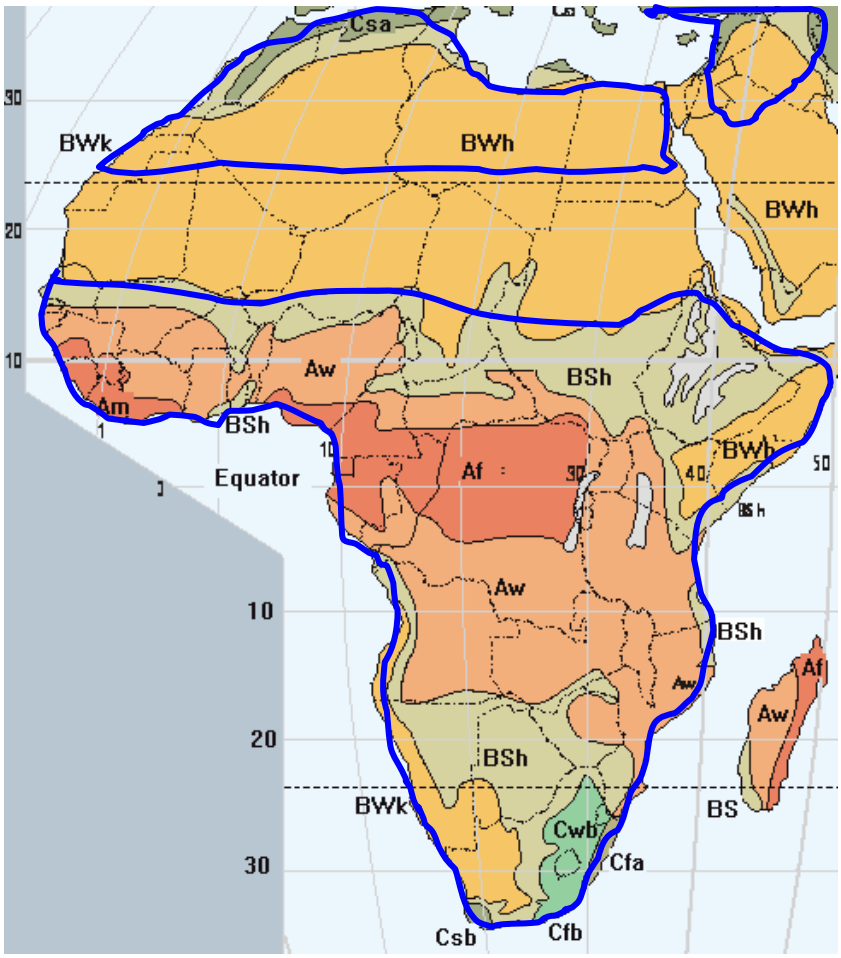

Figure 4. Approximate *H. armigera* distribution in Africa (Crop Protection Compendium 2000).

KOPPEN WORLD CLIMATES (Kimmel 2000)

A.	**HUMID EQUATORIAL CLIMATE**
Af	No dry season
Am	Short dry season
Aw	Dry winter
B.	**DRY CLIMATE (h = hot, k = cold)**
BS	Semiarid
BW	arid
C.	**HUMID TEMPERATE CLIMATE**
Cf	No dry season
Cw	Dry winter
Cs	Dry summer
D.	**HUMID COLD CLIMATE**
Df	No dry season
Dw	Dry winter
E.	**COLD POLAR CLIMATE**
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Koppen maps courtesy of Lewis 2000.

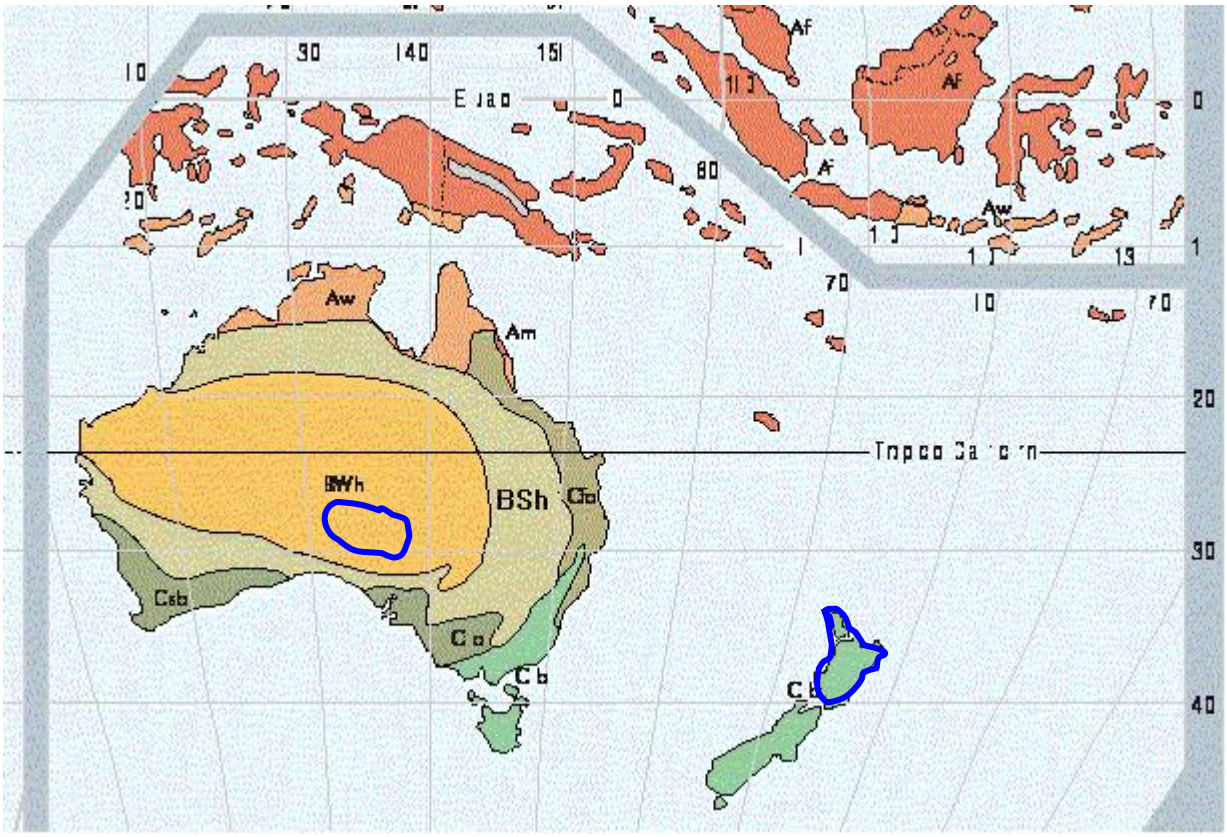

Figure 5. Approximate *H. armigera* distribution in Australia (Crop Protection Compendium 2000).

KOPPEN WORLD CLIMATES (Kimmel 2000)

A.	**HUMID EQUATORIAL CLIMATE**
Af	No dry season
Am	Short dry season
Aw	Dry winter
B.	**DRY CLIMATE (h = hot, k = cold)**
BS	Semiarid
BW	arid
C.	**HUMID TEMPERATE CLIMATE**
Cf	No dry season
Cw	Dry winter
Cs	Dry summer
D.	**HUMID COLD CLIMATE**
Df	No dry season
Dw	Dry winter
E.	**COLD POLAR CLIMATE**
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Koppen maps courtesy of Lewis 2000.

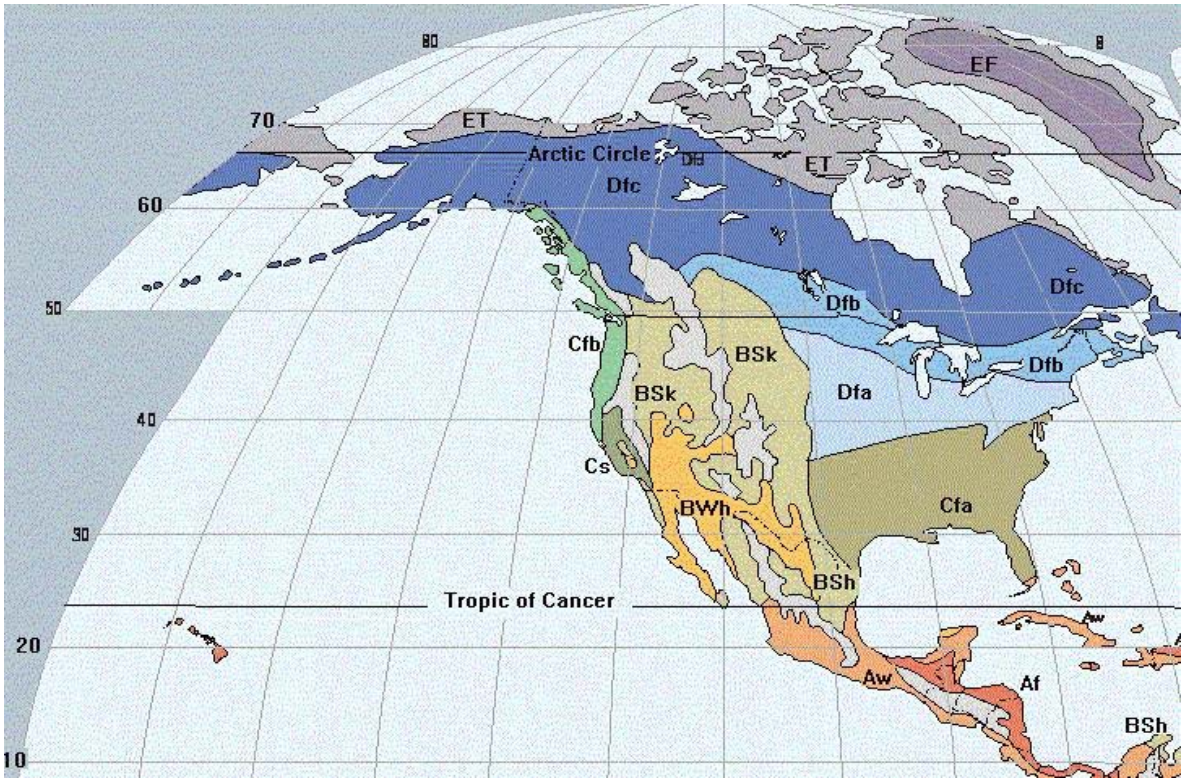

Figure 6. Koopen classification of North America.

KOPPEN WORLD CLIMATES (Kimmel 2000)

A.	**HUMID EQUATORIAL CLIMATE**
Af	No dry season
Am	Short dry season
Aw	Dry winter
B.	**DRY CLIMATE (h = hot, k = cold)**
BS	Semiarid
BW	arid
C.	**HUMID TEMPERATE CLIMATE**
Cf	No dry season
Cw	Dry winter
Cs	Dry summer
D.	**HUMID COLD CLIMATE**
Df	No dry season
Dw	Dry winter
E.	**COLD POLAR CLIMATE**
ET	Tundra climate
EF	Icecap Climate
H.	**HIGHLAND AREAS**
	a = hot summer
	b = cool summer
	c = short cool summer
	d = very cold winter

World Distribution for *H. armigera* (Koppen Classification)

Af, Am, Aw
BSh, BSk, BWh, BWk
Cfa, Cfb, Csa, Csb, Cwb
Dfa, Dfb, Dwa
H

Koppen maps courtesy of Lewis 2000.

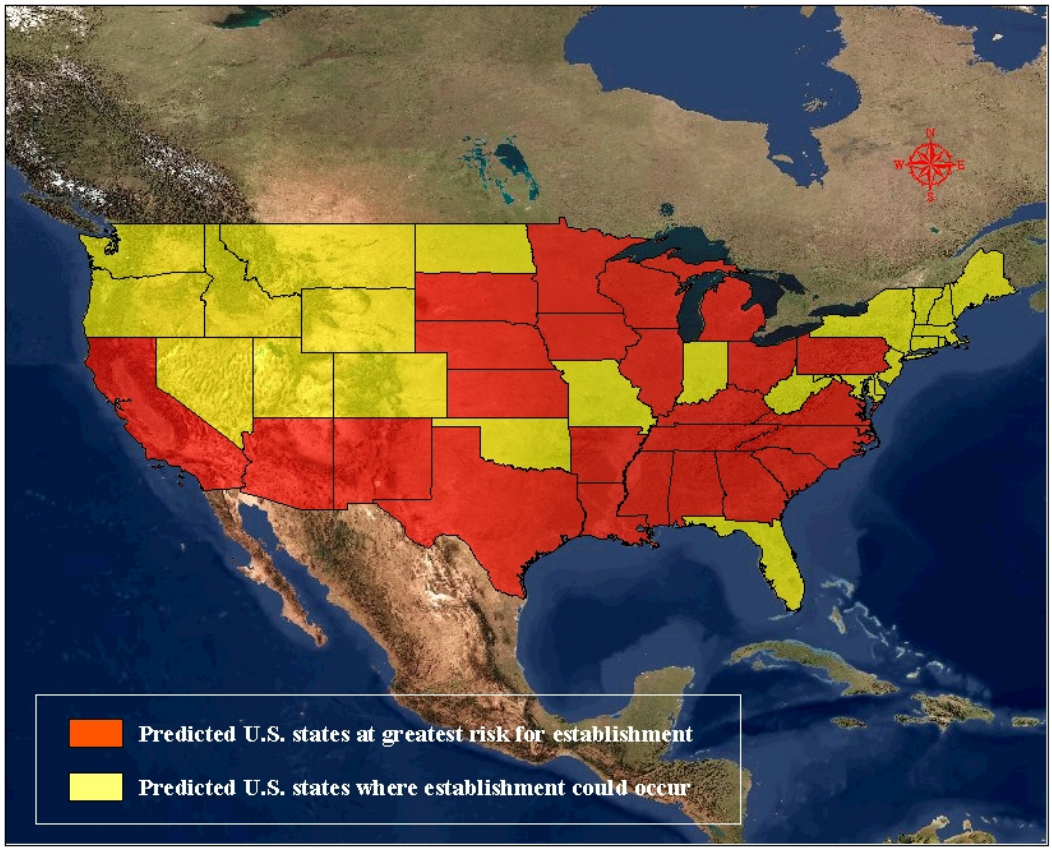

Figure 7. States at greatest risk for *H. armigera* establishment based on habitat suitability and commercial host presence. Note that *H. armigera* could establish in every state in the U.S.

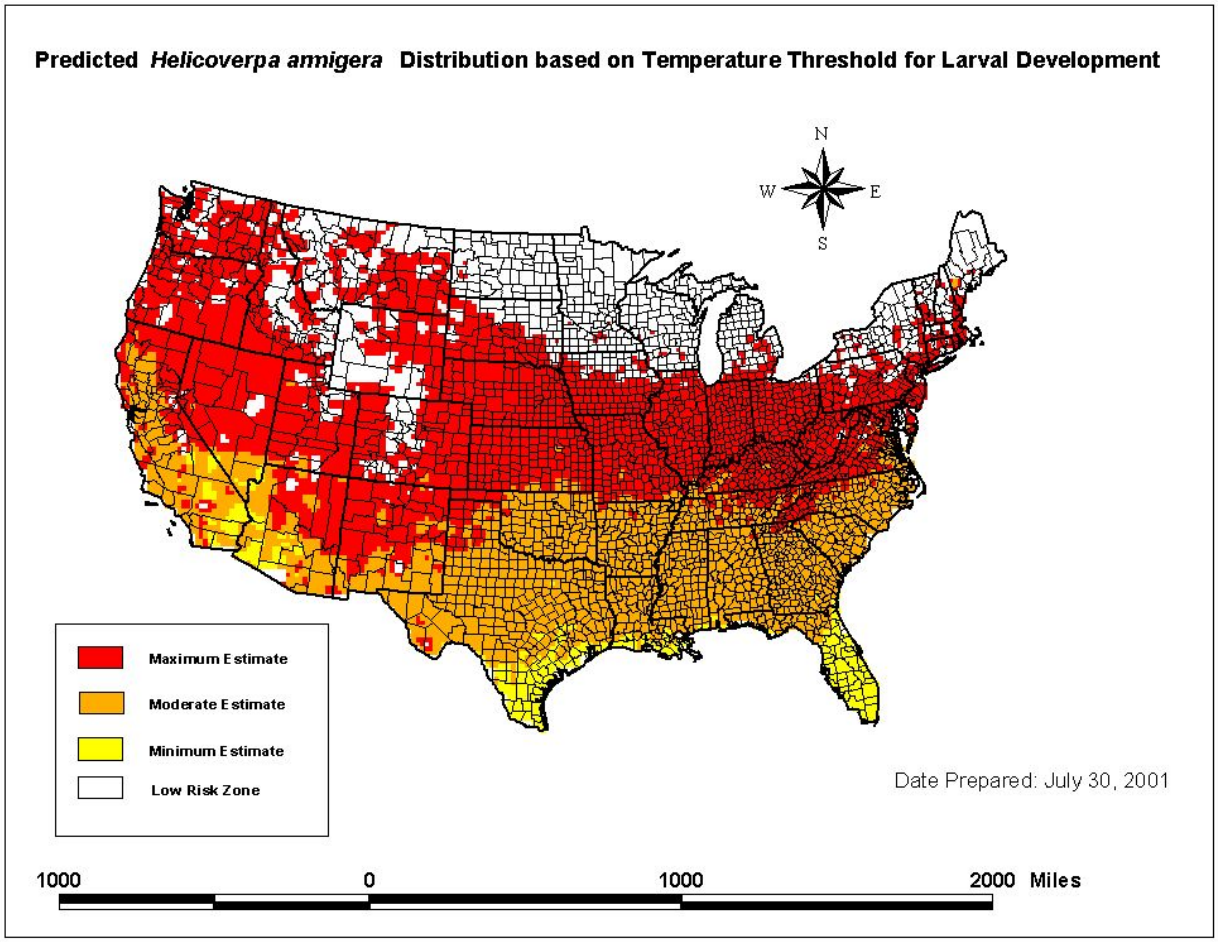

Figure 8. Predicted distribution of *H. armigera* based on larval development thresholds of 57.2°F and 96.8°F (Crop Protection Compendium 2000). Minimum, moderate and maximum distributions based on mean daily minimum, average and maximum temperature respectively.

Section B: Consequences of Introduction

Risk element 1: Habitat suitability in the United States

Rating	Numerical Score	Explanation
High	**3**	Attacks and survives on hosts in 4 or more plant hardiness zones
Medium	2	Attacks and survives on hosts in 2 or 3 plant hardiness zones
Low	1	Attacks and survives on hosts in at most a single plant hardiness zone

Rank: High

Helicoverpa armigera's current world distribution includes the following Koopen climate zones: Af, Am, Aw, BSh, BSk, BWh, BWk, Cfa, Cfb, Csa, Csb, Cwb, Dfa, Dfb, Dwa and H (Figures 2, 3, 4 and 5) (Lewis 2000). Comparable regions found in the United States are: Aw, BSh, BSk, BWh, Cs, Cfa, Cfb, Dfa and Dfb (Figure 6). These Koopen climate zones make up the entire continental United States.

Every State in the U.S. grows suitable host crops for *H. armigera* commercially (United States Department of Agriculture-National Agricultural Statistics Service 1992, 1997 and 2000a). States growing primary host of *H. armigera* commercially, *e.g*. cotton, corn tomato and tobacco, include: Alabama, Arizona, Arkansas, California, Georgia, Illinois, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Nebraska, New Mexico, North Carolina, Ohio, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Virginia and Wisconsin (United States Department of Agriculture-National Agricultural Statistics Service 1992, 1997, and 2000a). If Introduced, *H. armigera* would probably pose the greatest economic threat to these states. It should be noted that ***H. armigera* is highly polyphagous** (King 1994). Consequently, the above estimate for habitat suitability is **highly conservative**.

The predicted range for *H. armigera* based on habitat suitability and hosts availability includes 8 USDA plant hardiness zones (3-10) (United States Department of Agriculture 1990). This confers *H. armigera* a **high risk rating** for habitat suitability in the United States.

Risk element 2: Host range or Plant damage potential

Rating	Numerical Score	Explanation
High	**3**	Insect attacks multiple species within multiple host families
Medium	2	Insect attacks multiple species within a single host family
Low	1	Insect attacks only a single species or multiple species within a single genus

Rank: High

Helicoverpa armigera has been shown to attack multiple species within over 13 familes (Crop Protection Compendium 2000). This confers *H. armigera* a **high risk rating for host range or plant damage potential**.

Economically important crops that *H. armigera* attacks include cotton, tomato, chickpea, field beans, soybeans, tobacco, potatoes, corn, stone fruits, citrus crops, onions, wheat and curcurbits (Crop Protection Compendium 2000).

Risk Element 3: Spread potential after establishment, Dispersal potential

	Dispersal Considerations
X	Consistent and prolific reproduction (Shanower and Romeis 1999)
X	Rapid growth to reproductive maturity (Rajagopal and Channa Basavanna 1982, Reed 1965)
X	Wide range of hosts (Manjunath et al. 1989, Shanower and Romeis 1999)
X	Tolerant to temperature extremes (King 1994)
	Phoresy, *i.e*. dispersal by utilizing another organism
X	Ability to utilize different host during different life stages (Shanower and Romeis 1999)
	Social behavior
X	Migratory behavior/Swarming behavior (McCaffery *et al.* 1989)
	Alteration of generations/parthenogenesis/phase polymorphism
	Can reside within host
X	Diapause (King 1994)
X	Stress tolerance, including ability to resist insecticides and/or adverse weather conditions (Armes *et al.* 1996, King 1994)
	Lack of natural control agents
	Wind dispersal
	Water dispersal
	Machinery dispersal
	Animal dispersal
	Human dispersal

Rating	**Numerical score**	**Explanation**
High	**3**	Insect has high reproductive potential (*e.g*., prolific egg production, high survival rate, reproduction by parthenogenesis, bimodal population behavior) **AND** highly mobile life stages (*i.e*., capable of moving long distances aided by wind, water or vectors.)
Medium	2	Insect has either high reproductive potential **OR** highly mobile life stages.
Low	1	Insect has neither high reproductive potential nor highly mobile life stages

Rank: High

Helicoverpa armigera exhibits high reproductive potential with a single female capable of laying 3,000 eggs (Shanower and Romeis 1999). There can be up to 11 generations per year with overlapping generations in the field. The adult moth is capable of migrating up to 155 miles (250 km). This confers *H. armigera* a **high risk** rating for dispersal potential after establishment.

Risk Element 4: Economic impact

Impact Categories:

1. Reduced commodity yield (*e.g*., feeding, disease vector).
2. Lower commodity value (*e.g*., by increasing costs of production, lowering the market price, or a combination); or if not an agricultural insect, by increasing costs of control.
3. Loss of markets (foreign or domestic) due to presence of a new quarantine pest.

Rating	**Numerical score**	**Explanation**
High	**3**	Insect causes all three of the above impacts, or causes any one impact over a wide range of economic plants, plant products or animals (over 5 types)
Medium	2	Insect causes any two of the above impacts, or causes any one impact to 3 or 4 types of economic plants, plant products, or animals.
Low	1	Insect causes any one of the above impacts to 1 or 2 types of economic plants, plant products, or animals.
Nil	0	Insect causes none of the above impacts

Rank: High

Helicoverpa armigera could cause all 3 of the above mentioned economic impacts. This confers *H. armigera* a **High risk rating for economic impact**. *Helicoverpa amigera* larva are extremely damaging because they prefer to feed and develop on the reproductive structures of crops which are rich in nitrogen (Fitt 1989). These structures are often the part of the crop that is harvested (King 1994). Depending on the crop, bollworm induced damage can range from 50 to 90 percent of the yield (Reed and Pawar 1982, Sehgal and Ujagir 1990). The need to prevent the spread of *H. armigera* could also result in the loss of markets due to quarantine and containment measures.

The 1999 combined value of production for United States cotton , corn , tomato, tobacco and sorghum was over 25 billion dollars (United States Department of Agriculture-National Agricultural Statistics Service 2000b). *Helicoverpa armigera* could be a significant threat to these crops. Other economically important crops on which *H. armigera* feeds include: potato, soybean, okra, beans, stone fruits, citrus, pines, onions, bell peppers, cruciferous crops, cucurbits, kidney bean, pea, wheat, oats, and barley. It is probable that *H. armigera* would threaten these crops as well if introduced.

Risk Element 5: Environmental impact

Impact Categories:

1. Cause impacts on ecosystem processes (*e.g.* increases fire risk due to feeding or disease transmission).
2. Cause impacts on natural community composition (*e.g*., reduce bio-diversity, affect native populations, affect endangered or threatened species).
3. Cause impacts on community structure (*e.g*., change density of a layer, cover the canopy, eliminate or create a layer).
4. Have impacts on human health such as disease transmission or production of allergens.
5. Stimulate control programs including toxic chemical pesticides or introduction of a non-indigenous biological control agent.

Rating	Numerical Score	Explanation
High	**3**	Three or more of the above.
Medium	2	Two of the above.
Low	1	One of the above.
Nil	0	None of the above.

Rank: High

Helicoverpa armigera could cause environmental impacts 1, 2, 3 and 5 mentioned above. This confers *H. armigera* a **High risk rating** for environmental impact. In addition to feeding on a variety of agricultural crops, *H. armigera* will also attack timber, e.g. *Pinus* (Crop Protection Compendium 2000). Damage to these plants could: 1) increase the risk of fire due to elevated levels of dead pines, 2) deleteriously impact indigenous ecosystem composition, and 3) impact community structure in areas where pines are the dominant tree species.

The larvae of *H. armigera* are quite polyphagous, feeding on multiple species within 13 plant families. Endangered and threatened (E&T) species are found in each of these families. Amaranthaceae has 5 E&T species in 3 genera; Anacardiaceae has 1 E&T species in 1 genus; Asteraceae has 85 E&T species in 42 genera; Cistaceae has 2 E&T species in 2 genera; Euphorbiaceae has 15 E&T species in 6 genera; Fabaceae has 46 E&T species in 24 genera, Liliaceae has 14 E&T species in 11 genera; Linaceae has 1 E&T species in 1 genus; Malvaceae has 24 E&T species in 10 genera; Pinaceae has 1 E&T species in 1 genus; Poaceae has 23 E&T species in 12 genera; Rosaceae has 9 E&T species in 8 genera; and Solanaceae has 6 E&T species in 3 genera (United States Fish and Wildlife Service 2001). With current information, there is an uncertainty whether *H. armigera* may affect one or more E&T species should the moth become established in the U.S. The U.S. Fish and Wildlife Service should be notified immediately in the event that *H. armigera* is discovered in the U.S. At that time other host associations should also be evaluated to determine whether *H. armigera* may affect additional E&T species.

Chemical control *of H. armigera* is difficult due to evolved resistance to organophosphates and pyrethroids (Armes et al. 1996). Consequently the release of non-indigenous biological control agents, *e.g. Trichogramma spp.*, may be necessary.

ECONOMIC and ENVIRONMENTAL IMPORTANCE SUMMARY: Consequences of Introduction: cumulative Risk Element Score

Cumulative Risk Element Score	Risk Rating	Risk Score
5-7	Low	1
8-11	Medium	2
12-15 (Habitat Suitability = 3) + (Host Range = 3) + (Spread Potential = 3) + (Economic Impact = 3) + (Environmental Impact = 3) = **15**	**High**	**3**

Rank: High

Section C: Likelihood of introduction

Risk element 6: Entry potential Considerations

1. Is the host likely to be imported at a stage where the pest is present?
   Yes, based on the number of interceptions since 1998.
2. Are there hosts available in the vicinity of where the pest may be imported or distributed for processing?
   Probably, since *H. armigera* is highly polyphagous and capable of long distance migration.
3. Is the pest species easily detected?
   Probably, since it has been intercepted 41 times since 1998.

Method of introduction into the United States:

Since 1998, there have been 41 interceptions of *H. armigera* at U.S. ports on plant parts (20) , leaves (5), fruit (5) and flowers (11) from over 18 species of plant. Infested articles and respective number of interceptions were: baggage (7), general cargo (1), permit cargo (31) and stores (2).

Plant families and respective examples of species on which *H. armigera* has been intercepted are: 1) Malvaceae; *Abelmoschus esculentus* (okra), 2) Liliaceae; *Allium sp*. (onion), 3) Apiaceae; *Bupleurum sp*. (thorough-wax), 4) Solanaceae; *Capsicum sp*. (bell pepper), 5) Amaranthaceae; *Celosia sp*. (wool-flower), 6) Asteraceae; *Lactuca sativa* (lettuce), 7) Caryophyllaceae; *Dianthus sp*. (pink), 8) Gentianaceae; *Eustoma grandiflorum* (prairie gentian), 9) Lamiaceae; *Leonotis sp*. (Lion's ear), 10) Plumbaginaceae; *Limonium sp*. (marsh rosemary), 11) Orchidaceae; *Ornithocephalus sp*. (orchid), and 12) Rosaceae; *Rosa sp*. (rose).

Likelihood of Introduction:

Since 1998, there have been 41 interceptions of *H. armigera* at U.S. ports. The countries of origin and respective number of interceptions were: Senegal (2), Netherlands (20), Korea (1), United Kingdom (3), Italy (2), Spain (5), Turkey (1), Morocco (2), New Zealand (2), Zimbabwe (1), Portugal (1) and India (1).

Control efforts: The following control measures have been used in countries where *H. armigera* is considered an economic pest (King 1994).

I. **Chemical Control:** Listing of these chemical control methods does not imply that they are either efficacious or labeled for this use in the United States, or specific states within the United States.

Broad Spectrum Insecticides: (Haasan *et al*. 1990) Chemical insecticides have been used extensively to control *H. armigera*. Unfortunately this has led to the evolution of resistance to many chemical insecticides. The majority of chemical treatments are aimed at controlling the larval stages (King 1994). To combat insecticide resistance, crops are treated systematically with different types of compounds.

1. Chlordimeform (ovicide)
2. Methomyl (ovicide)

II. **Biological Control**: The following organisms have been used to control *H. armigera* but may need approval from APHIS and/or state regulatory agencies for importation into and within the United States.

1. Microbial: *Bacillus thuringiensis* formulations have been used to control *H. armigera* (Karim *et al.* 2000)
2. Parasites: Biological control has focused on augmenting *H. armigera* natural enemies with large numbers of parasites (King 1994). Parasites which have been used include *Trichogramma spp*. (Hymenoptera: Trichogrammatidae) And *Microplitis croceipes* (Hymenoptera: Braconidae) (King *et al*. 1985)

III. **Cultural Control:** The following measures should be used in conjunction with one another consistently.

1. Early harvesting using short season cultivars (King 1994)
2. Plant growth regulators which increase the efficacy of insecticide application (Bradley *et al*. 1986)
3. Cultivation after harvesting to kill over wintering pupae (Rummel and Neece 1989)
4. Field sanitation (Fitt and Forrester 1988)
5. Using a “close season” to remove host from the bollworm (King 1994)
6. Trap cropping (Fitt 1989)

Acknowledgements: This Pest Risk Assessment (PRA) is based on a PRA process developed in USDA-APHIS by Mike Firko and Joe Cavey for evaluation of arthropod pests. Later, the PRA process was expanded by Polly Lehtonen, also an APHIS employee, to evaluate pest plants (weeds).

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Section D:

References Cited:

Armes N.J., Jadhav, D.R. and DeSouza K.R. 1996. A survey of insecticide resistance *in Helicoverpa armigera* in the Indian subcontinent. Bulletin of Entomological Research. 86(5): 499-514.

BASF. 1998. http://www.inra.fr/Internet/Produits/HYPPZ/RAVAGEUR/6helarm.htm

Bradley J.R., Herzog G.A., Roach S.H., Stinner R.E. and Terry L.I. 1986. Cultural control in southeastern U.S. cropping systems. *In* Johnson S.J., King E.G. and Bradley J.R. (*eds*). Theory and tactics of *Heliothis* population Management: 1-Cultural and Biological Control. Southern Cooperative Series Bulletin. 316: 22-27.

Courtin R./OPIE. 1998. http://www.inra.fr/Internet/Produits/HYPPZ/RAVAGEUR/6helarm.htm

Crop Protection Compendium. 2000. "Reproduced from the Crop Protection Compendium-Global Module, Second Eddition. Copyright CAB Internatio nal, Wallingford, UK, 2000."

Fitt G.P. 1989. The ecology of *Heliothis* in relation to agroecosystems. Annual Review of Entomology. 34: 17-52.

Fitt GP, 1991. Host selection in the Heliothinae. In: Bailey WJ, Ridsdill-Smith TJ, eds. Reproductive Behaviour in Insects - Individuals and Populations. London, UK: Chapman & Hall, 172-201. . "Reproduced from the Crop Protection Compendium-Global Module, Second Eddition. Copyright CAB Internatio nal, Wallingford, UK, 2000."

Fitt G.P. and Forrester N.W. 1988. Overwintering of *Heliothis*-the importance of stubble cultivation. Australian Cotton Grower. 8: 7-8.

Hardwick D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada. 40. 247 pp.

Hassan S.T.S., Wilson L.T. and Blood P.R.B. 1990. Oviposition by *Heliothis armigera* and *H. punctigera* (Lepidoptera: Noctuidae) on okra leaf and smooth-leaf cotton. Environmental Entomology. 19: 710-716.

Jayaraj S. 1982. Biological and ecological studies of *Heliothis*. *In* Reed W. and Kumble V. (*eds*.), Proceedings of the International Workshop on Heliothis Management, 15-20 November 1981. ICRISAT Center, Patancheru , A.P., India. ICRISAT, Patancheru, A.P. India. pp. 17-28.

Karim, S., Zafar A.U., Nasir I.A. and Riazuddin S. 2000. Field efficacy of CAMB *Bacillus thuringiensis* biopesticide to control *Helicoverpa armigera* (Hubner) and *Earias vitella* (Fabricius) in okra crop. Pakistan Journal of Biological sciences. 3(8): 1296-1298.

Kimmel M. 2000. GRG301K-Weather and climate Koppen climate classification flow chart. Department of Geography. University of Texas at Austin. http://www.utexas.edu/depts/grg/kimmel/GRG301K/grg301kkoppen.html

King E.G., Powell J.E. and Coleman R.J. 1985. A high incidence of parasitism of *Heliothis spp*. (Lepidoptera: Noctuidae) larvae in cotton in southeastern Arkansas. Entomophaga. 30: 419-426.

King A.B.S. 1994. *Heliothis/Helicoverpa* (Lepidoptera: Noctuidae). *In* Insect Pests of Cotton, Mathews G.A. and Turnstall J.P. (*eds*.). CAB International. Wallingford, U.K. pp. 39-106.

Lewis L. 2000. Professor of Geography. Western Illinois University. Macomb, Il. http://www.wiu.edu/users/mfltl/geog120/toc_120.htm

Manjanuth TM, Bhatnagar VS, PawaR CS, Sitanatham S, 1989. Economic importance of Heliothis spp. in India and an assessment of their natural enemies and host plants. In: King EG, Jackson RD (eds) Proceedings of the Workshop on Biological Control of Heliothis: Increasing the Effectiveness of Natural Enemies November 1985, New Delhi. New Delhi, India: Far Eastern Regional Research Office, US Department of Agriculture, 196-228. "Reproduced from the Crop Protection Compendium-Global Module, Second Eddition. Copyright CAB Internatio nal, Wallingford, UK, 2000."

McCaffery A.R., King A.B.S., Walker A.J. and El-Nayir H. 1989. Resistance to synthetic pyrethroids in the bollworm, *Heliothis armigera* from Andhra Pradesh, India. Pesticide Science. 27: 65-76.

Pearson E.O. 1958. The insect pests of cotton in tropical Africa. Commonwealth Institute of Entomology. London. 355 pp.

Rajagopal D. and Channa Basavanna G.P. 1982. Biology of the maize cob caterpillar, *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae). Nysore Journal of Agricultural Science. 16: 153-159.

Ramaswamy S.B. 1990. Periodicity of oviposition, feeding and calling by mated female *Heliothis virescens* in a field cage. Journal of Insect Behavior. 3: 417-427.

Reed W. 1965. *Heliothis armigera* (Hb.) (Noctuidae) in western Tanganyika. 1. Biology, with special reference to the pupal stage. Bulletin of Entomological Research. 56: 117-125.

Reed W. and Pawar C.S. 1982. *Heliothis*: A global problem. *In* Reed W. and Kumble V. (*eds*.), Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, ICRISAT Center, Patancheru, A.P., India. ICRISAT, Patancheru, A.P., India. pp. 9-14.

Rummel D.R. and Neece K.C. 1989. Winter survival of *Heliothis zea* (Boddie) in cultivated soil in the southern Texas High Plains. Southwestern Entomologist. 14: 117-125.

Sehgal V.K. and Ujagir R. 1990. Effect of synthetic pyrethroids, neem extracts and other insecticides for the control of pod damage by *Helicoverpa armigera* (Hubner) on chickpea and pod damage-yield relationship at Pantnagar in northern India. Crop Protection. 9: 29-32.

Shanower T.G. and Romeis J. 1999. Insect pests of pigionpea and their management. Annual Review of Entomology. 44: 77-96.

United States Department of Agriculture. 1990. The United States National Arboretum Plant Hardiness Zone Map. USDA Miscellaneous Publication No. 1475.

United States Department of Agriculture. 1992. National Agricultural Statistics Service. Mann Library Cornell University. United States crop rankings.

United States Department of Agriculture. 1997. National Agricultural Statistics Service. Mann Library Cornell University. United States crop rankings.

United States Department of Agriculture. 2000a. National Agricultural Statistics Service. 2000 all wheat harvested acres (000) and change from previous year.

United States Department of Agriculture. 2000b. National Agricultural Statistics Service. Mann Library Cornell University.

United States Fish and Wildlife Service. 2001. Species information: threatened and endangered animals and plants. http://endangered.fws.gov/wildlife.html