Review of literature

Geographic distribution

The cotton bollworm, *H. armigera* is widely distributed as an agricultural pest throughout Africa, the Middle East, southern Europe, India, central and southeastern Asia, eastern and northern Australia, New Zealand, and many eastern Pacific Islands (Common, 1953; Hardwick, 1965; CIE 1967a, b, 1968, 1969; Zalucki et al., 1986). In India, three species of *Helicoverpa* are noticed in Andhra Pradesh, viz., *Heliothis armigera* (Hübner), *Helicoverpa assulta* Guenée, and *Heliothis peltigera* (Denis & Schiffermüller), but *H. armigera* being the predominant species. In view of polyphagous feeding nature, it attacks a wide range of food, fiber, oil, and fodder crops as well as many horticultural and ornamental crops. Relative to the areas grown, cotton, soybeans, tobacco, and the pulses, which are high value crops or staple foods, account for most of the economic loss due to *H. armigera*. Cotton, tobacco, sweet corn, and many horticultural crops receive a disproportionate amount of pesticide usage, because of their low degree of tolerance. Economic losses from direct yield reduction and the cost of chemicals, their application, and scouting require serious efforts. It was found to feed on over 181 host plants belonging to 45 families in India (Reed and Pawar, 1982; Manjunath et al., 1989). It commonly destroys more than half the yield with an estimated annual loss US$ 300 - 500 million to cotton and pulses in India (King, 1994).

Ecobiology

Adults mate on the third night after emergence, and begin laying eggs over a period of 5 - 6 days. Eggs are laid singly, with an appearance of subequatorial girdling pink band after 24 h. After 36 h incubation period, they gradually become greyish-yellow, and the girdling band darkening to a dull-red. Eggs hatch in 60 - 70 h at 23 - 25°C. Soon after emergence, the neonate larva feed on the egg-shell and find its way to the
flowering/fruiting structures of the cotton plant. Instar-3 is characterized by green or red-brown ground color, which corresponds with a greenish-fawn or cream to fawn color head capsule. The brown colored form usually predominates in *H. armigera*. The characteristic color pattern becomes more prominent and becomes darker in later instars, although this depends to some extent upon the nature of the host on which it feeds. The number of larval instars varies from five to six, with six being very common and completed in 16-18 days (Hardwick, 1965). The larval period depends on the host quality, and temperature. Reed (1965) recorded an average larval period of 21.1 days on cotton buds including a prepupal period of 2.7 days at varying temperatures of 21 - 27°C.

Before undergoing pre-pupation, the sixth instar larva enters 2 - 3 cm deep inside the soil. Normally, the pupal size is 14 - 22 mm long, and 4.5 - 6.5 mm wide. Female pupae are heavier than male ones (King, 1994), and the pre-pupal stage lasts for 2 - 3 days. The pupae remain in the soil for 10-12 days before the adults eclose in the dusk to midnight (20.00 – 22.00 h) (Roome, 1975; Tripathi and Sharma, 1985; Riley et al., 1992). Adult feeding is essential to mating and oviposition (Parsons et al., 1938). In cotton, the extra-floral nectar provides a source of food and could be important in developing nectariless cotton varieties to reduce the rate of oviposition (Maxwell et al., 1976; Lukefahr, 1982).

A single female moth can lay as many as 1500 – 2000 eggs (*av.* 713) over a period of 5-10 d at 24°C. Oviposition begins on the 4th night after emergence, and continues to the next 3 - 4 days. In Andhra Pradesh, around 7-8 overlapping generations are completed in a cropping season during June-May (Bhatnagar and Davies, 1978). In cotton, the adults prefer to lay more number of eggs on the leaves and squares than young bolls.

**Host plant relationships**

The polyphagous nature of *H. armigera* has been well documented (Pearson, 1958; Hardwick, 1965; Hardwick, 1965; Bilapate; 1984; Zalucki et al., 1986). Host plants differ
considerably in acceptability not only for oviposition (Ramaswamy, 1988; Firempong and Zalucki, 1990b) but also their suitability for larval development (Stadelbacher et al., 1986; Topper, 1987a). In Andhra Pradesh, the cotton bollworm could not complete life cycle on major weed hosts such as *Datura metel* and *Lagasca mollis* (Bhatnagar and Davies, 1978; Armes et al, 1992). Intriguing host preferences and geographical differences have been recorded (Reed and Pawar, 1982). *H. armigera* moths tend to oviposit on those plants or adjacent plants on which their larvae would develop, provided they have flowering and fruiting structures. Jallow et al. (1999) investigated the oviposition behavior of *H. armigera* on cotton genotypes and suggested that the photochemical soluble in pentane is most efficient in eliciting behavior with female moths laying more eggs on pentane extracts treated flowers.

On hatching, the neonate larva usually eats the egg shell before feeding on the plant. The neonates travel to some distance by taking occasional bites from the surface of the plant, before settling at a preferred site. In cotton, they scrape the leaf surface and then move onto the flower bud or flower, with the older larvae moving onto the young cotton bolls. Larvae tend to destroy many bolls or fruiting structures. Cannibalism in *H. armigera* is very common.

**Host plant resistance**

Host plant resistance has been largely dependent on the different *Gossypium* species. Some of the biochemical traits such as tannins (Chan et al., 1978), and gossypol content in the calyx of flower buds (Hedin et al., 1983) were found associated with resistance to feeding. Morphological traits such as pubescent glandular trichomes were found to reduce the neonate movement (Ramalho et al., 1984).

**Resistance to insecticides**

Extensive use of insecticides than any other insect species has been made, and the cotton crop alone receives more than 60% of the chemical groups in Andhra Pradesh.
Indiscriminate application of insecticides on cotton to control *H. armigera* larvae is common (Armes et al., 1996; Kathy et al., 2001). Resistance to different chemical group of insecticides include: cyclodiienes, organophosphates, synthetic pyrethroids, and carbamates is well documented in Andhra Pradesh and Maharashtra states (Dhingra et al., 1988; McCaffery et al., 1989; Armes et al., 1996; Kranthi et al., 2002, 2005). Kranthi et al. (2001) recorded over 8000- and 2000-fold increase in resistance to *H. armigera* strains from Maharashtra and Andhra Pradesh, respectively. Resistance is quite widespread against endosulfan, quinalphos, monocrotophos, and carbamates in Andhra Pradesh and southern India as well as in Australia (Kay, 1977; McCaffery et al., 1989; Price, 1991; Gunning et al., 1992; Kranthi et al., 2002). Further, in southern India, the resistance is well documented to synthetic pyrethroids, organophosphates, cyclodienes, and carbamates (Pasupathy and Regupathy, 1994). In addition, resistance to DDT has been reported in Australia (Wilson, et al., 1994; Gunning et al., 1990), Pakistan (Ahmad et al., 1995), and Thailand (Ahmad and McCaffery, 1988); monocrotophos in Thailand (Ahmad and McCaffery, 1988), India (McCaffery et al., 1989), China (Cheng and Liu 1996), Pakistan (Ahmad et al., 1995), and Turkey (Ernst and Dittrich, 1992); methomyl in India (Armes et al., 1992, 1996; Kranthi, 2001), and China (Cheng and Liu, 1996). Among the pyrethroids, resistance was reported to cypermethrin, deltamethrin, and fenvalerate in India (Armes et al., 1992; Phokela et al., 1989; Armes et al., 1996; Kranthi et al., 2001), Indonesia (McCaffery et al., 1988), Pakistan (Ahmad et al., 1997), and China (Shen et al., 1993).

**Natural enemies**

*H. armigera* is attacked by several parasites and predators on different crops and weeds hosts in India (Romeis & Shanower, 1996). In the USA, there are several examples where in the absence of insecticides, the natural enemies maintain *Heliothis* spp. below economic threshold levels (King et al., 1982). Much work in India on natural enemies was directed in compiling the parasitism levels of *H. armigera* on various crops and weeds (Bhatnagar et al., 1983; Pawar et al., 1985a,b; 1986a,b; 1989a,b). Reviews on natural parasitism of *H. armigera* have received little or no attention in Andhra Pradesh.
Bilapate (1981) gave an account of the levels of parasitism in cotton in Marathwada region of Maharashtra. Jadhav et al. (2000) reported egg-parasitism in sorghum and cotton in Ranga Reddy district of Andhra Pradesh. The significance of egg-parasitism has been constrained due to tediousness and time consuming. Sustainability of the annual cropping systems also plays an important role in encouraging the natural enemies. The literature is very thin on this aspect of work. Nevertheless, in the USA significant work has been done on the movement of natural enemy fauna from sorghum to cotton. Importantly small-scale agriculture with small-land holdings is much more promising and the advent of newer cultivars and hybrids had dramatic change in small-scale agriculture.

Influence of cropping systems

Most cropping systems support diverse natural enemy fauna, whose impact is encouraging (King et al., 1982; King et al., 1985; Hearn and Fitt, 1988). The role of parasites has been given major emphasis on their impact in regulation of \textit{H. armigera} populations both at local and regional levels (Smith et al., 1972; Barducci, 1972), and migration of natural enemies from sorghum to neighboring cotton (Massey et al., 1975; Krauter et al. 1998; Krauter et al. 1998; Prasifka et al., 1999a,b, 2004). Altieri (2002) indicated that the resource-poor farmers are located in risk-prone and marginal environments, and remain untouched by modern agricultural technology. This warrants a new approach to natural resource management to tailor adopting highly variable and diverse farm conditions replica of resource-poor farmers.

Sustainable cotton production and their implications on dryland crops in Andhra Pradesh had a dramatic effect in the past one-and-half decade (Gulati and Kelley, 1999). Kensuke (2004) reported significant changes in cropping pattern, where cereals such as sorghum have been completely replaced by oilseed crops including cotton, which has led to disasters in the farming community in Andhra Pradesh. The changing pattern of cropping systems was a major theme studied at state levels of Andhra Pradesh and Maharashtra (Sawant and Achutan, 1995; Bahadur et al., 1971; Dayakar et al., 1997; Directorate of Economics and Statistics, 1970-2001; Agricultural Situation in India,
1970-2001; Janaiah et al., 1992; Kelley et al., 1995). One of the most dramatic changes recorded in cropping pattern in districts of Andhra Pradesh over the last three decades has been the shifting away from the coarse cereals to cotton and paddy.

Aggregation of cotton fields, monocrop practices, over-use of insecticides, and destroyal of natural enemies, resurgence, habitat, and ecology are the common causes for the insect outbreaks (Barbosa and Schultz, 1983; Risch, 1983; Andow, 1983). In addition, weather factors such as temperature, and drought stress also contributed to the pest outbreaks. Bottrell and Adkisson (1977) described the outbreak of *H. virescens* due to spraying of DDT, organochlorine, and organophosphates and consequent to the mortality of natural enemies, causing severe outbreaks of *Heliothis* complex. Kranthi et al. (2002) clearly demonstrated that the outbreaks of *H. armigera* during 1997-98 on cotton was due the overuse of pesticides in Andhra Pradesh.

**Pupal diapause**

During adverse weather conditions such as shortened day length with cool temperatures, and in summer undergo a facultative diapause, which lasts for 5 - 6 wk to several months. In general, the total life cycle from egg-to adult may take 40-45 days, which is shorter in the summer (February – May) and coincided with a temperature range of 35 - 42ºC in Andhra Pradesh. Diapause has been reported in *H. armigera* in Botswana and Tanzania (Roome, 1979; Reed, 1965), but not Uganda (Coaker, 1959). While winter diapause has been noticed in South Africa (Jones 1937), and Rhodesia (Parsone, 1939; Nel, 1961). In India, Bhatnagar and Davies (1978) were the first to report winter diapause in the pupae of *H. armigera* from Andhra Pradesh.