Mini Risk Assessment
Old World bollworm, *Helicoverpa armigera* Hübner
[Lepidoptera: Noctuidae]

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Introduction

Helicoverpa armigera is a highly polyphagous pest of many economically significant crops in portions of Africa, Asia, Australia (including Oceania), and Europe (King 1994). The likelihood and consequences of establishment by *H. armigera* have been evaluated in pathway-initiated risk assessments and pest risk assessments. *Helicoverpa armigera* is considered highly likely of becoming established in the US if introduced; the consequences of its establishment for US agricultural and natural ecosystems are consistently rated high (i.e., severe) (Cave and Redlin 1996a, b, c, Lightfield 1997a, b, Ogden and Podleckis 2000, Fowler and Lakin 2001). Because of the number of crops that this pest affects, it has many common names: scarce bordered straw worm, corn earworm, African cotton bollworm, American bollworm, and tomato worm (Zhang 1994, Begemann and Schoeman 1999).

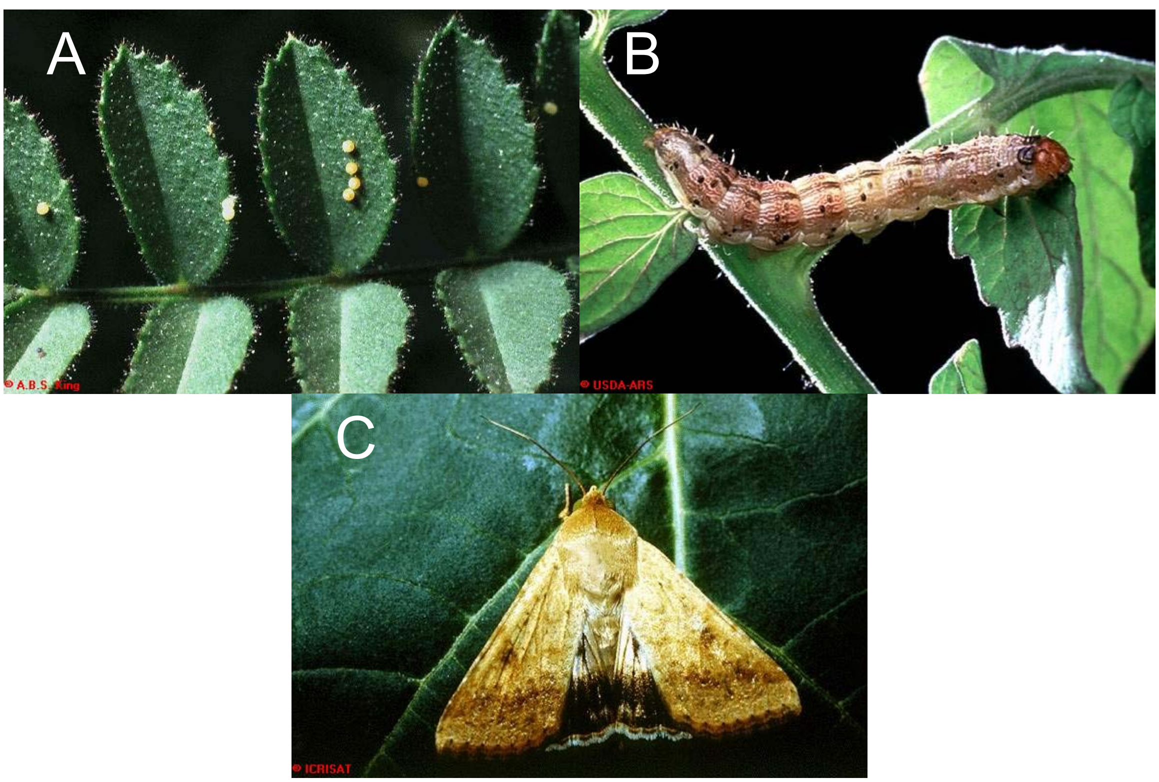

Figure 1. Life stages of *Helicoverpa armigera*, images not to scale: (A) eggs; (B) larva; and (C) adult. [Photos from (CAB 2003)].

1. **Ecological Suitability. Rating: High.** *Helicoverpa armigera* is found in the Palearctic, Oriental, Ethiopian, and Austalian zoogeographis provinces, south of a line at approximately 52°N (IIE, 1993). This range occupied by the species includes tropical, dry, and temperate climates (CAB 2000). The currently reported global distribution of *H. armigera* suggests that the pest may be most closely associated with deserts and xeric shrublands; Mediterranean scrub; temperate broadleaf and mixed forests; tropical and subtropical grasslands, savannas, and shrublands; and tropical and subtropical moist broadleaf forest. Based on the distribution of climate zones in the US, we estimate that approximately 49% of the continental US would be suitable for *H. armigera* (Fig. 2). See Appendix A for a more complete description of this analysis.

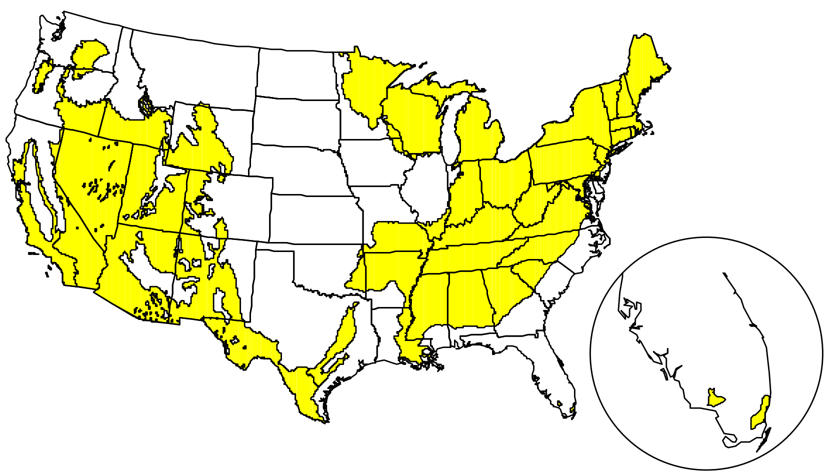

Figure 2. Predicted distribution of *Helicoverpa armigera* in the continental US. Southern Florida is enlarged for detail.

2. **Host Specificity/Availability. Rating: Low/High.** This pest feeds on a number of host plants, many of which commonly occur or are produced in the US. These plants include over 180 cultivated and wild species in at least 45 families: African marigold (*Tagetes erecta*), alfalfa/lucerne (*Medicago sativa*), annual verbine (*Psoralea cinera, Psoralea* sp.), apple (*Malus* sp.), apple of Peru (*Nicandra physlodes*), asthma weed (*Euphorbia hirta*), barley (*Hordeum vulgare*), Bermudagrass (*Cynodon dactylon*), berseem clover (*Trifolium alexandrinum*), billy buttons (*Ixiolaena brevicompta*), black henbane (*Hyoscyamus niger*), black nightshade (*Solanum nigrum*), black pigweed (*Trianthema portulacastrum*), *Blumea oblique*, bottle gourd (*Lagenaria siceraria*, *L. leucantha*), cabbage (*Brassica oleraceae*), burr-daisy (*Calotis ancyrocarpa, C. cuneifolia, C. multicaulis*), burr medic (*Medicago denticulata*), carnation (*Dianthus caryophyllus*), carrot (*Daucus carota*), castor (*Ricinus communis*), cauliflower (*Brassica oleracea*), chaff-flower (*Achryranthes aspera*), cheeseweed mallow (*Malva parviflora*), chickpea (*Cicer arietinum*), chinese spinach/vegetable

amaranth (*Amaranthus polygamus*), chrysanthemum (*Brachysome* sp., *Chrysanthemum coronarium*), citrus (*Citrus sinensis*, *Citrus* spp.), cocklebur (*Xanthium strumarium*), common white sunray (*Helipterum floribundum*), copperleaf (*Acalypha* sp.), copper-wire daisy (*Podolepis canescens, P. jaceoides*), corn (*Zea mays*), cotton (*Gossypium hirsutum*), cowpea (*Vigna unguiculata*), *Chrozophora rottleri,* cucumber (*Cucumis sativus*), curry leaf (*Muraya koenigii*), drumsticks (*Craspedia globosa*), East Indian globe thistle (*Sphaeranthus indicus*), eggplant/aubergine (*Solanum melongena*), eryngo (*Eryngium plantagineum*), *Euphorbia microphylla,* field bindweed (*Convolvulus arvensis*), firecracker flower/crossandra (*Crossandra infundibuliformis*), flax/linseed (*Linum usitatissimum*), French millet (*Panicum miliaceum*), gallant-soldier (*Galinsoga* sp.), *Gamolepis tagetes*, gerbera daisy (*Gerbera jamesonii*), gladiolus (*Gladiolus* sp.), golden billy buttons (*Craspedia chrysantha),* gomphrena (*Gomphrena* sp.), grain amaranth (*Amaranthus* sp.), green bean/dry edible bean/French bean (*Phaseolus vulgaris*, *Phaseolus* spp.), *Hibiscus panduraeformis,* Hindu datura (*Datura metel*), hollyhock (*Alcea rosea*), hyacinth bean (*Lablab purpureus*), Indian mallow (*Abutilon indicum*), Indian Valley false mallow (*Malvastrum americanum*), jute (*Corchorus olitorius*), kale (*Brassica napus*), ladies' false fleabane (*Pentanema indica*), lambsquarters (*Chenopodium album*), lentil (*Lens culinarus*), lettuce (*Lactuca* spp.), lily/tuberose (*Polianthes tuberosa*), mahua (*Madhuca longifolia*), mango (*Mangifera indica*), Mexican fire plant (*Euphorbia heterophylla*), Monterey pine (*Pinus radiata*), mung bean/green gram (*Vigna radiata*), oat (*Avena* sp.), okra (*Abelmoschus esculentus*), onion (*Allium cepa*, *Allium* spp.), pea (*Pisum sativum*), pearl millet (*Pennisetum glaucum*), peanut/groundnut (*Arachis hypogaea*), pepper/chili (*Capsicum annuum*, *Capsicum* spp.), pigeon pea (*Cajanus cajan*), pine (*Pinus* spp.), pongame oiltree (*Pongamia pinnata*), potato (*Solanum tuberosum*), purple/slender amaranth (*Amaranthus viridis*), red ambadi (*Hibiscus subdariffa*), red pigweed (*Amaranthus thunbergii*), ridge gourd (*Luffa acutangula*), rose (*Rosa* spp.), safflower (*Carthamus tinctorius*), Santa Maria feverfew (*Parthenium hysterophorus*), salvation Jane (*Echium plantagineum*), silk leaf (*Lagascea mollis*), sorghum (*Sorghum* sp.), sowthistle (*Sonchus oleraceus*), soybean (*Glycine max*), spiderflower (*Cleome* spp.), strawberry (*Fragaria ×ananassa*), strawflower (*Helianthis annuus*), stone fruit (*Prunus* spp.), sunberry (*Physalis minima*), sunflower (*Helianthus annuus*), sweetpea (*Lathyrus odoratus*), thorn apple (*Datura stramonium*), tobacco (*Nicotiana tabacum*), tomato (*Lycopersicon esculentum*), toothed groundsel (*Senecio platylepis*), tridax (*Tridax procumbens*), triticale (×*Triticosecale*), upright sunray (*Helipterum strictum*), velleia; smooth (*Velleia glabrata*), waxgourd (*Benincasa cerifera*), wedelia (*Wedelia asperrima*), weed silene (*Silene conoidea*), wheat (*Triticum aestivum*), and white lupine (*Lupinus albus*) (Kirkpatrick 1961b, ICRISAT 1990, Zalucki et al. 1994, Zhang 1994, Verma and Kakar 1996, Akashe et al. 1997, Butter et al. 1997, CABI/EPPO 1997, Patil and Kulkarni 1997, Jallow and Zalucki 1998, Begemann and Schoeman 1999, Casimero et al. 1999, Gu and Walter 1999, Rosaiah and Reddy 1999, Sarode 1999, Tripathy et al. 1999, Bantewad and Sarode 2000, Das et al.

2001, Fowler and Lakin 2001, Jallow et al. 2001, Seymour and Jones 2001, CAB 2003).

Physalis minima, *Euphorbia microphylla*, and *Euphorbia hirta* may serve as alternate hosts for *H. armigera*, while other plants commonly considered as weeds may serve as secondary hosts (Sarode 1999). African marigold (*Tagetes erecta*) has been used as a trap crop in tomato and red ambadi (*Hibiscus subdariffa*) has been used as an intercrop in cotton to help manage *H. armigera* pest populations (Bantewad and Sarode 2000).

Host preferences, including artificial diet, by *H. armigera* have been studied in a laboratory setting. Pigeon pea was found to be the most "suitable," followed by an artificial diet, maize, sorghum, red ambadi, cowpea and marigold (Bantewad and Sarode 2000, Hou and Sheng 2000). *Helicoverpa armigera* prefers particular host plants and appears to follow a hierarchy in food choice when a preferred host is unavailable (Gu et al. 2001, Jallow and Matsumura 2001). From laboratory studies, tobacco, maize and sunflower were categorized as most preferred hosts; soybean, cotton and lucerne were categorized as intermediate hosts; and cabbage, pigweed and linseed were least preferred (Firempong and Zalucki 1990). In other food preference studies, maize has been ranked as a highly preferred host while cowpea has been ranked low (Jallow and Zalucki 1998). Feeding studies on neem (*Azadirachta indica*) have identified it as an unsuitable host plant for *H. armigera* (Ma et al. 2000). Grapevine (*Vitis vinifera*) has also been identified as an unsuitable host, though an isolated case notes *H. armigera* feeding on this plant (Kirkpatrick 1961b, Voros 1996).

See Appendix B for maps showing where various hosts are grown commercially in the continental US.

3. **Survey Methodology. Rating: Medium**. Visual inspections of plants for eggs and/or larvae common are frequently used to monitor and assess population sizes for *H. armigera*. In vegetative Australian cotton, a minimum of 60 whole plants per 100 ha commercial field is examined for the presence of *H. armigera* eggs or larvae; when plants begin to produce squares, only the upper terminal (approximately 20 cm) of a plant is inspected (Brown 1984, Dillon and Fitt 1995). In experimental plots, visual inspections for *H. armigera* in pigeon pea were restricted to the upper third of whole plants (4 sets of five plants in a 30x30 m plot) (Sigsgaard and Ersbøll 1999). Leaves of tomato plants are more attractive than flowers or fruits as *H. armigera* oviposition sites, but use of a single-leaf sample unit (with a sample size of 30 plants per field) has proven ineffective in detecting low densities of *H. armigera* (Cameron et al. 2001). On some tomato cultivars, leaves in the upper half of the plant are preferentially selected for oviposition (Saour and Causse 1993). Larvae that are feeding on the surface of plant are easily detected, but only entry holes or frass may be visible when larvae penetrate a plant; in this case, plant dissections are needed to confirm the presence of the pest (CAB 2003).

Pheromone traps using (*Z*)-11-hexadecenal and (*Z*)-9-hexadecenal in a 97:3 ratio have been used to monitor populations of *H. armigera* (Pawar et al. 1988, Loganathan and Uthamasamy 1998, Loganathan et al. 1999, Visalakshmi et al. 2000, Zhou et al. 2000a). Of three pheromone doses tested in the field (0.75, 1.0, and 1.25 mg/septum), 1 mg attracted the most males (Loganathan and Uthamasamy 1998); the trap type was not specified. Rubber septa impregnated with these sex pheromone components (1 mg/septum) were equally effective in capturing males for 11 days in the laboratory (Loganathan et al. 1999). Captures of *H. armigera* in the field were significantly lower with 15-day-old lures than with fresh lures, and the authors recommend replacing lures every 13 days (Loganathan et al. 1999). Similar observations were reported by Pawar et al. (1988).

Trap design has a significant impact on the number of male *H. armigera* moths that will be captured with pheromone lures. Funnel traps and Texas traps are substantially more effective than sticky traps (Kant et al. 1999). Hartstack (i.e., hollow cone) traps have also been used to effectively monitor densities of adults (Walker and Cameron 1990). Cone traps are significantly more effective than water-pan traps (Sheng et al. 2002). Traps should be placed approximately 6 ft (1.8 m) above the ground (Kant et al. 1999, Zhou et al. 2000a), and they should be separated by a distance of at least 160 ft (50 m) (Kant et al. 1999). For routine monitoring of pests, pheromone traps are deployed at a density of 5 traps/ha (Sidde Gowda et al. 2002).

4. **Taxonomic Recognition**. **Rating: Low.** Several Noctuid pests can be confused easily with *Helicoverpa armigera*, including *H. assulta* [not known in the US]*, H. punctigera* [not known in the US]*, H. zea* [present in the US]*,* and *Heliothis virescens* [present in the US] (Kirkpatrick 1961a, CAB 2000, 2003). Adults may be identified by distinct differences in genitalia (Kirkpatrick 1961a, Hardwick 1965). A morphological study of *H. assulta, H. punctigera,* and *Heliothis virescens* (formerly *H. rubrescens*) compares similarities and differences between species; a key is provided for identifying adults (Kirkpatrick 1961a). Immunological tests are available to differentiate *H. punctigera* and *Heliothis virescens* in egg or larval stages (Ng et al. 1998). The LepTon test, an ELISA based approach, has been developed to distinguish between *H. armigera* and *H. punctigera* in all stages (Trowell et al. 1993).

   For a more complete taxonomic and morphological description of *H. armigera*, see Appendix C.

5. **Entry Potential. Rating: High.** Interceptions of *H. armigera* or "*Helicoverpa* sp." have been reported 4,431 times since 1985 on fruits, vegetables, ornamentals, and other miscellaneous plants (USDA 2003). Annually, about 280 (±12 standard error of the mean) interceptions are reported (USDA 2003). Interceptions have been associated primarily with permit cargo (67%), airline passengers (20%), and general cargo (11%). The vast majority of interceptions have been reported from

JFK International Airport (52%), Los Angeles (11%), Honolulu (6%), Des Plaines (6%), and Chicago (5%). These ports are the first points of entry for cargo or airline passengers into the US and do not necessarily represent the final destination of infested material. Movement of potentially infested material is more fully characterized in the next section.

Helicoverpa armigera has been listed with more than 300 plant taxa. A remarkably high proportion of interceptions occur on hosts in the genera *Bupleurum* (10%), *Allium* (7%), and *Ornithogalum* (7%).

6. **Destination of Infested Material. Rating: High.** When APHIS officers intercept an actionable pest, they ask for the final destination of the conveyance. Cargo or passengers with material infested with *H. armigera* or "*Helicoverpa* sp." were destined for 21 states (including the District of Columbia, USDA 2003). The most commonly reported destinations were New York (25%), California (15%), Massachusetts (14%), Florida (9%), and Georgia (7%). We note that some portion of these five states has climate and hosts that would be suitable for establishment by *H. armigera*.

7. **Potential Economic Impact. Rating: High.** *Helicoverpa armigera* is a severe economic pest in most places where it occurs (Mabbett et al. 1980, Reed and Pawar 1982, Wilson 1982, Twine 1989, Bhatnagar and Khurana 1992, CABI/EPPO 1997, Agusti et al. 1999, CAB 2003). *Helicoverpa armigera* is an important pest of cotton, particularly in Australia and China (King 1994). All parts of the cotton plant are vulnerable to attack. Cotton yields were reduced by 50-60% by *H. armigera* each year from 1980-1990 in China (Xiao et al. 2002). In Queensland Australia, *H. armigera* damage accounted for 7% yield loss in cotton in spite of pest control costs of A$800/ha in 1998 (Sequeira 2001). In Andhra Pradesh region of India, *H. armigera* reduced yields of seed cotton from 436 kg/ha in 1986-87 to 168 kg/ha in 1987-88 (Sekhar et al. 1996, Loganathan et al. 1999). Significant tomato crop loss also occurred in Burkina Faso, India and New Zealand, particularly in unsprayed or late season varieties (Tewari and Prasado Rao 1987, Bouchard et al. 1992, Cameron et al. 2001). In New Zealand, *H. armigera* attacked Monterey pine and "consumed more than 50% [of the] foliage [off] about 60% the trees" (CABI/EPPO 1997). Pigeonpea and chickpea are severely damaged in India, where losses up to 90-100% in the 1992/93 and 1997/98 growing seasons have been reported. Worldwide, annual losses from this pest on chickpea are approximately 10%, equaling $300 million dollars (Shanower et al. 1997, Mulimani and Sudheendra 2002, Sidde Gowda et al. 2002).

   Control is most often in the form of chemical sprays, but *H. armigera* has developed resistance to many insecticides (Mabbett et al. 1980, Maelzer and Zalucki 2000). Overall, the pest affects economies by reducing yields, lowering crop values, and causing market loss from quarantine restrictions (Fowler and Lakin 2001). The pest is listed by the European and Mediterranean Plant

Protection Organization as an A2 quarantine pest and is considered a quarantine pest by the Caribbean Plant Protection Commission (CPPC), Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA), and the country of Brazil (EPPO 2000). As a result, establishment of *H. armigera* in the US would likely have a severe negative impact on international trade.

8. **Establishment Potential. Rating: High.** Despite the number of *H. armigera* that are introduced into the US each year, no occurrences of the pest have been reported in the wild. A wide variety of factors may contribute to the failed establishment of any introduced population, thus it is generally recognized that biological invasion is a difficult, unlikely event. Nevertheless, we must acknowledge the other possibility, that *H. armigera* has in fact already established (conceivably small, non-damaging) populations that have gone unnoticed or been misidentified as another *Helicoverpa*/*Heliothis* species.

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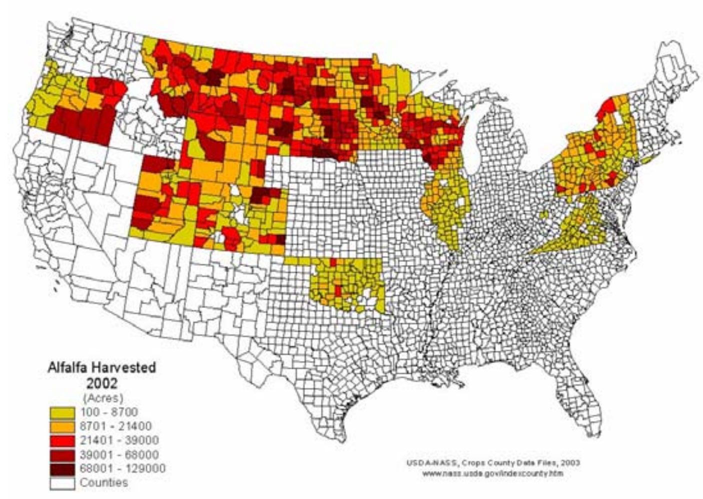
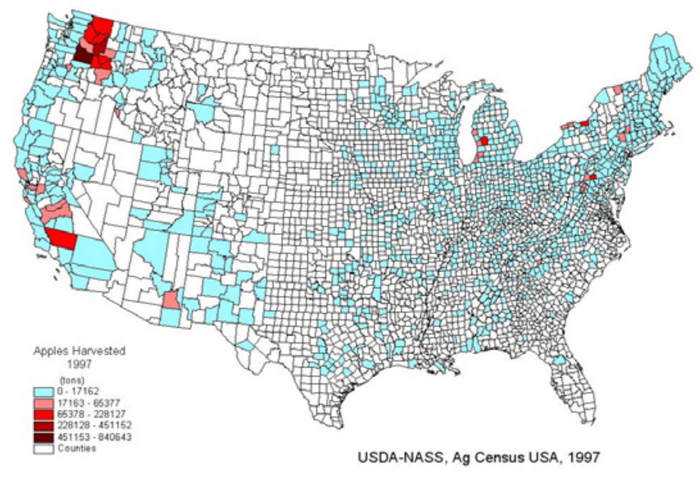
Appendix A. Comparison of climate zones. To determine the potential distribution of a quarantine pest in the US, we first collected information about the worldwide geographic distribution of the species (CAB 2000). We then identified which biomes (i.e., habitat types), as defined by the World Wildlife Fund (Olson et al. 2001), occurred within each country or municipality reported for the distribution of the species. Biomes were identified using a geographic information system (e.g., ArcView 3.2). An Excel spreadsheet summarizing the occurrence of biomes in each nation or municipality was prepared. The list was sorted based on the total number of biomes that occurred in each country/municipality. The list was then analyzed to determine the minimum number of biomes that could account for the reported worldwide distribution of the species. Biomes that occurred in countries/municipalities with only one biome were first selected. We then examined each country/municipality with multiple biomes to determine if at least one of its biomes had been selected. If not, an additional biome was selected that occurred in the greatest number of countries or municipalities that had not yet been accounted for. In the event of a tie, the biome that was reported more frequently from the entire species' distribution was selected. The process of selecting additional biomes continued until at least one biome was selected for each country. The set of selected biomes was compared to the occurrence of those biomes in the US.

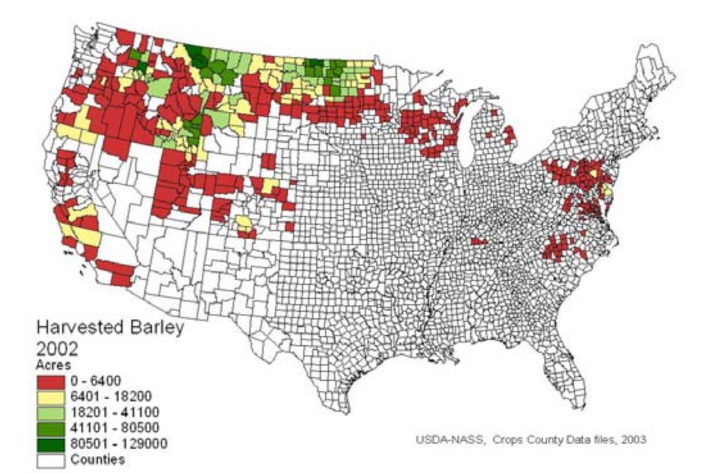
Appendix B. Commercial production of hosts of *Helicoverpa armigera* in the continental US.



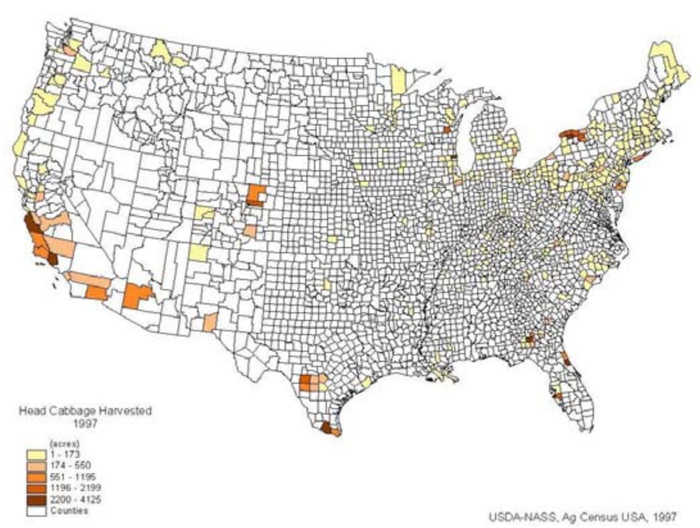
Map 1. Alfalfa/lucerne (*Medicago sativa*)



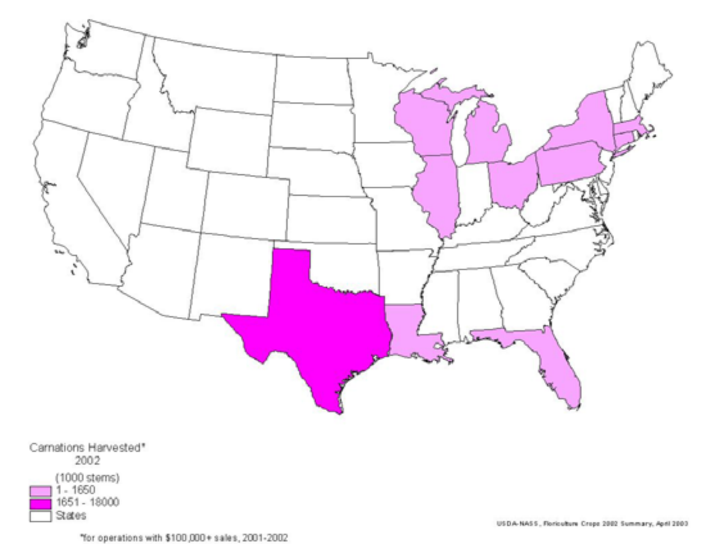
Map 2. Apple (*Malus* spp.)



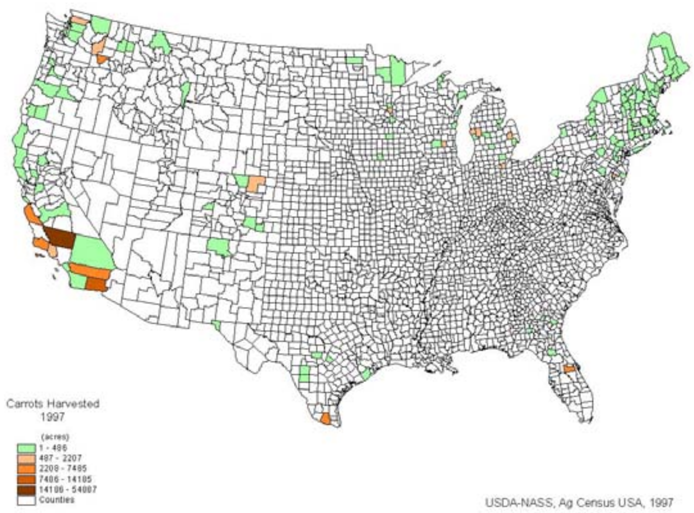
Map 3. Barley (*Hordeum vulgare*)



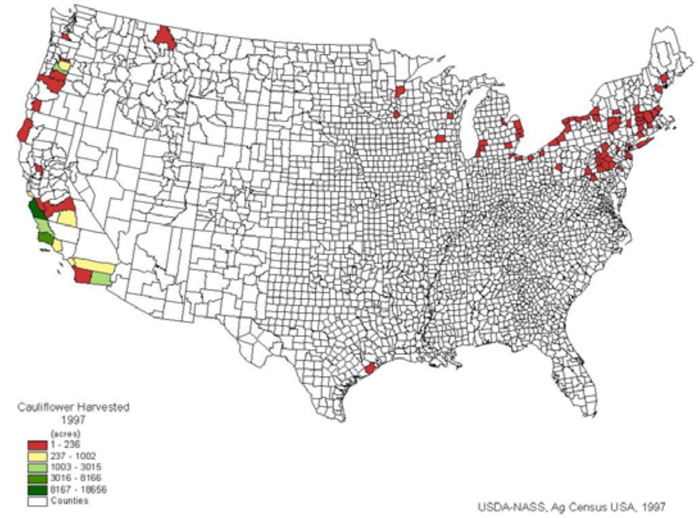
Map 4 Cabbage (*Brassica oleracea*)



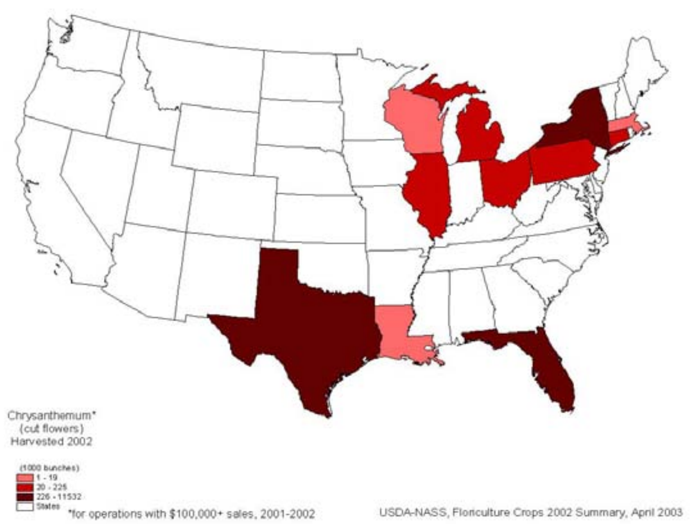
Map 5. Carnation (*Dianthus caryophyllus*)



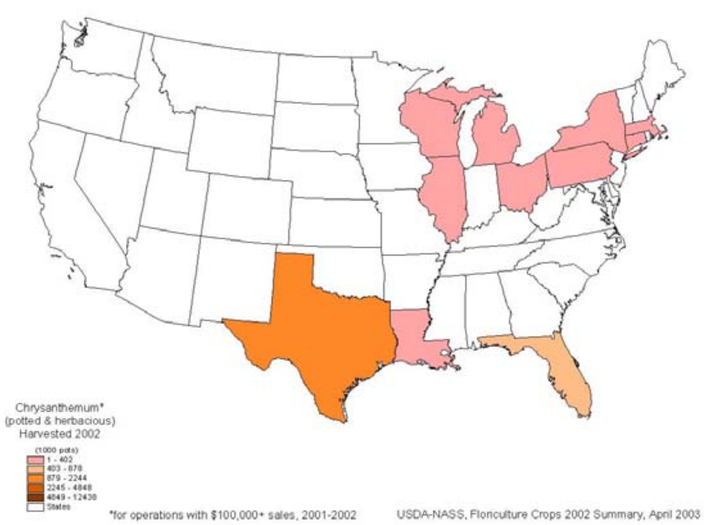
Map 6. Carrot (*Daucus carota* ssp. *sativis*)



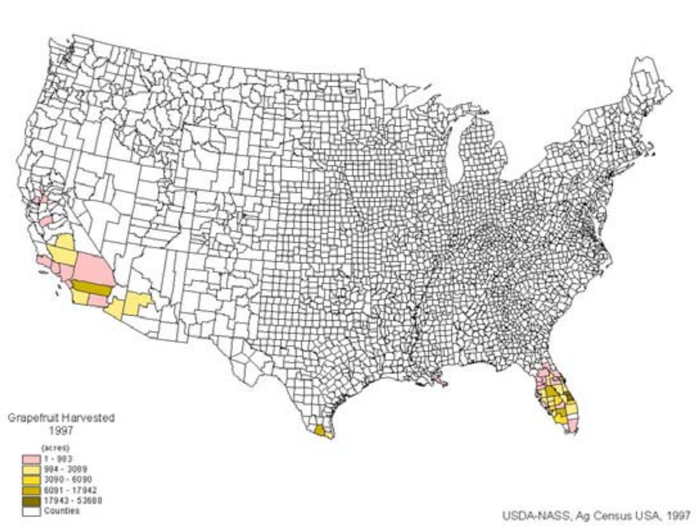
Map 7. Cauliflower (*Brassica oleracea*)



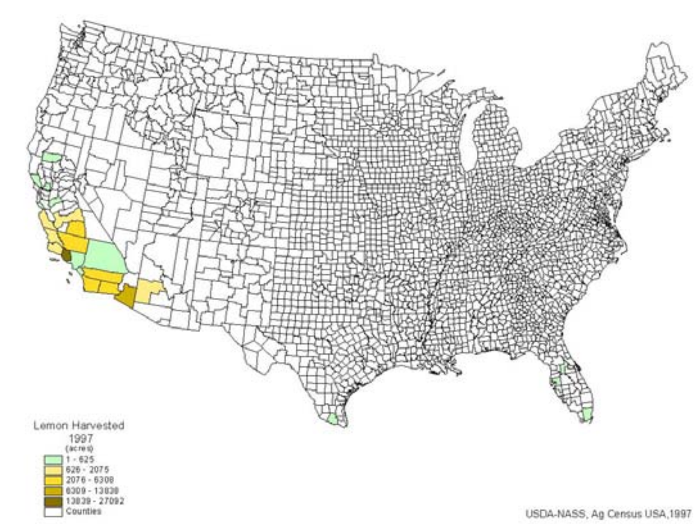
Map 8. Chrysanthemum (*Brachysome* sp., *Chrysanthemum coronarium*) for cut flowers



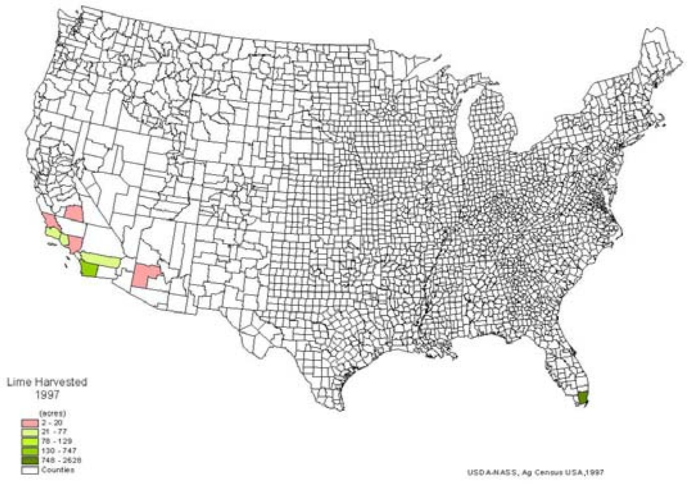
Map 9. Chrysanthemum (*Brachysome* sp., *Chrysanthemum coronarium*) as potted plants



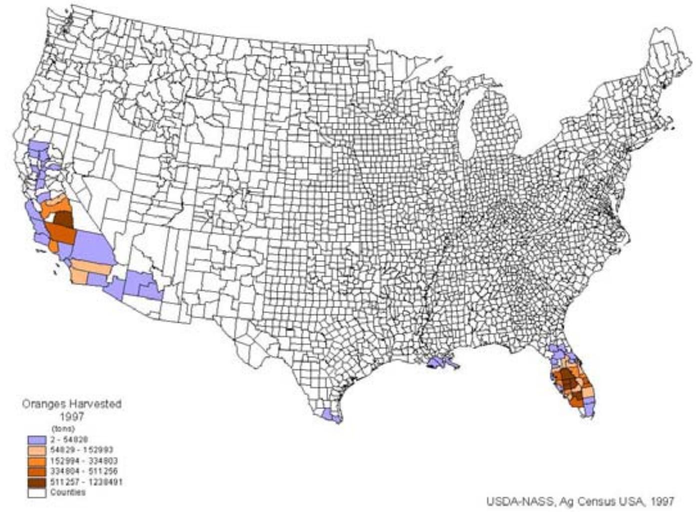
Map 10. Citrus; grapefruit (*Citrus x paradisi*)



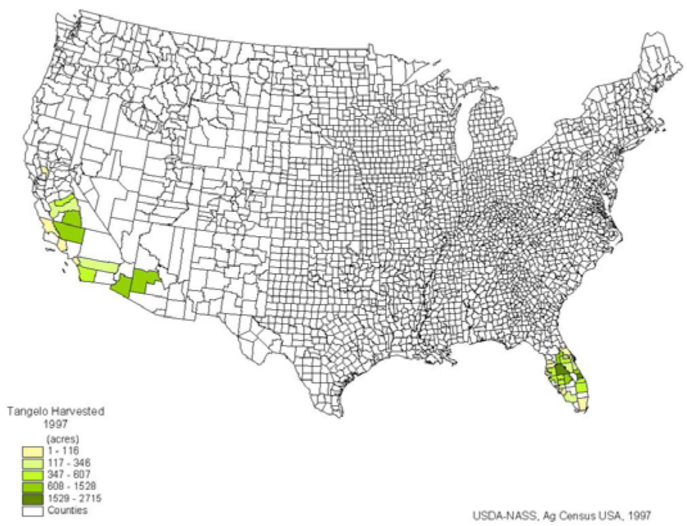
Map 11. Citrus; lemon (*Citrus limon*)



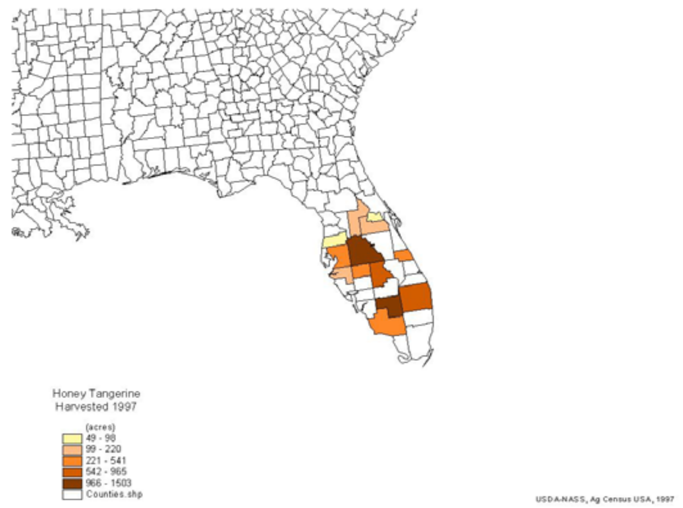
Map 12. Citrus; lime (*Citrus aurantifolia*)



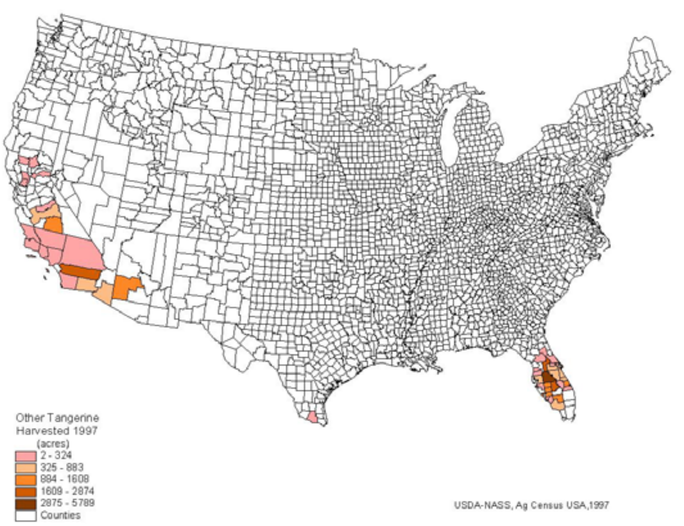
Map 13. Citrus; oranges (*Citrus sinensis*)



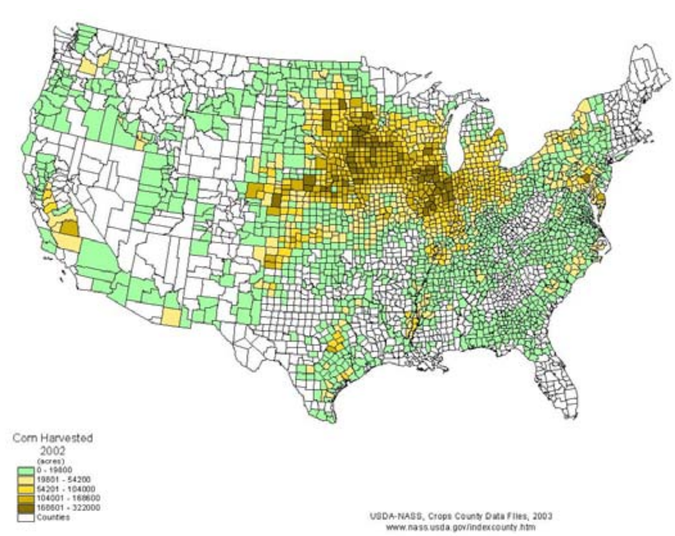
Map 14. Citrus; tangelo (*Citrus x tangelo*)



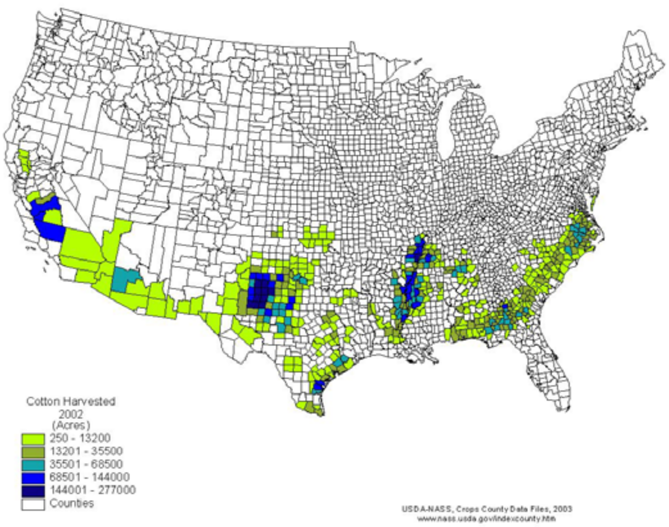
Map 15. Citrus; tangerine (honey) (*Citrus reticulata*)



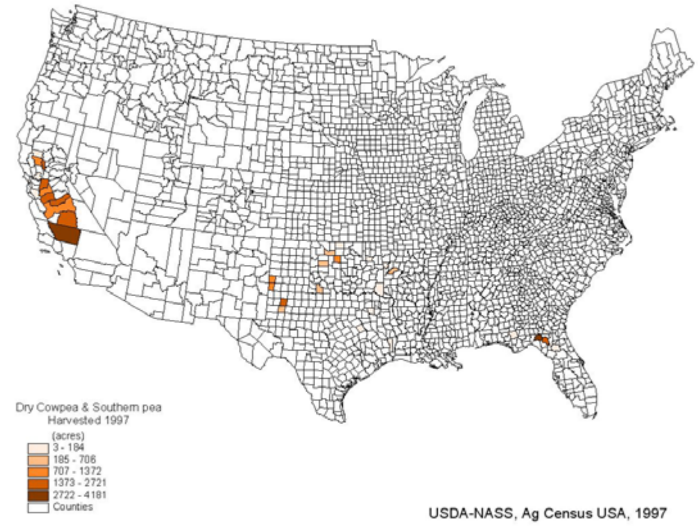
Map 16. Citrus; tangerine (*Citrus reticulata*)



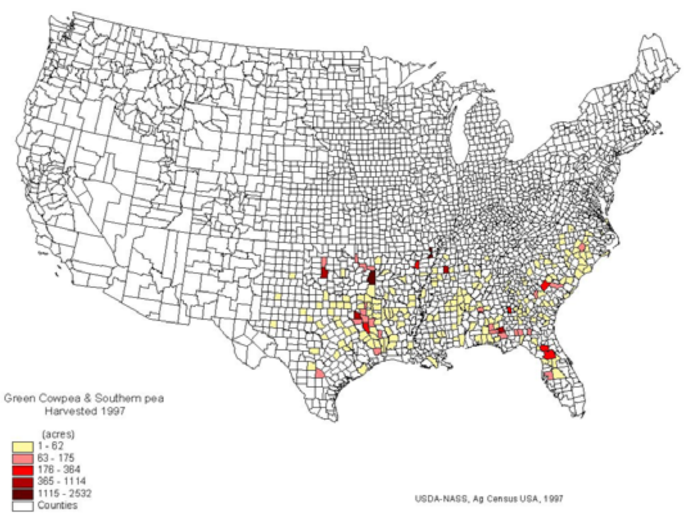
Map 17. Corn (*Zea mays*)



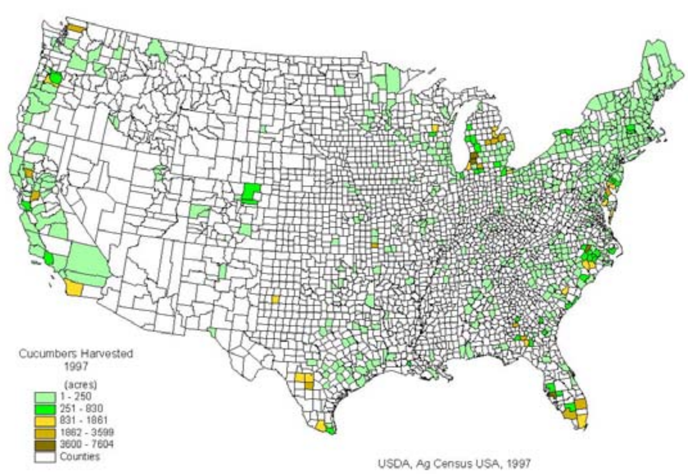
Map 18. Cotton (*Gossypium hirsutum*)



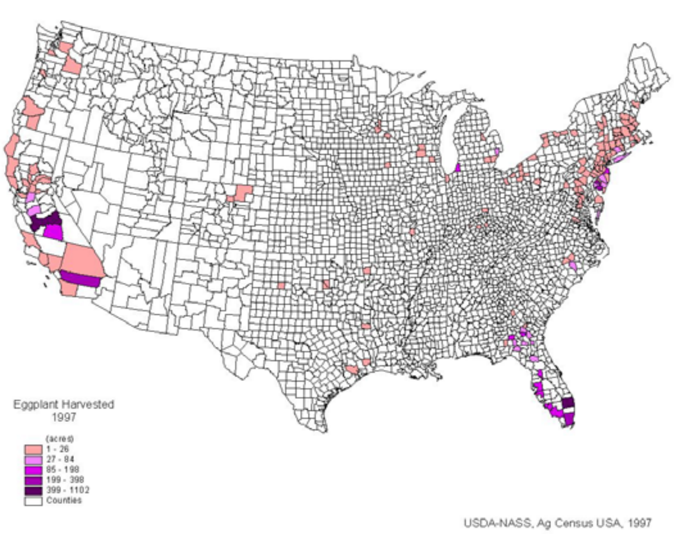
Map 19. Cowpea; dry (*Vigna unguiculata*)



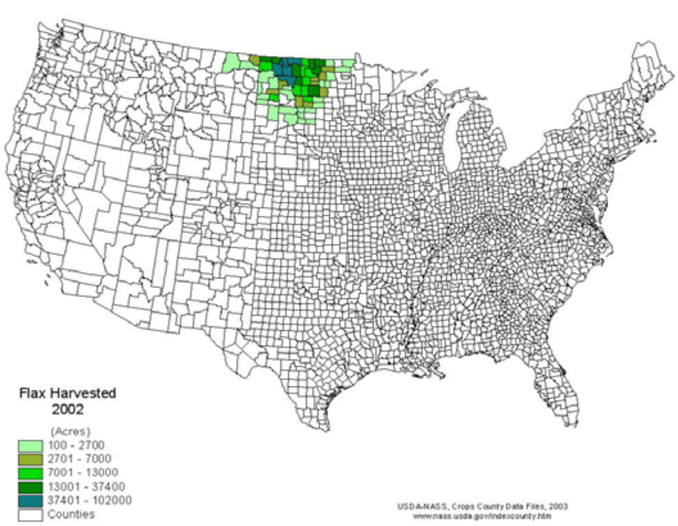
Map 20. Cowpea; green (*Vigna unguiculata*)



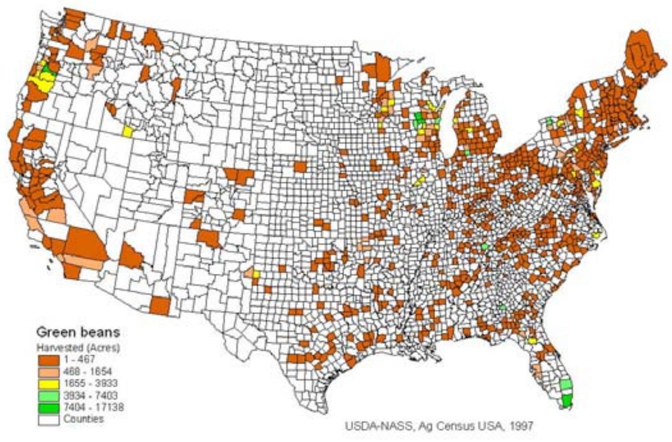
Map 21. Cucumber (*Cucumis sativus*)



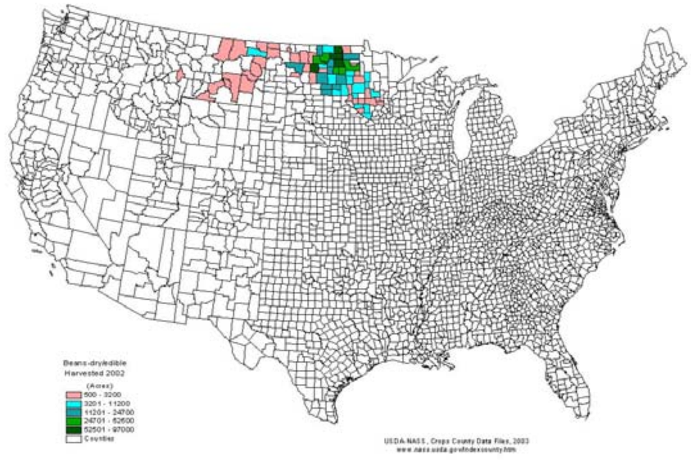
Map 22. Eggplant/aubergine (*Solanum melongena*)



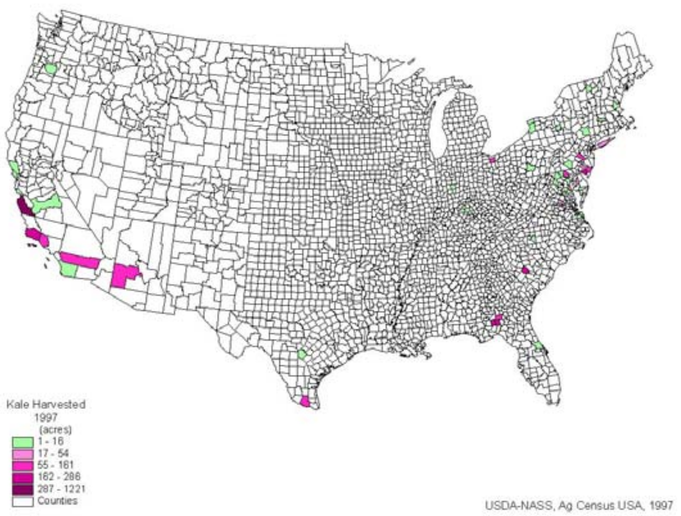
Map 23. Flax/linseed (*Linum usitatissimum*)



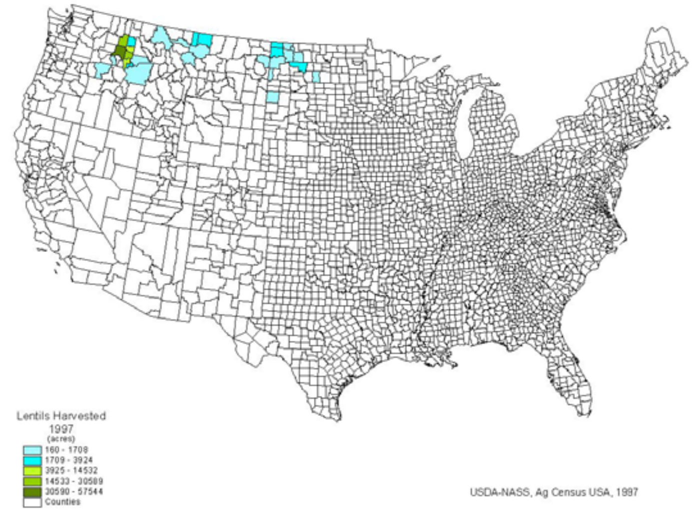
Map 24. Green bean (*Phaseolus vulgaris*)



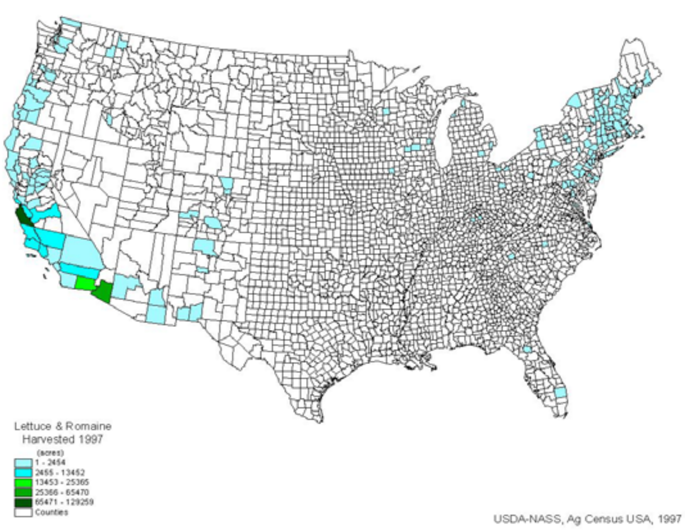
Map 25. Dry edible bean (*Phaseolus vulgaris*)



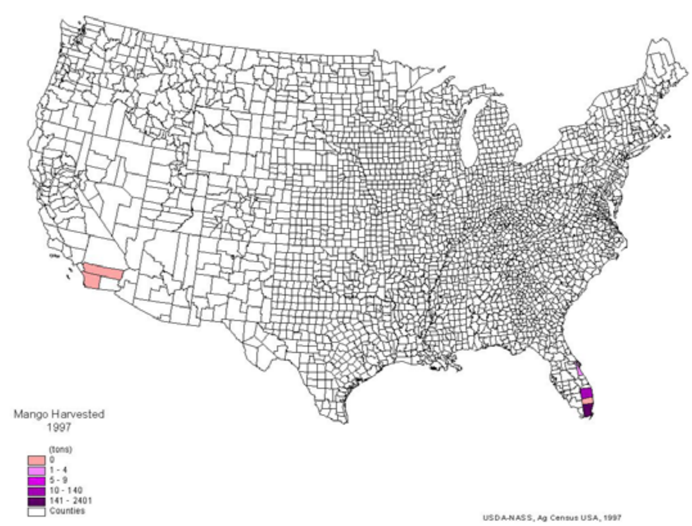
Map 26. Kale (*Brassica napus*)



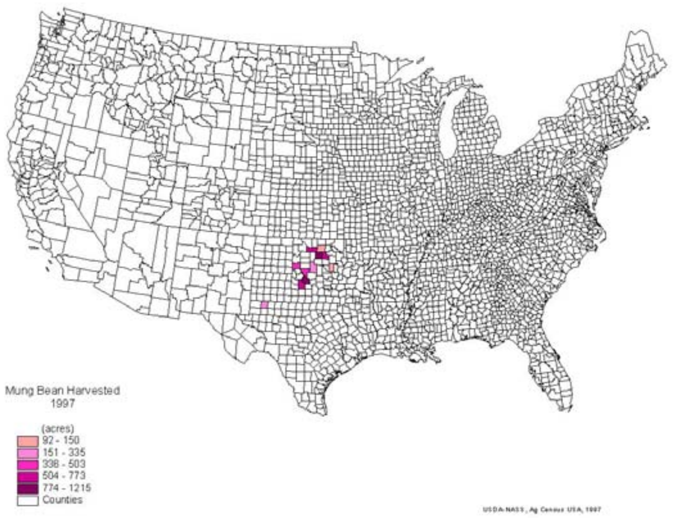
Map 27. Lentils (*Lens culinarus*)



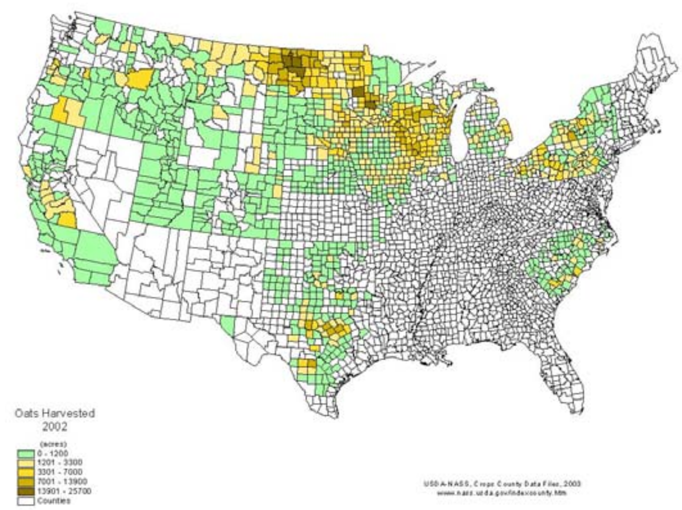
Map 28. Lettuce (*Lactuca* spp.)



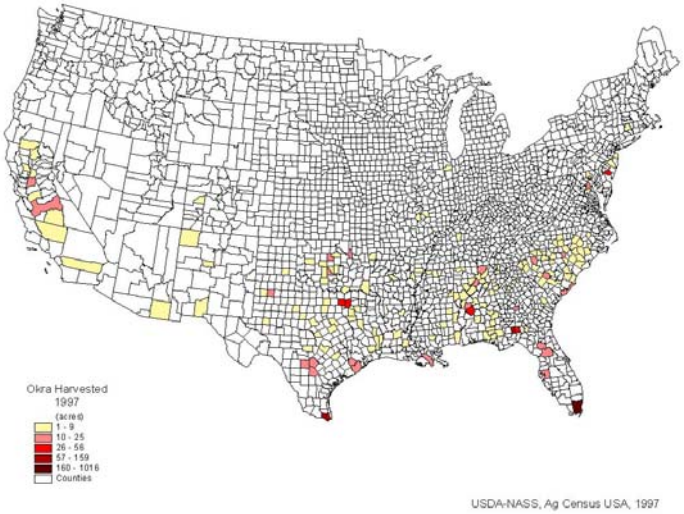
Map 29. Mango (*Mangifera indica*)



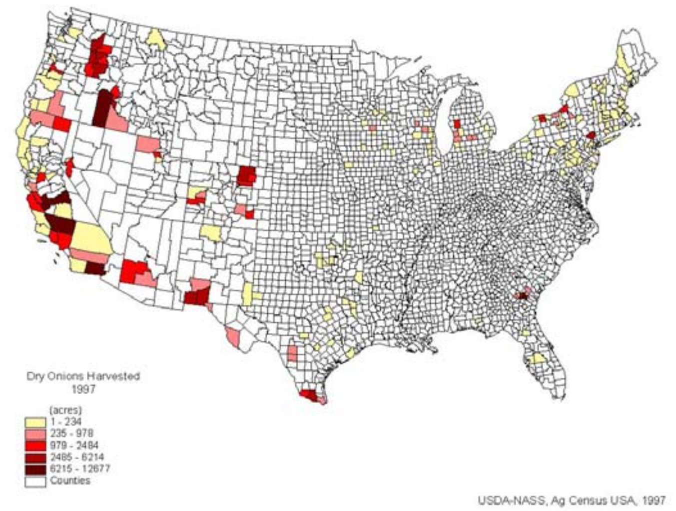
Map 30. Mung bean/green gram (*Vigna radiata*)



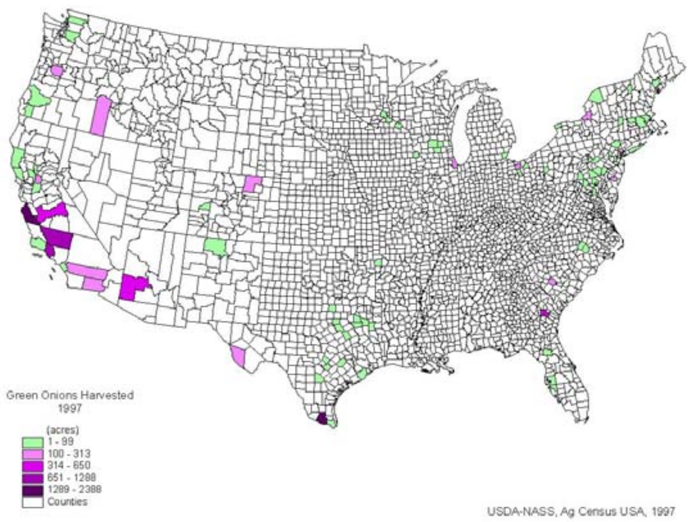
Map 31. Oat (*Avena* spp.)



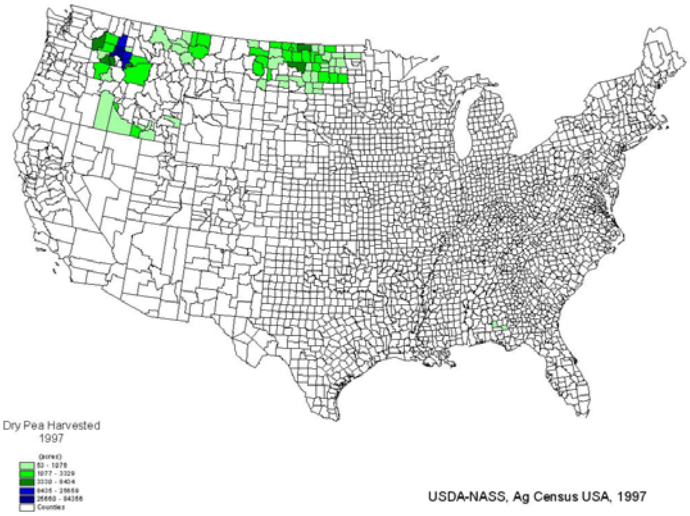
Map 32. Okra (*Abelmoschus esculentus*)



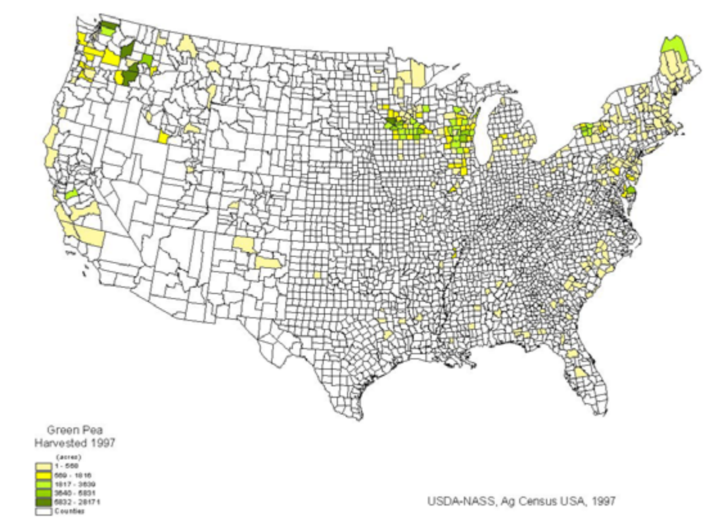
Map 33. Onion; dry (*Allium cepa*, *Allium* spp.)



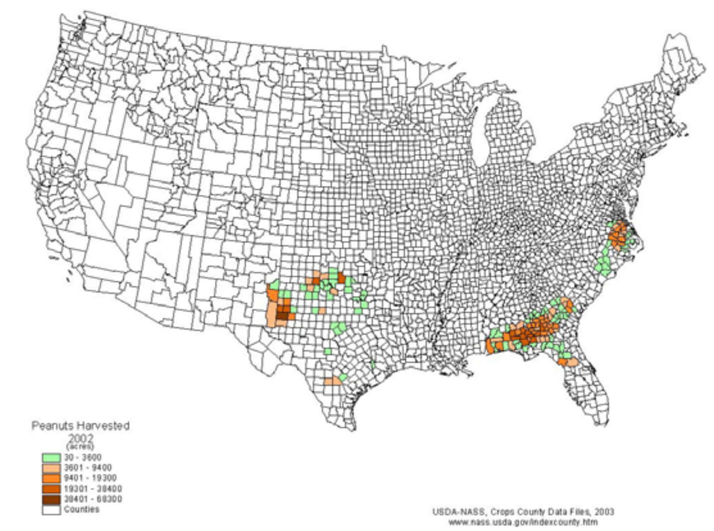
Map 34. Onion; green (*Allium cepa*, *Allium* spp.)



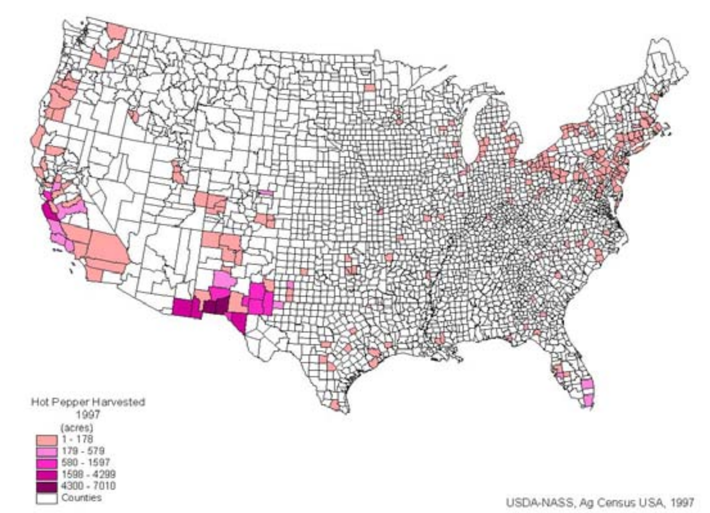
Map 35. Pea; dry (*Pisum sativum*)



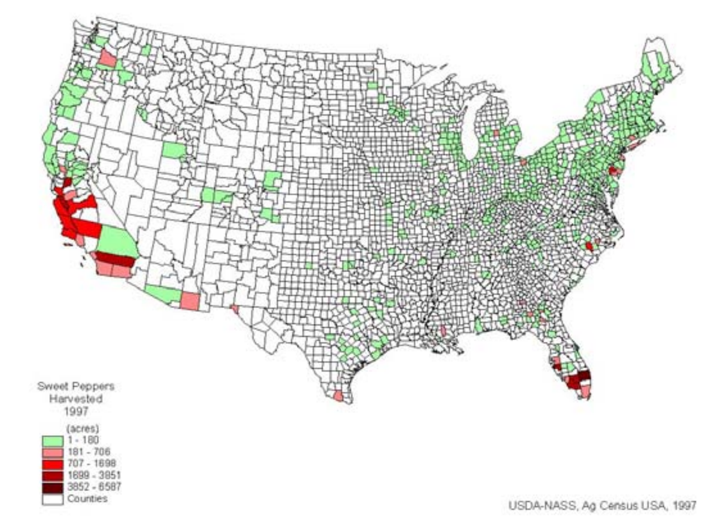
Map 36. Pea; garden/green (*Pisum sativum*)



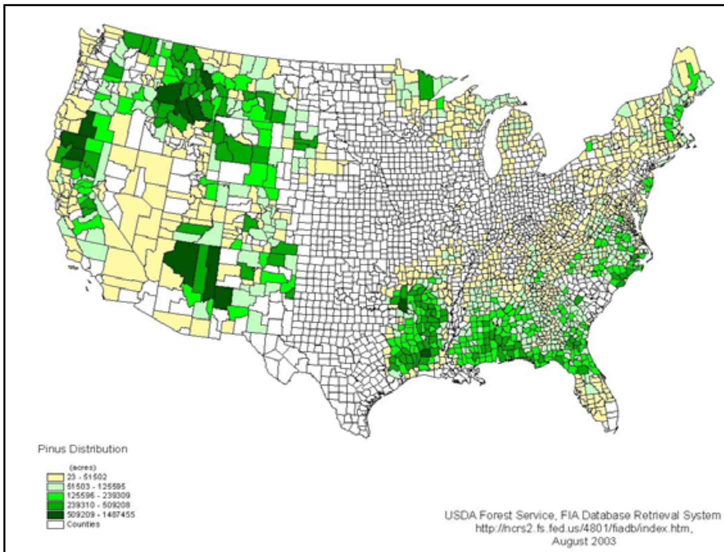
Map 37. Peanut/groundnut (*Arachis hypogaea*)



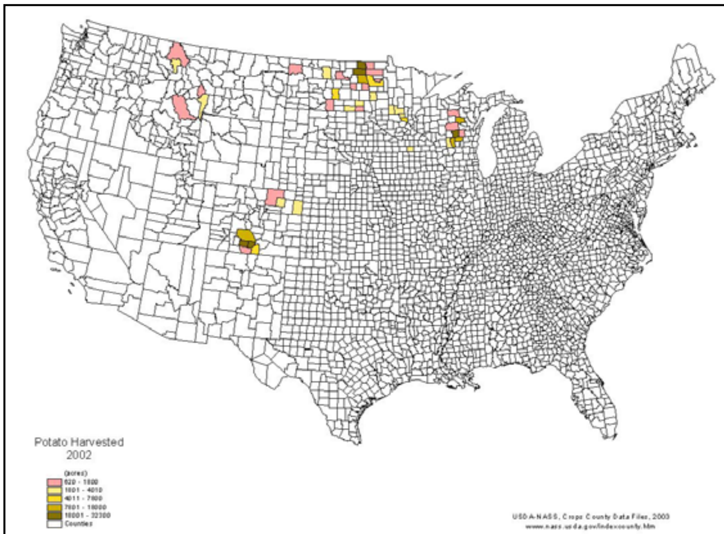
Map 38. Pepper; chili/hot (*Capsicum annuum*, *Capsicum* spp.)



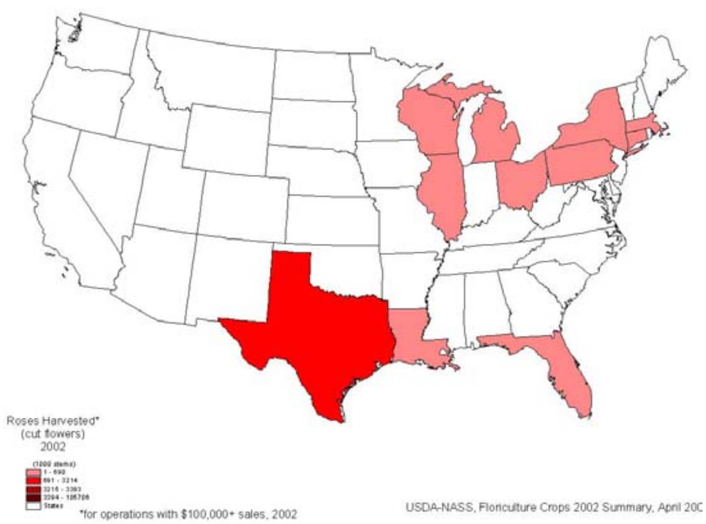
Map 39. Pepper; sweet (*Capsicum annuum*, *Capsicum* spp.)



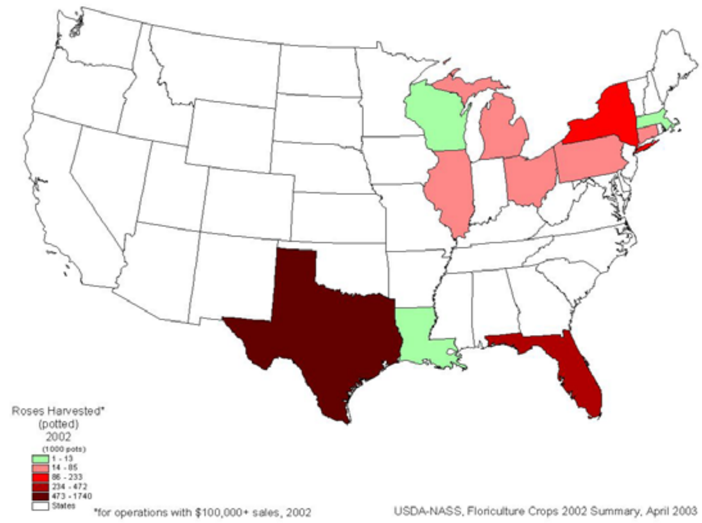
Map 40. Pine (*Pinus* spp.)



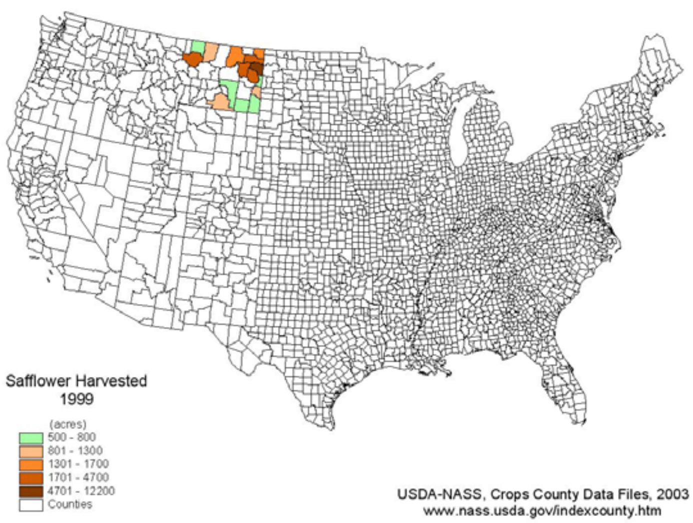
Map 41. Potato (*Solanum tuberosum*)



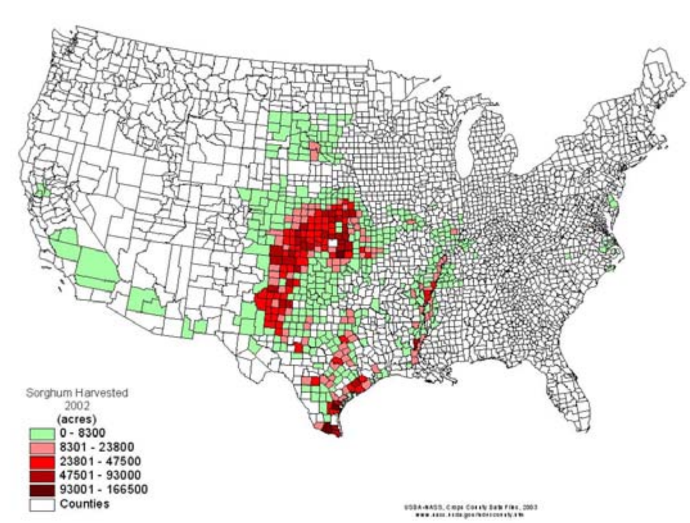
Map 42. Rose; cut (*Rosa* spp.)



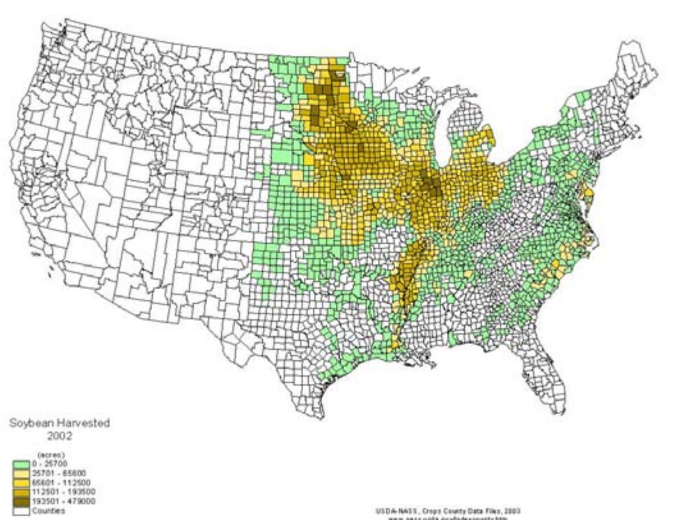
Map 43. Rose; potted (*Rosa* spp.)



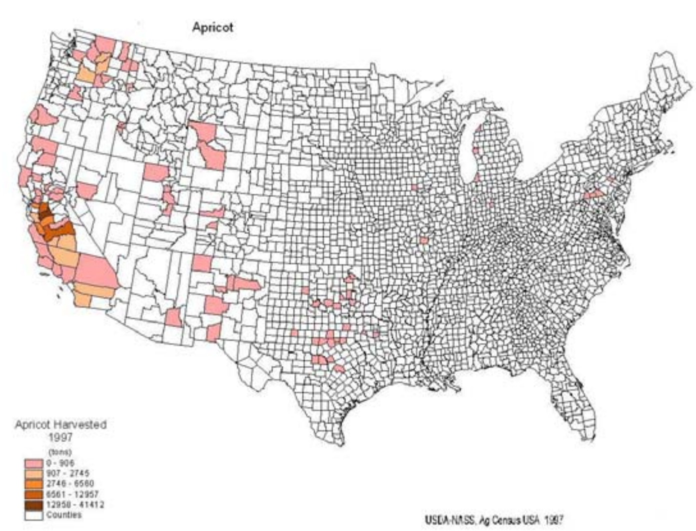
Map 44. Safflower (*Carthamus tinctorius*)



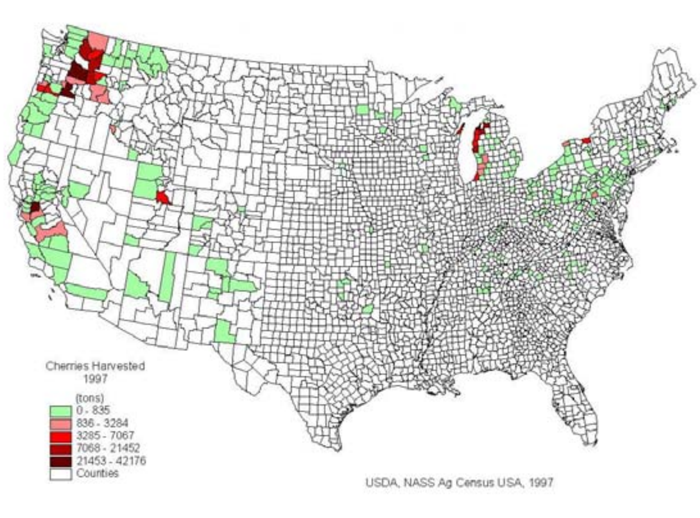
Map 45. Sorghum (*Sorghum* sp.)



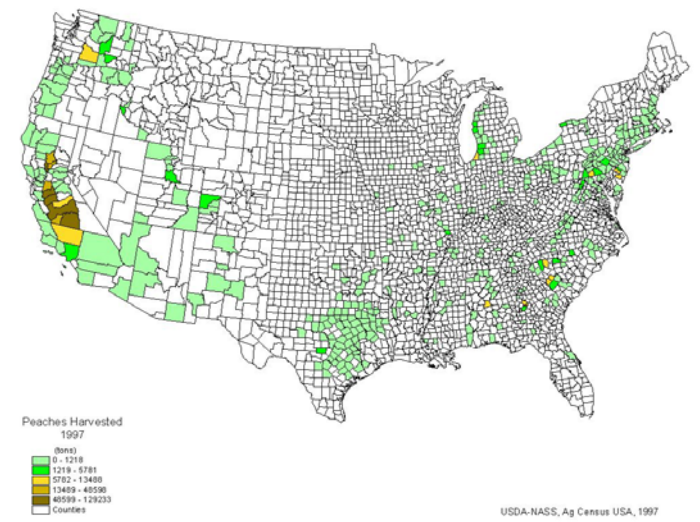
Map 46. Soybean (*Glycine max*)



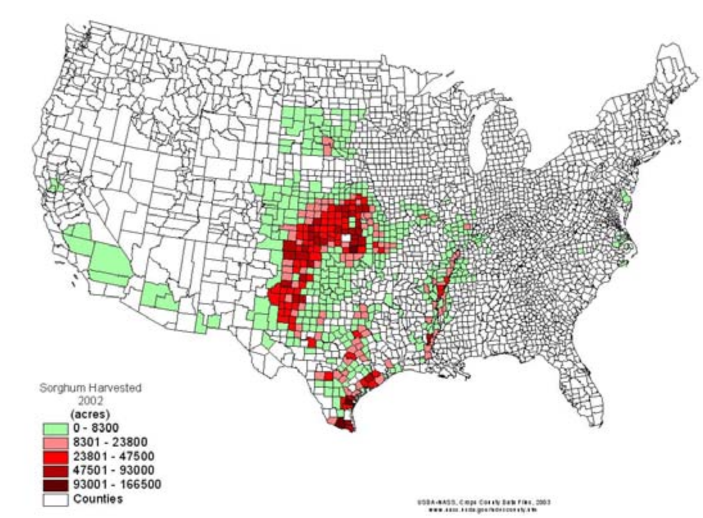
Map 47 Stone fruit; apricot (*Prunus armeniaca*)



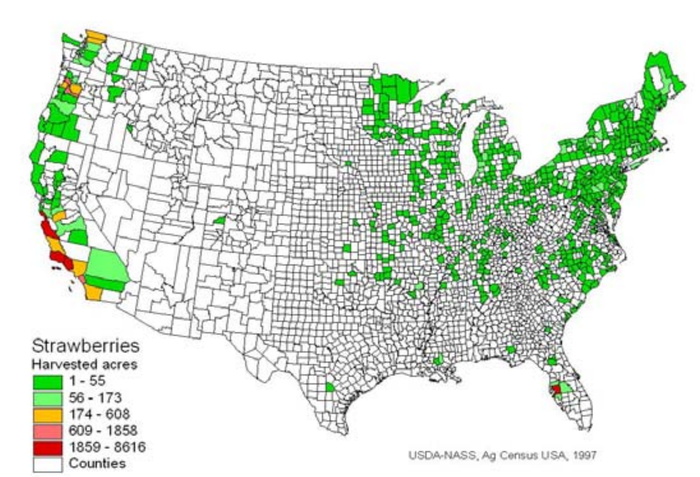
Map 48. Stone fruit; cherry (*Prunus avium*)



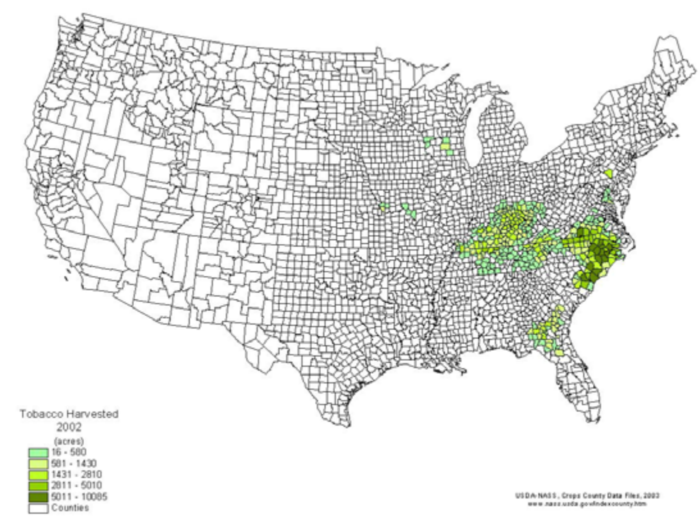
Map 49. Stone fruit; peach (*Prunus persica*)



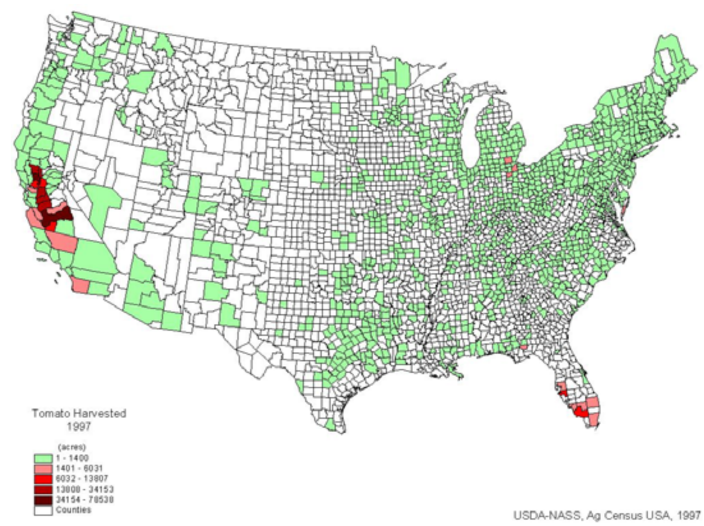
Map 50. Stone fruit; peach (*Prunus persica*)



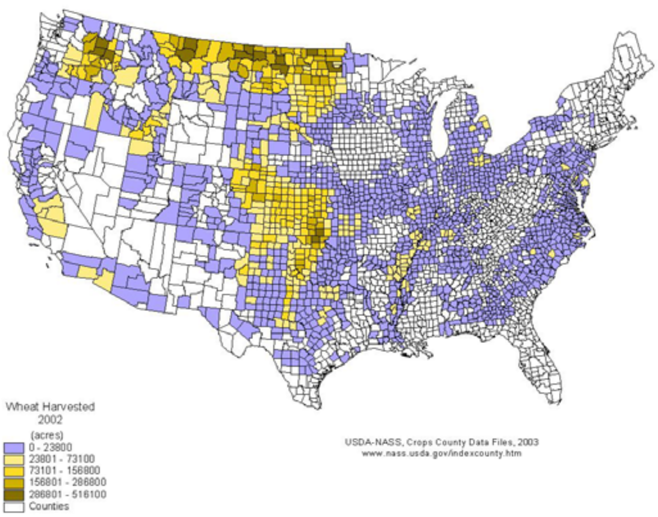
Map 51. Strawberry (*Fragaria ×ananassa*)



Map 52. Tobacco (*Nicotiana tabacum*)



Map 53. Tomato (*Lycopersicon esculentum*)



Map 54. Wheat (*Triticum aestivum*)

Appendix C. Taxonomy of *Helicoverpa armigera* Hübner and related Noctuidae (prepared by J. Zaspel)

Figure. C1 *Helicoverpa armigera* Hübner
[image from Paolo Mazzei, http://www.leps.it/SpeciesPages/HelicArmig.htm]

Helicoverpa armigera, the Old World bollworm is a widely distributed economic pest that has been taxonomically confused with several existing *Helicoverpa* species (Common 1953). Further, some ecological and economical literature use the old generic name *Heliothis* (Zalucki 1991), and some authors treat *Helicoverpa* as a subgenus of *Heliothis* in the taxonomic literature (Common 1990). Although Mathews (1987) supports separation of *Helicoverpa* and *Heliothis*, Common (1990) retains the old generic name and treats *Helicoverpa* as a subgenus of *Heliothis* (Zalucki 1991). Significant inconsistency and instability in the literature over the years has resulted in much confusion, making identification and discussion of species difficult; therefore, additional work may be necessary to reach conclusions about the taxonomic status of these pests. *H. armigera* and other species in *Helicoverpa* feed on a wide range of crops, thus, correct species determination is critical for sucessful risk assessment and management practices (Kirkpatrick 1961b). Genitalic and wing characteristics can help distinguish *Helicoverpa armigera* males from morphologically similar species such as *H. assulta*, *H. punctigera* and *H. rubrescens* (Common 1953). Wing color and pattern and genitalic characteristics can be used to separate *H. armigera* females from similar species such as *H. assulta*, *H. punctigera* and *H. rubrescens* (Common 1953).

Synonyms

At the generic level [as per Hardwick (1965)]:
Helicoverpa Hardwick, 1965, p. 9; *Noctua armigera* cited as type.

- ***Heliothis*** Todd, 1965, p. 1328
- ***Chloridea*** Boursin, 1965, p. 186
- ***Noctua*** Fabricius 1794

At the species level:
Heliothis armierga (Hübner) [as per Common (1953)]

- ***Noctua armigera*** Hübner, 1805, Sammlung europäischer Schmetterlinge Noctuae (Lepidoptera IV) pl. 79, fig. 370.
- ***Heliothis armigera*** (Hübner) Ochsenheimer, 1826, Die Schmetterlinge von Europa 5 (3): 215. Butler, 1883, Proc. Zool. Soc. Lond. 1883: 162. Hampson, 1894, Fauna Brit. India, Moths 2: 174-75. Swinhoe, 1900, Cat. Eastern Australian Lep. Heterocera Oxford Univ. Mus., Pt. II: 591. Meyrick, 1912, Trans. N.Z. Inst. 44 (1911): 93. Meyrick, 1928, Revised Handb. Brit. Lepidoptera, p. 91. Hudson, 1928, Butterflies Moths N.Z. p. 46, pl. 6, fig. 26, and pl. 1, figs. 15, 16 (larvae). Tams, 1935, Insects of Samoa 2 (3) (Lepidoptera): 196.
- ***Heliothis pulverosa*** Walker, 1857, List Lep. Ins. Coll. Brit. Mus. 11: 688 (type locality: Cape of Good Hope, South Africa).
- ***Heliothis conferta*** Walker, 1857, List. Lep. Ins. Coll. Brit. Mus. 11: 690 (type locality: Auckland, N.Z.).
- ***Heliothis uniformis*** Wallengren, 1860, Wien. ent. Monatschr. 4: 171 (type locality: Wahlberg, South Africa).
- ***Chloridea armigera*** (Hübner) Hampson, 1903, Cat. Lep. Phalaenae Brit. Mus. 4: 45.
- ***Chloridea obsoleta*** (Fabricus) Hampson, 1903, Cat. Lep. Phalaenae Brit. Mus. 4: 657.
- ***Heliothis obsoleta*** (Fabricus) Turner, 1920, Trans. Roy. Soc. S. Aust. 44: 131.

Helicoverpa armigera (Hübner) [as per Hardwick (1965)]

- ***Noctua barbara*** Fabricius, 1794. Ent. Systematica 3(2): 111; Barbaria
- ***Noctua armigera*** Hübner [1803-1808] Samml. Europaeische Schmett., Noct. 2, fig. 370.
- ***Heliothis pulverosa*** Walker, 1857 List Lep. Ins. British Mus. 11: 688; Cape.
- ***Heliothis uniformis*** Wallengren, 1860. Wiener Ent. Monatschr. 4: 171; Caffraria.

Description of the genus *Helicoverpa* [Description from Hardwick (1970)]
Adult: Frons only moderately bulging, and with a rather weakly developed ventral lip. Labial plap clothed with spatulated and hair-like vestiture, the former predominating; vestiture forming a moderate curtain ventral to palp. Antenna of both sexes filiform, that of male ventrally ciliate, that of female ventrally very sparsely ciliate. Eye full and globular. Head and thorax densely clothed in a mixture of hair-like and spatulated scales, the former predominating on the surface. Wing pattern typically noctuiform. Foretibia setose. Foretarsus without enlarged setae. Mid and hind tibiae setose.

Male genitalia: Valve long to moderately long, often apically broadened. Corona consisting of numerous closely set setae arranged in several rows. Ampulla absent. Sacculus somewhat stouter than remainder of valve but otherwise poorly distinguished. Juxta roughly rectangular, broader than high. Aedeagus elongate, with a slender, finely denticulate band along right apical margin. Vesica in the form of a long spiral tube consisting of six to twelve coils; armed with clusters of spines or occasionally with a continuous row of spines on outer surface of coils; vesica provided with various small diverticula at base with a small plate often bearing a spine.

Female genitalia. Ovipositor valve soft and pad-like; rather densely setose. Apophyses moderately elongate, very slender. Ninth abdominal segment membraneous. Ductus bursae membraneous except for a well-defined subostial plate, and a slender, sclerotized band in its wall anteriorly. Corpus bursae consisting of a membraneous, globular fundus, and an elongate, alternately dilated and constricted appendix of a peculiar leathery consistency. Fundus bursae provided with one short and three long signa. Sclerotized band in an anterior wall of ductus extending anteriorly to form a partial collar around base of appendix bursae. Oriface of ductus seminalis at apex of appendix bursae.

Species in this genus can separated from species in *Heliothis* by the "multi-coiled" vesica in the male genitalia.

Description of *Helicoverpa armigera* [Description from Common (1953)]
Adult: *Helicoverpa armigera* males have yellowish-olive to a yellowish-gray color heads and thoraces, with a pinkish color lightly infused on the labial palps and antennae (Fig. C1). The legs are grayish brown, and may have a pinkish color infused throughout. The male abdomen is yellowish gray (Figs. C1, C2). The male forewing is yellowish-olive with orange-brown to grayish brown distinct transverse lines (Figs. C1, C2). The hindwing is yellowish white infused with a gray color towards the base (Fig. C2). The under side of the hindwing is yellowish white, with a reddish postmedial line.

Figure C2. *Helicoverpa armigera* female (left) & male (right)
[Reproduced from Hardwick (1965)].

H. armigera females have light reddish brown heads, thoraces and forewings, respectively (Fig. C2). *H. armigera* female forewings have distinct, dark reddish brown transverse lines (Fig. C2). The under side color of the hindwing is heavily infused with a reddish color beyond the postmedial line.

***Wings*:** The orbicular spot on a male wing is a brownish black dot with a ring of grayish brown (Figs. C2, C3) and the reniform spot is distinct with a brownish black center surrounded by a grayish brown "quadrangle" with the outer side joined to costa by a short bar. The male hindwing has veins that are outlined with fuscous. Female wings have a pale marginal patch between M3 and Cu2 (Fig. C4) in the black terminal area of the hindwing (Fig C2).

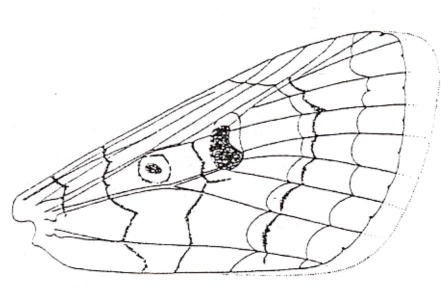


Figure C3. Forewing of *H. armingera*
[Reproduced from Kirkpatrick (Kirkpatrick

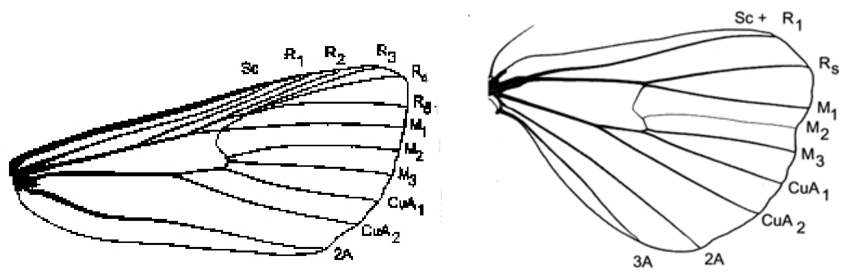


Figure C4. General diagram of venation in forwing (left) and hindwing (right)
[Reproduced from Pogue (2002)].

Male genitalia**:** *H. armigera* males have broad valves that are bent outward in the middle (Fig. C5). *H. armigera* males have a "short backwardly curved and heavily sclerotized thorn" on the aedeagus (Fig. C5). There is a single band of 12-15 cornuti with many spines associated with the aedeagus (Figs. C5).

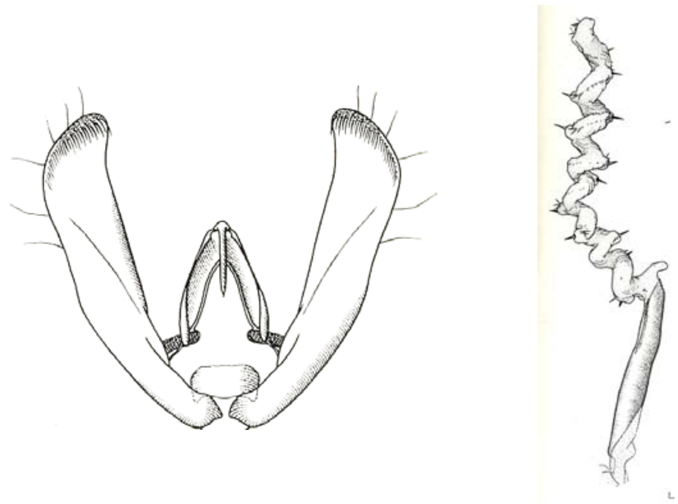


Figure C5. *Helicoverpa armigera* valve (left) & aedeagus (right)
[Reproduced from Hardwick (1965)].

Female genitalia**:** *H. armigera* females have nearly symmetrical genitalia (bursa copulatrix) with 3 long signa, one short signa and several spines on the inner surface (Figs. C6). The genital plate is described as being "deeply cup-shaped" (Figs. C6).

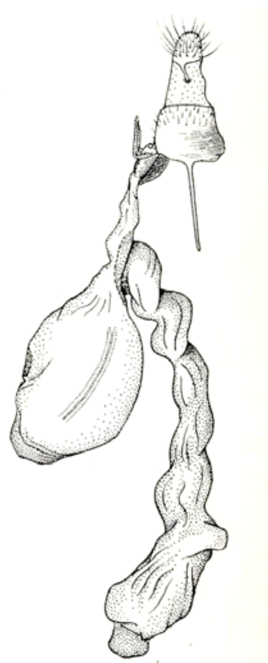


Figure C6. *Helicoverpa armigera* female genitalia
[Reproduced from Hardwick (1965)]].

Larva: [Description from Kirkpatrick (1961b)] *Helicoverpa* larvae are difficult to identify because several species (*H. armigera, H. assulta, H. punctigera*, and *H. rubrescens*) have the same larval characteristics. The head color of the first instar is black or dark brown and later instars are light brown green with a constant pattern of darker spotting (Fig C7). Body length is 10-12 times width and spiracles are found on prothorax and abdominal segments 1-8, with height about 1 ½ times the width. Larval skin is covered with small spines (Fig. C8). The background color in the first instar is grayish white and can vary from green to pinkish brown in later instars (Figs. C6). The prothoracic shield is dark brown or black in all instars. The dorsal area that extends from the midline to just above the first seta in all segments is heavily pigmented and the area just below this is lightly pigmented. The supraspiracular area is heavily pigmented extending from the subdorsal area to just above the spiracle on the prothorax to just above the spiracles in abdominal segments. The subspiracular area is white with very light brown markings, sometimes with infused with a pinkish color, extending from the lower edge of the subspiracular area to midway between setae on the prothorax and other segments. For extensive technical descriptions of all instars, see Hardwick (1965).

Figure C7. Larvae of *Helicoverpa armigera* (left) & *H. punctigera* (right) [Reproduced from Hardwick (1965)]].

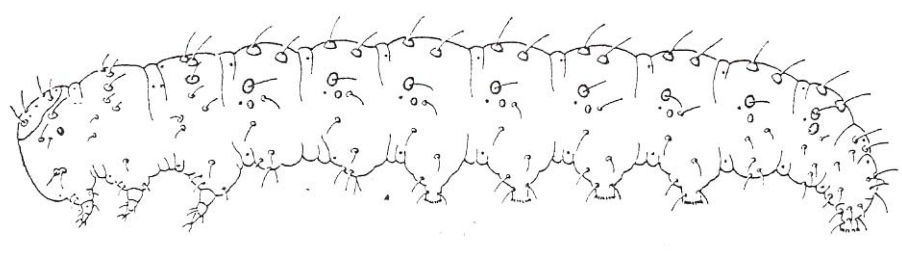


Figure C8. Larva of *Helicoverpa armigera* [Reproduced from Kirkpatrick (1961b)].

Similar species:

Figure C9. *Helicoverpa assulta* female (left) & male (right)
[Reproduced from Hardwick (1965)].

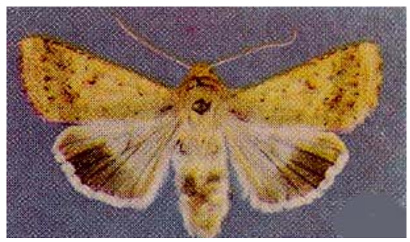


Figure C10. *Helicoverpa punctigera* male
[Reproduced from Hardwick (1965)].

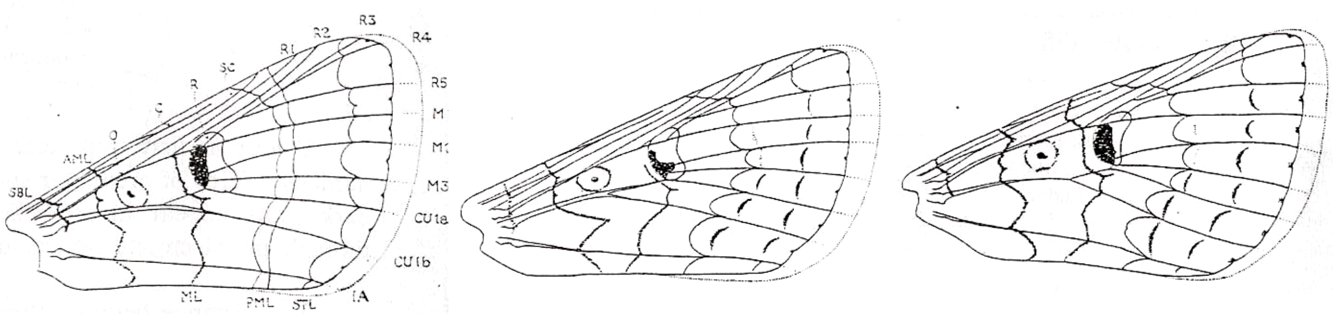
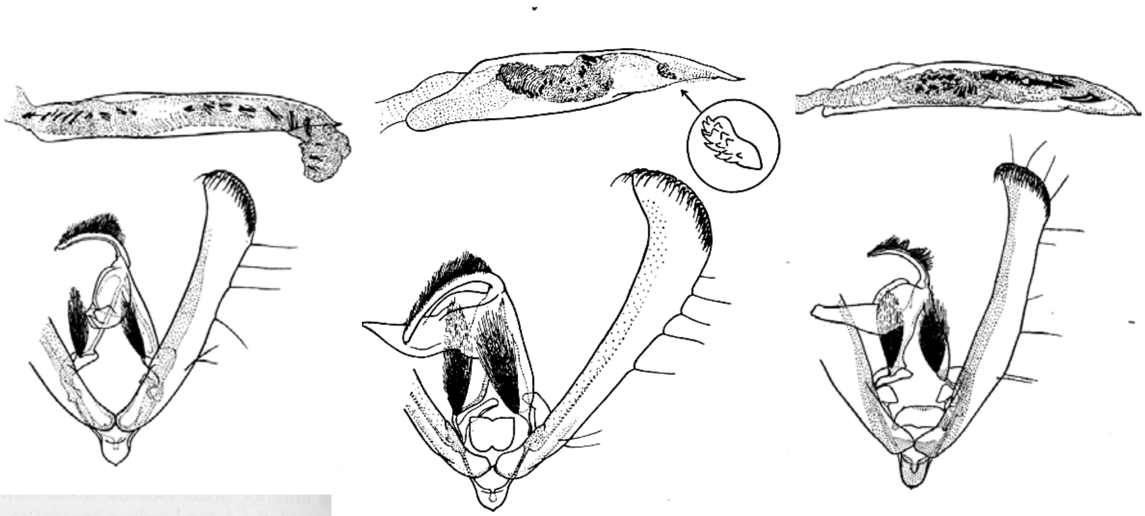


Figure C11. Forewing of *Helicoverpa assulta* (left), *H. punctigera* (center), and
H rubrescens (right). [Reproduced from Kirkpatrick (1961b)]



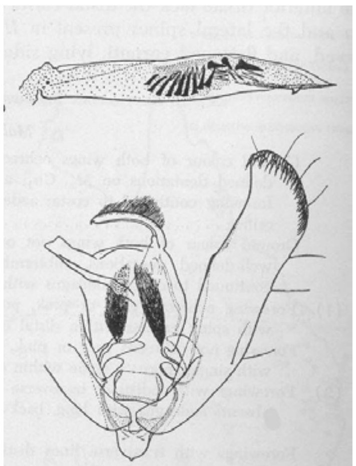


Figure C12. Aedeagus and valve of *Helicoverpa assulta* (upper left), *H. punctigera* (upper center), and *H. rubrescens* (upper right), and *H. armigera* (lower left). [Reproduced from Common (1953)]

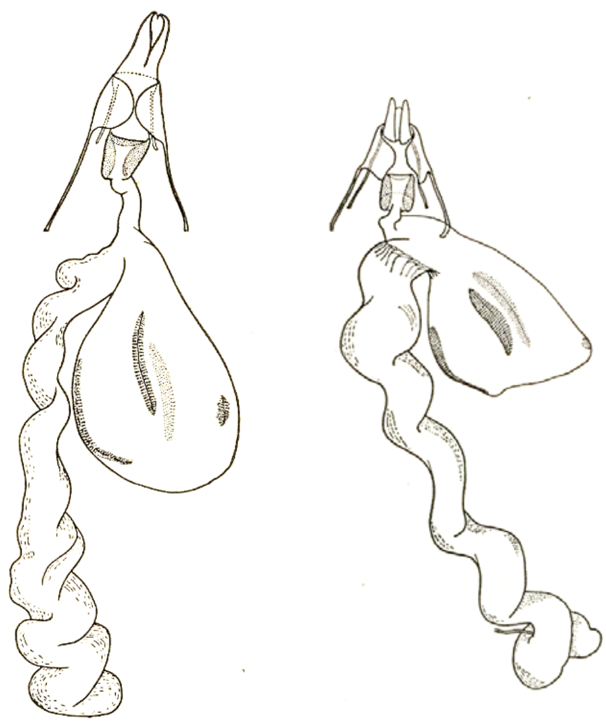


Figure C13. Female genitalia of *Helicoverpa assulta* (left), *H. punctigera* (center), and *H. rubrescens* (right) [Reproduced from Common (1953)]

Appendix D. Biology of *Helicoverpa armigera*

Population phenology

Because *H. armigera* exhibits overlapping generations, it can be difficult to determine the number of completed generations, but typically 2-5 generations are achieved in subtropical and temperate regions, and up to 11 generations can occur under optimal conditions, particularly in tropical areas (Tripathi and Singh 1991, King 1994, Fowler and Lakin 2001). In Australia, up to 7 generations can be completed in warmer regions of the country (Kirkpatrick 1962b). If larvae do not diapause, approximately 4 or 5 generations can be completed from late-September to early April, and 1-2 generations can be completed in winter (Kirkpatrick 1962b, Maelzer and Zalucki 1999). In China, *H. armigera* completes 3-4 generations annually (Xiao et al. 2002). In eastern New Zealand coastal regions, a more temperate climate where the average summer temperature is 23.5°C, 2-3 generations are completed (Cameron et al. 2001).

Temperature and availability of suitable host plants are the most important factors influencing the seasonality, number of generations, and the size of *H. armigera* populations (King 1994). Population size is also influenced by the size of the previous generation, timing of adult emergence, timing of migrant arrival, and climatic conditions (King 1994). Population size in fall serves as an indicator of the size of the spring population (Begemann and Schoeman 1999).

Stage specific biology

Adults emerge from the ground in the spring between dusk and midnight, climb vertical structures, and dry their wings for a period of 2 or more hours (King 1994, CAB 2003). In order to mate and lay eggs, adults typically feed on nectar. In particular, amino acids and sugars are key components of the adult diet (King 1994, CAB 2003). About 2-5 days after emergence, females release a pheromone during early morning hours before dawn to attract mates (King 1994). Mating occurs 1-4 days after emergence and is strongly influenced by humidity and temperature (King 1994, Saito 1999, Fowler and Lakin 2001). Mating occurs during cool, humid conditions and ceases during warm, dry conditions (King 1994). Moths can mate more than once, and multiple mating has been observed in captivity (King 1994).

H. armigera lays eggs prolifically (Tripathi and Singh 1991). A female may produce a maximum of 4394 eggs, but on average a female will produce 730-1,702 eggs (King 1994, Fowler and Lakin 2001, CAB 2003). Eggs can be laid over 10 to 23 days (King 1994). Oviposition begins 2-6 days after emergence, and egg laying often occurs at night (Kyi and Zalucki 1991, Akashe et al. 1997, Fowler and Lakin 2001, CAB 2003). Moths tend to lay eggs singly, on or near floral structures. Peak egg-laying typically occurs prior to or during host flower production (King 1994). Depending on the quality of the host, *H. armigera* may also lay eggs on leaf surfaces. Female moths tend to choose pubescent (hairy) surfaces for oviposition rather than smooth leaf surfaces (King 1994).

King (1994) reviews several adult longevity studies and reports a range in adult life span of 5 to 36 days. Adult longevity depends on several factors including pupal weight, food (nectar) supply, food quality (sucrose content), temperature, water availability, disease pressure, and predator activity (King 1994). Without adequate food sources, the adult dies within a few days (King 1994).

Under adverse conditions, moths can migrate long distances (King 1994, Zhou et al. 2000b, Shimizu and Fujisaki 2002, CAB 2003). Adults can disperse distances of 10 km during “non-migratory flights” and hundreds of kilometers (up to 250 km) when making “migratory flights”, which probably occur when host quality or availability declines (Saito 1999, Zhou et al. 2000b, Casimero et al. 2001, Fowler and Lakin 2001). Studies on *H. armigera* flight and dispersal are thoroughly reviewed by King (1994).

Egg incubation lasts 3-14 days, depending on temperature (King 1994, Fowler and Lakin 2001, CAB 2003). Eggs hatch in about 3 days at 25°C, but at lower temperatures, hatch may take up to 11 days (CAB 2003).

Larvae may complete up to 7 instars, though generally there are between 5 and 7 instars (Twine 1978, King 1994, Fowler and Lakin 2001). The time required to complete each larval stage varies considerably depending on host plant, temperature and other factors. In laboratory studies, the complete larval period (all instars combined) lasted between 12-36 days (Kirkpatrick 1962b, Bhatt and Patel 2001, Fowler and Lakin 2001). During summer, larval development is completed in 14-18 days, while it may take up to 21 days in fall (CAB 2003). First generation larvae require more time to develop (24-36 days) than the second or third generations, which are typically complete between 16-30 days and 19-26 days, respectively (CAB 2003). First instar larvae have a high mortality rate, most likely caused by larval movement or predators (Kyi and Zalucki 1991). The prepupal stage lasts 1-4 days, and during this time larval activity decreases (King 1994). Moulting often occurs in full sun on leaf surfaces (King 1994).

Larval development depends primarily on temperature and secondarily on host nutritional quality (King 1994, CAB 2003). Before feeding on their host plant, newly hatched larvae typically consume all or part of their egg shells; larvae may then feed on leaf surfaces or floral structures, moving about the plant for a short distance before selecting a preferred feeding spot (King 1994). When larval mobility is limited, development times can vary widely and survival is largely determined by host plant selection of egg-laying females (Jallow and Zalucki 1996, Gu and Walter 1999). Small, young larvae have the ability to feed inside floral structures, detectable only by a small hole with spun silk at the entrance and visible frass; larger larvae feed with a portion of their body outside the floral or fruiting structure (King 1994). *Helicoverpa armigera* is particularly damaging to crops because larvae can move from plant to plant, particularly when food is scarce (King 1994). Late-instar larvae are more damaging to the host plant due to their attraction to “full buds” (Mabbett et al. 1980). “Antagonism” and “cannabalism” have been observed among older larvae on corn in situations where several eggs were deposited (King 1994).

Pupae. Once feeding is completed, larvae move between 2.5-17.5 cm below the soil surface to pupate depending on soil moisture, organic matter on the surface, and other factors (King 1994). Less frequently, pupation occurs within a spun web on the host plant (e.g. in a corn cob) or on the soil surface (King 1994). Depending on temperature, the pupal stage lasts between 6-33 days, unless the insect goes into diapause, in which case pupation may require several months. *H. armigera* overwinter as pupae (Kirkpatrick 1962a, b, King 1994, Akashe et al. 1997, Maelzer and Zalucki 1999, Bhatt and Patel 2001, Fowler and Lakin 2001, CAB 2003).

Diapause is facultative and occurs during the pupal stage (King 1994). Diapause induction begins when larvae are exposed to daylengths between 11.5-12.5 hours, and low temperatures (19-23˚C), or when larvae are exposed to lengthy periods of extremely hot and dry weather (≥35˚C) (King 1994, Zhou et al. 2000b, Shimizu and Fujisaki 2002, CAB 2003). Little to no diapause occurs in tropical areas (King 1994).

Total longevity (from egg to adult death) is 30-40 days with females generally living 2-3 days longer than males (King 1994, Akashe et al. 1997). Bhatt (2001) recorded a slightly longer life span of about 51 days for males and 54 days for females. Rochester (2002) reported a span 35-75 days from egg to adult.

Interactions

Temperature and Relative Humidity, Photoperiod, Water and Biotic Factors

Generally, *H. armigera* populations are negatively affected by strong winds, heavy rains, or extremes in temperature. Heavy rainfall and winds can decrease the population at the egg and larval stages (Karmawati and Kardinan 1995, Maelzer and Zalucki 1999, Fowler and Lakin 2001). Dry seasons can adversely affect pupal development (Karmawati and Kardinan 1995). High humidity can lead to fungal attack (Karmawati and Kardinan 1995).

Extremely high temperatures have a negative effect on *H. armigera* (Tripathy et al. 1999). The optimum temperature for development from 1st instar larva to adult was 33.9°C (Twine 1978). However, Twine (1978) reported optimal survival temperatures of 27° C for pupae and 24° C for larvae. In a laboratory study, high temperatures (above 37°C) caused pupal dormancy (Nibouche 1998).

A standard threshold for development of *H. armigera* was determined to be 11°C (Twine 1978, Maelzer and Zalucki 1999). Several studies describe the developmental thresholds and accumulated degree days necessary for the completion of each life stage (Table D1).

Table D1. Developmental thresholds and degree day requirements for *Helicoverpa armigera*

Stage	Developmental threshold (˚C)	Degree Days ± SE	Notes	Reference
Egg	10.5	51	Field collected	(Jallow and Matsumura 2001)
	11.6	NA		(Su et al. 2002)
Larva	11.3	215.1	On tomato in lab	(Jallow and Matsumura 2001)
	13.6	NA	1st instar	(Su et al. 2002)
	11.9	16.3 ± 2	1st instar; diet; from author's Table 1	(Twine 1978)
	12.8	NA	2nd instar	(Su et al. 2002)
	11.8	16.5 ± 2.1	2nd instar; diet; from author's Table 1	(Twine 1978)
	11.5	NA	3rd instar	(Su et al. 2002)
	12.6	23.9 ± 3.9	3rd instar; diet; from author's Table 1	(Twine 1978)
	6.4	NA	4th instar	(Su et al. 2002)
	10.4	39.1 ± 2.8	4th instar; diet; from author's Table 1	(Twine 1978)
	11.8	NA	5th instar	(Su et al. 2002)
	13.1	22.3 ± 7.8	5th instar; diet; from author's Table 1	(Twine 1978)
	9.769	NA	6th instar	(Su et al. 2002)
	8.9	87.9 ± 6.4	6th instar; diet; from author's Table 1	(Twine 1978)
	13.89	NA	Pre-pupae	(Su et al. 2002)
	9.3	50.0 ± 6.4	Pre-pupae; diet; from author's Table 1	(Twine 1978)
	10.6	260	L1-L6; lab diet	(Twine 1978)
Pupa	13.8	151.8	Field collected	(Jallow and Matsumura 2001)
	11.4	211	Laboratory study	(Twine 1978)
	10	150	Non-diapause; calculated from author's report	(King 1994)
Complete life cycle	11.0	475	From larva to adult, in laboratory study	(Twine 1978)