Chapter II – REVIEW OF LITERATURE

Review of Literature

INTEGRATED PEST MANAGEMENT

The use of agrochemicals has been a common practice adopted by agriculturists to control insect pests. The huge success of chemical insecticides and herbicides is the result of increase in productivity (Dann *et al.* 1994), low cost and high efficiency (Dent, 1995). In the recent past the growing realization towards side effects of pesticides has led several countries to adopt strict measures for reduction in the pesticide usage (Matteson, 1995). Sweden, Denmark and Netherlands were the first countries to adopt strict control over the indiscriminate use of pesticides. The indiscriminate use of insecticides reduces beneficial insect populations within the crop, leading to a rapid resurgence of the pest species, and secondary outbreaks of previously harmless insects (Stern *et al.* 1959). Many pest species now show resistance to certain insecticides as a result of field selection pressures.

Integrated pest management came into being to limit the use of pesticides and use more ecofriendly methods for the control of insect pests (Gullan and Cranston, 1994). One of the important components of integrated pest management is biological control. Biological control can be defined in simple terms as "the use of living organisms for controlling insect pest population". There are two types of biological control practiced today. (I) Classical Biological control and (II) Conservation Biological control.

Classical Biological control involves the introduction of an exotic natural enemy for the control of pests (Caltagirone, 1981). It involves the release of laboratory reared biological agents into the field in order to increase the population of natural enemies in the field (Augmentation). The success of classical biological control is huge but there are limitations to this. This type of augmentative release can be done to target a single species of pest or a few related species and it requires periodic releases in the field (New, 2002). This means that classical biocontrol agents can rarely establish themselves in agroecosystems. This is due to the fact that most of these biocontrol agents are stenophagous. Once, the prey density decreases the population of these biocontrol agents also decreases whereas Conservation biological control aims to encourage the natural populations of beneficial insects so that sufficient numbers are present to exert a controlling influence on a developing pest population (Dent, 1995; Gurr and Wratten, 1999) throughout the cropping season and beyond. DeBach (1974) defined IPM as "Manipulation of the environment to favour natural enemies either by removing or mitigating adverse factors or by providing lacking requisites." The concept of Conservation Biological Control has its basis in the principles of Integrated Pest Management Programs. Conservation Biological Control presents various means to modify or manipulate the environment to enhance the activities of natural enemies of pests.

Conservation Biological control establishes a conceptual link between ecology and the agricultural use of agents for biological control. It encourages generalist predators present in the environment by improvement in natural enemy versus pest ratios and modification of the habitat using trap crops or over-wintering sites in form of field margins. Conservation Biological control today is a concept which is fast gaining acceptance among both the researchers as well as agriculturists. One of its major components is population of generalist predators found in the agroecosystems. Among the generalist predators carabid beetles and spiders are found in high densities and diversities in the agroecosystems and along field margins (Turnbull 1973, Wise 1993). Generalist predators, such as spiders and carabid beetles, are thought to be more efficient than specialist predators for pest suppression in frequently disturbed habitats such as crop fields (Wiedenmann and Smith, 1997; Riechert and Lockley, 1984). Spiders can be used for limiting pests in the agroecosystems (Marc *et al.*, .1999). Besides direct predation, indirect effects like feeding cessation in presence of a predator and superfluous killing of prey are two factors that augment the influence of spiders in targeted insect populations (Riechert, 1999). The success of biological control programs will ultimately depend on cultural practices that encourage the development of a heterogeneous agricultural landscape (Wissinger, 1997). Generalist predators can be sustained by alternative prey, for example detritivores, in the absence of herbivore prey (Chen and Wise, 1999). As a result, the predators can establish in the field at low pest densities.

SPIDERS AS PREDATORS OF INSECT PESTS

Spiders are among the dominant predators in vegetable agroecosystems, as compared to any other predator (Riechert and Bishop, 1990). Small changes in the spider density in soyabean agroecosystem had a significant effect on the insect pest damage on the crop (Carter and Rypstra, 1995). Studies done in laboratory and in caged plots have shown that spiders and carabids significantly suppress *Rhopalosiphum padi* in cereal crop (De Barro, 1992; Mansour and Heimbach, 1993; Kromp, 1999). Spiders having a strong functional and numerical response can effectively bring down the population of herbivorous insects (Maloney *et al.*, 2003). The biomass of insects killed by the spiders was positively correlated with spider biomass (Carter and Rypstra, 1995). *Cheiracanthium mildei* was also the most effective predator of leaf roller larvae in apple orchards Miliczky and Calkins (2002). The most abundant natural enemies found in Cambodian rice field are spiders, mostly *Araneus inustus* and *Pardosa pseudoannulata* (Sigsgaard, 2000). These contribute to Brown plant hopper (BPH) population control (Preap *et al.*, 2001). Higher web density within the field and along field margins can bring down the population of aphids density (Wyss *et al.*, 1995). The abundance of lepidopteran caterpillars is reduced on spider-inhabited plants and there is an increase in plant productivity (Hooks *et al.*, 2003). Lepidopteran eggs in cotton, corn and soybean crops are significantly reduced by spiders (Pfannenstiel and Yeargen, 2002)

Besides the role of the spiders as generalist predators in pest suppression, they are also a substantial part of the total biodiversity in agroecosystems (Marc *et al.*, 1999). Suppression of insect pests by local populations of natural enemies is particularly important for farmers who wish to reduce or eliminate the use of agrochemicals. In organic management, where agrochemical applications are prohibited, the diversity of natural enemies may be economically important (Östman *et al.*, 2003).

Studies on conservation of natural enemies and habitat manipulation in agroecosystem are very few and needs to be explored (Naranjo, 2001).Habitat diversification increases the abundance and diversity of spiders in agricultural fields which in turn increases the chances of interaction between spiders and insect pests (Samu, 2003). Selective use of pesticides so that they work with, rather than against, natural enemies, needs development, and can only be based on a sound understanding of the ecotoxicology of spiders and other natural enemies (Sunderland and Greenstone, 1999).

Nearly 35,000 species of spiders have been reported world wide (Platnick, 2008). Most of them are predatory in nature, with cannibalistic tendencies. However, few of the species exhibit contradictory behaviour and live in large groups with more than 1000 individuals per colony. These spiders make communal webs, subdue prey and feed collectively. 23 species of group living spiders have been reported by various workers.

STUDIES ON SOCIAL SPIDERS

Social spider *Stegodyphus sarasinorum* Karsch was one of the most numerous spiders found along the field margins of the study site. One of its earliest descriptions was given by Jacson and Joseph (1973). They studied the life history, bionomics and behaviour of this spider. Burgess (1976) gave the term 'communal cooperative' to the type of sociality shown by *Stegodyphus sp*. Its taxonomic details are also given by Tikader in 1987 in his book "Handbook of Indian spiders'; Zoological survey of India.

These spiders have been of interest to ethologists due to their intriguing behaviour. Seibt and Wickler (1988) inferred that social spiders adopt this kind of behavior to protect themselves from risk of predation and individual survival. Rypstra and Tirey (1989) studied the prey capture strategies and sex ratio in social spider *Anelosimus domingo* in South western Peru. Another species *Anelosimus eximius* was studied by Aviles and Tufino (1998) for influence of colony size on individual fitness of the spiders. Female dimorphism and skewed sex ratio in the colonies of social spider *A. eximius* were studied by Aviles *et al.*, 2006. Crouch and Lubin (2006) studied effect of climate and prey availability on foraging behaviour of *Stegodyphus mimosarum.*

In India, an International Non-Government Organisation (NGO) named IAASTD (International Assessment of Agricultural knowledge, Science and Technology for Development) has shown interest in role of social spider *S. sarasinorum* as biological control agent (Shankar 2002). Nentwig (1985) suggested that social spiders were successful in trapping prey several times larger than its own body as compared to solitary spiders. This study was further supported by Pasquet and Krafft (1992) and Yip *et al.* (2008). Uetz (1989) suggested that increased prey capture efficiency in social spiders is due to 'Ricochet Effect' i.e. spiders capture prey after they bounce off several webs in succession. Despite the success of social spiders as effective hunters, their role as biological control agents remains unexplored.

FIELD MARGINS AS REFUGE FOR GENERALIST PREDATORS

Pesticides and inorganic fertilizers are used to increase the yields, and there have been substantial changes in landscape structure. Non-cropping habitats (for example island habitat and ditches) have been erased, and fields have become larger (Krebs *et al.*, 1999; Chamberlain *et al.*, 2000), which has transformed the agricultural landscape into a homogeneous landscape where only a few monoculture crops are grown. This has led problems like nutrient leaching, pesticide contamination, species extinction, and evolution of pesticide resistance because of continuous use of pesticides (French-Constant *et al.*, 2000).

Field margins are used by spiders as overwintering sites and refuges and can thus act as a source of dispersal to arable fields (Lemke and Poehling, 2002; Schmidt and Tscharntke, 2005a). The edge between the field margin and the arable field is noteworthy, because spider species that are normally only present in one of the two habitats (field margin and arable field) may meet in the overlapping edge (Samu *et al.*, 1999). As for spiders, carabid abundance and diversity have been shown to be enhanced by a complex landscape and organic management (Mäder *et al.*, 2002; Shah *et al.*, 2003). Higher amount of grassland and complex landscapes enhance the population of carabid beetles as well as encourages species diversity (Purtauf *et al.*, 2005). Management of landscape and farms should aim to encourage species diversity which can result in positive effects in organic farming (Bengtsson *et al*, 2005). A diverse landscape with easy access to perennial crops and field margins will augment both number of species and individuals of spiders and have a significant impact on suppression of aphid pests (Oberg, 2007). Larger field margins and perennial crops in relation to annual crops increase alternative prey abundance and overwintering sites for the generalist predators and thereby their abundance, which can enhance biological control of cereal aphids (Ostman, 2002).

Structural simplification of landscapes, as in intensively managed regions, has been shown to reduce diversity and abundance of predators (Clough *et al.*, 2005; Schmidt *et al.*, 2005; Schmidt and Tscharntke, 2005b). Landscape management not only encourages diversity, it also allows specific effects on local communities and encourages use of resource of local species available in an agricultural landscape (Schweiger *et al.*, 2005). Lower abundance in turn reduces the natural control potential of important crop pests (Riechert and Lawrence, 1997; Schmidt *et al.*, 2003). Ostman *et al.* (2001) showed that a high perimeter to area ratio and high proportions of non-crop habitats in the surrounding landscape was positively related to the strength of predator impact on aphid establishment early in spring. Providing suitable environmental conditions for generalist predators promotes biocontrol of pests and can reduce costs in agriculture (Ostman *et al.*, 2003). For sustaining pest control and enhancing biodiversity in an agroecosystem, diversified landscapes offer maximum potential (Bianchi *et al.*, 2006).

Non-crop habitats bordering agricultural fields have been found to have favourable effects on beneficial abundance and diversity (Coombes and Sotherton, 1986; Hickman and Wratten, 1996; Dyer and Landis, 1997). These non-crop habitats may include stands of native vegetation, herbaceous crop edges, or weed strips. Hickman and

Wratten (1996) found that flowering strips around the margins of wheat fields led to higher numbers of adult hoverflies within the crop.

Natural enemy abundance in cropping habitats, of both generalists and specialists, has been shown to be dependent on the quality of the field margins (Thomas *et al.*, 1991, 1992; Corbett and Rosenheim, 1996; Denys and Tscharntke, 2001), as well as the configuration, composition and structure of non-cropping habitats in the landscape (Lys *et al.*, 1994; Marino and Landis, 1996; Thies and Tscharntke, 1999; Kruess and Tscharntke, 2000; Landis *et al.*, 2000).

TOXICITY STUDIES

Chemical pesticides today have become the primary component of pest control measures in all the agricultural crops. Several classes of pesticides are widely used in India. The dominant and widely used are organophosphates, carbamates, synthetic pyrethroids, neonicotinoids, organochlorines and botanical pesticides. With the development in pest management the type of pesticide used has changed from broad spectrum to narrow spectrum, which target specific pest types/ species/ related species. Insecticides can kill natural enemies and affect the abundance or quality of their prey (Wallin *et al.*, 1992). Herbicides affect vegetation structure in the crops and thereby prey diversity (Samu *et al.*, 1999).

Numerous studies have shown that there is toxic effect of pesticides on natural enemies particularly on carabid beetles, ladybird beetles (Haynes, 1998) green lacewings (Buneo and Freitas, 2004) and honey bees (Pollinators). Very few studies on lethal and sublethal effect of agrochemicals on the survival of spiders have been done so far in the world.

Among the commonly used Agrochemicals, the order of toxicity to web-building spiders increases from herbicides and fungicides (having low mortality rates), to pyrethroids, organophosphates and carbamates (having moderate mortality rates) and cyclodiene compounds (having high mortality rates) (Mansour and Nentwig, 1988). Other studies on spiders have shown that several classes of chemicals have no effect on the spider densities (Richert and Lockley, 1984; Hilborn and Jennings, 1988; Van den berg *et al.,* 1990). Other workers have shown that environmental risk of pesticides on spiders is very low (Highley and Wintersteen, 1992). Primicarb and lambda cyhalothrin have been shown to be non toxic to *Erigone atra and Oedothorax apicatus* (Dinter *et al.,* 1998) in laboratory. Linyphid spiders were found to be relatively more tolerant to agroechmicals (Dinter and Phoeling, 1992). Glyphosate (herbicide) though is non toxic to spider but it indirectly reduces the population density of web building spiders by reducing the web attachment sites (Haughton *et al.*, 2001). Hunting spiders are more susceptible to pesticides and among web building spiders, irregular and sheet web builders are more resistant than orb web builders (Pekar, 1999).

Another study by Pekar and Benes (2008) showed that herbicide (clomazone) was non toxic to *Pardosa* sp., *Philodromus* sp., *Theridion* sp. and *Dictyna* sp. Deltamethrin treatments were highly toxic to all the above mentioned spiders. Botanicals, bio-pesticides and avermectins are non toxic to *Hibana velox* (Araneae: Anyphaenidae) while other broad spectrum insecticides are highly toxic to the spiders (Amalin et al., 2000). Few chemicals like imidacloprid have been shown to promote spider assemblages in transgenic cotton (Kannan et al., 2004). The route of uptake of glyphosate and deltamethrin on epigeal fauna is from the substrate surface via tarsi (Everts, 1990). Pekar and Charles (2005) studied the residual toxicity of commonly used pesticides in Apple orchards on the susceptibility of 6 species of spiders, Phosalone treatment repelled all the spiders, but with time the repellence got reduced. BT spraying produced repellence only in *Philodromus sp.* In terms of mortality neither Phosalone/ BT produced any lethal effects. But permethrin was toxic to all the spiders.

More than the lethal effect, the sublethal effect of pesticides usually goes unnoticed, but is a very important parameter affecting the population densities of spider (Chu et al., 1977). The sublethal effect of pesticides includes/ may interfere with mate location, reproductive and oviposition behaviour (Haynes, 1988); they may interfere with the foraging behaviour (Shaw et al, 2006). The Sublethal effect of pesticides on beneficial arthropods (effect on neurophysiology, behaviour, learning and performance) especially honeybees and spiders are important for pesticide registration procedures (Desneux, 2007). Pyrethroids are highly potent in suppressing the web building activity, accuracy of web building and web size of *Araneus diadematus* (Samu and Vollrath, 1992). Foraging efficiency of *Pardosa amentata* exposed to cypermethrin is drastically reduced and there is severe ataxia and paralysis of hind legs (Shaw et al., 2006). The Sublethal effect of pesticides cannot be understood completely by estimating LC_{50} and LD_{50} values rather it should also include the sublethal effect of pesticides on population densities of arthropods (Stark and Banks, 2003). Pekar and Benes (2008) showed that in addition to mortality, pesticide input can lead to long term decline in abundance and prolonged behavioural disturbance of spiders in agroecosystems; while comparing the direct toxicity versus residual toxicity both were lethal to spiders

The effect of agrochemicals on spiders may show a species specific effect for narrow spectrum insecticide. However the sublethal effect of pesticides on neurophysiology, behaviour and foraging efficacy has to be assessed for understanding the mechanism of long term effect of pesticide toxicity on spiders.

SUBLETHAL EFFECT OF PESTICIDES AND DETOXIFICATION ENZYMES PRESENT IN SPIDERS

Sublethal responses of organophosphates insecticide on wolf spiders, showed that Cholinesterase activity was suppressed between 14% - 61%, in males and females while the pesticide had no effect on Glutathione S Transferase (GST) (Van erp *et al.*, 2002), Effect of cypermethrin on the activity of Glutathione S Transferase (GST) and Glutathione Peroxidase (GPx) in hibernating and actively living *Pardosa amentata* showed that spiders use a variety of detoxification mechanisms during hibernation whereas in activity periods they rely more on inducibility (Neilsen *et al.*, 1999). Apart from pesticides other factors like quality of prey also influenced the survival of spiders in a study done by Pedersen *et al.* (2002). Effect of Dimethoate treatment and hunger level on survival of *Pardosa prativaga* was studied by Nielsen and Toft (2000). Results showed that Dimethoate exposure and hunger has a synergistic effect on AChE inhibition showing that tolerance to Dimethoate might vary based on the hunger level of spiders. Hunger levels affect the activity of GPx, while it has no effect on GST activity.

Other researches into detoxification enzymes of spiders are in relation to heavy metal pollution gradients. Babczynska *et al.* (2006), studied the impact of Dimethoate exposure on spiders from polluted site versus lab reared ones. The results showed that in *A. labyrinthica* (web building spiders); there was a significant decrease in Carboxyesterase (CarE), GPx and Reduced Glutathione (GSH) levels, after a single exposure. Further, as compared to single exposure multiple exposures led to a higher degree of decreased activity. AChE and GST levels were constant in pre-exposed population of *Pardosa lugubris (*ground spider lycosidae) showing that it was slightly more resistant as compared to *A. labyrinthica.*

The relation between Glutathione dependent detoxifying enzymes on *Agelena labyrinthica* and *Pardosa lugubris* were studied by Wilczek *et al.* (2004). These spiders showed sex dependent detoxifying strategies for heavy metal pollutants. The males of *P.lugubris* and females of *A.labyrinthica* showed higher activity. Wilczek *et al.* (2008)

found that males of *A.labyrinthica, Linyphia triangularis* and *Xerolycosa nemoralis,* showed a high defensive activity against metals primarily by increased activity of GSH and Catalase; while in females of the same species, detoxification strategies were primarily dependent on GST and GPx.

There seems to be a variation in the modes of detoxification of pesticides or heavy metal pollutants. These modes vary between the sex and the species of spiders. In review I did not come across any work on social spiders, hence one of the aims of my thesis was to understand the detoxification mechanisms undertaken by social spider *S.sarasinorum* against commonly used pesticides.