Discussion
VI. DISCUSSION

6.1. Occurrence of spiders in different habitats

Forty two species of spiders belonging to thirteen families of the order Araneae were recorded in five different habitats of the present study area during the study period. Among the forty two species of spiders recorded, the paddy fields had twenty four species, the brinjal fields had twenty one species, the groundnut fields twenty two species, the garden twenty four species and thirteen species were observed in the godown. The species richness and composition varied among the different habitats during the study period (vide Table 5.2). The present findings are in accordance with the previous report of Grill et. al. (2005), on the richness and diversity of butterfly, spider and plant species in different land-use types in Sardinia, Italy, which indicated the community composition of 50 species of spiders differed according to land-use type (Quercus-forest<shrubland – with grass < low shrub < shrub land with trees < agriculture land). When the above authors measured 15 environmental variables to detect the most important factor determining pattern of variation in species richness, it was found that spiders reacted mainly to habitat heterogeneity and land-use type. However, variations in the habitat structure (Riechert and Bishop, 1990; Uetz, 1991; Sigsgaard, 2000), the plant architecture (Uetz, 1991), the microclimatic conditions (Canard, 1990) and the availability of prey (Turnbull, 1964; Marc, 1993, Sigsgaard, 2000) in different habitat types have been attributed to be responsible for variations in the richness and composition of spider species in a habitat.
In the present study more species of spiders were recorded in the paddy fields and garden (vide table 5.2). Earlier studies on spiders also supported the present findings. For e.g., according to Schoenly et al. (1998) the biodiversity of spiders in irrigated rice was higher when compared to many natural ecosystems. Oberg (2007) also reported that the species richness to be influenced by habitat types. Taxonomically diverse plant habitats often provide microclimates, greater availability of food sources and alternative hosts that encourage the natural enemies to insects such as spiders (Coll and Bottrell, 1995; Munyuli et al., 2008) and this might, perhaps, be the reason for greater richness of spider species in the garden.

The family-wise composition indicated that, the family Pholcidae was recorded only in the godown (vide table 5.2). Studies on the biology of spiders by Sebastian and Peter (2009) also indicated that Pholcidae prefer buildings, stones and dark places. Like wise the family Hersillidae was recorded only in the garden during the present study. The reason may be that these spiders prefer dry land habitats especially the walls and old tree trunks (Sinha, 1951). The family Scytodidae preferred buildings and dry land and it was recorded only in the godown and groundnut field. The Linyphiidae usually prefer wetland habitats and make irregular webs at the base of the plants above the water line and as such it was recorded only in the paddy fields and brinjal fields during the present study. The Thomisidae was recorded in the brinjal and groundnut fields and garden. This might probably due to their preference to warm habitats with more inflorescences (Tikader, 1987; Satpathi, 2004; Sebastian and Peter, 2009). The family Eresidae was found in the paddy, brinjal and groundnut fields. *S.sarasinorum* was the only species recorded under this family and they built their web in the *Acacia* tree and *Cherodentron* sp. The fact that
both these plants occurred only in the bunds of the above said fields might be the reason for the above preference.

*T. cochinensis* was recorded only in the paddy fields. This might be due to its association with exclusive wetland habitats (Gillespie, 1987). The species *N. nautica, C. lyoni, P. phalangioides* and *H. venatoria* usually prefer dry habitats (Satapathi, 2004) and as such they occurred only in the godown. Therefore one can infer that microclimatic and microhabitat features are responsible for habitat preferences and spider assemblages observed in the present study.

**6.2. Spiders of paddy field**

Twenty four species of spiders belonging to nine families were recorded during the study period in the paddy field. Earlier Nirmala (1990) reported 14 spider species grouped under eight families in the paddy fields of Coimbatore and Bhavanisagar region. Subsequently Anbalagan (1994) recorded 21 species belonging to 10 families in major rice growing area of Eastern parts of Tamil Nadu. Nineteen species belonging to 10 families were recorded in rice ecosystem of Coimbatore region by Rajeswaran *et al.* (2005). Ninety two species belonging to 16 families were recorded in the irrigated rice ecosystem in Kerala across different elevational ranges (Sebastian *et al.*, 2005). Sudhikumar *et al.* (2005) recorded 94 species belonging to 17 families in the Kuttanad rice fields, Kerala.

**6.2.1. Climatic season-wise variations**

Variations in the density of different families of spiders in the paddy field during different climatic seasons indicated that the families Araneidae, Lycosidae, Oxyopidae and Theridiidae were found in all the seasons of the study period (vide
This result was in accordance with the report of Satpathi (2004), who recorded Araneidae, Lycosidae, Oxyopidae, Salticidae, Thomisidae, Tetragnathidae, Linyphiidae and Clubionidae to be the common rice spiders in the Eastern Himalayas. The density of Araneidae was high during pre-monsoon and post-monsoon seasons of the present study period. Piterkina (2006) also reported seasonal variations in the abundance of Araneidae i.e., during spring and autumn in the clay semi desert of the northern Caspian. Species-wise density revealed that the *A. catenulata* was absent in the summer seasons of all the three years and its population was higher in the pre-monsoon season (Tukey’s test; ANOVA; P<0.001). *A. inustus*, *Neoscona* sp. (1) and *Neoscona* sp. (2) were also higher in the pre-monsoon seasons (vide tables 5.7 and 5.8) All these species belong to the family Araneidae and spiders belonging to the family Araneidae make vertical webs between the leaves or at the top of the canopy. According to Turnbull (1973), most spider webs required specific attachment and space requirements and Cherret (1964) found that adult orb weavers in the grass land habitat needed a vertical space of at least 25 – 30 cm². In *Kuruvai*, paddy attained its last stage of development during pre-monsoon season and in *Thaladi* it attained its last stage of development during post-monsoon period so as to provide support to the web of Araneidae. As such the higher density of Araneidae during pre-monsoon and monsoon seasons observed in the present study might be a response to the growth stages of the paddy during the seasons.

Lycosidae and Tetragnathidae were recorded more during summer and monsoon seasons in the present study. Among the species of these two families, *P. pseudoannulata* and *T. javana* were found in all the seasons of the study period except pre-monsoon of 2009-2010. However, the multiple comparisons revealed that
the populations of *P. pseudoannulata* and *T. javana* were more during the summer. Usually the *Kuruvai* crop cultivation starts in the summer. Family Lycosidae, especially *P. pseudoannulata* are highly mobile and readily colonize in dry land and the Tetragnathidae were reported to prefer the initial stages of paddy (Satpathi, 2004; Sudhikumar *et al.*, 2005). As such the higher densities of *P. pseudoannulata* and *T. javana* during summer in the paddy fields is understandable.

The occurrence of Eresidae was irregular. This might be due to the irregular pruning activities done on the shrubs and *Acacia* trees on the bunds as this species mainly inhabited the Acacia trees in the bunds of the paddy fields. The Theridiidae was recorded more in the monsoon seasons of the present study period. The species biology of Theridiidae also indicated that adult population was high in the monsoon seasons (Satpathi, 2004).

The Linyphiidae spiders were significantly more during monsoon. This result was similar to the findings of Thomas and Jepson (1997), Pfiffner and Luka (2000) and Lemke and Poehling (2002) who reported high abundance of spiders in adjacent semi-natural habitats and low abundance in crop fields during winter. Phenological flexibility in Linyphiidae spider had been documented in various other reports as well (Almquist, 1969; Buddle and Draney, 2004).

However, there were contradictory reports on the impacts of climatic seasons on spider populations as different research works were undertaken in different manner. For e.g., Spiders in the rice fields in Korea started to buildup their population in the middle of July (Kim, 1992; Pekar, 1999 ) and the same pattern was seen in Japan as well (Kobayashi and Shibata, 1973). The highest density of *P. viridana* was recorded in August and lowest in May on the *Cnidoscolus*
aconitifolius habitat (Arango et al., 2000). Young and Lockley, (1994) reported maximum density of ground runners in March and July where as peak population of spiders occurred during June, July, October and November at old fields in Mississippi. They observed no clear trend between years, as the most abundant family showed different trends that apparently depended on the climatic variability between years of the study.

Variation in the diversity of spider families during different climatic seasons of the present study period indicated that there were differences in the diversity, richness and evenness among the seasons (vide table 5.5). It also indicated that all the climatic seasons of the present study period showed different spider family compositions. Kato et al., (1995) also opined that it might be expected that climatic changes would influence the abundance of spiders.

Diversity analysis determines the significance of observed difference in community structure between different years and climatic seasons based on the species abundance distribution (Solow, 1993). A diversity index incorporates both species richness and evenness in a single value (Magurran, 1988). Two diversity indices used here in the present study are Shannon-Wiener index (H'), which is sensitive to change in the abundance of rare species in a community, and Simpson index (λ), which is sensitive to changes in the most abundant species in the community. In the present study the value of H' for spider diversity in the paddy field was high in the monsoon seasons of the year 2008-2009 and 2009-2010, while the post-monsoon had higher value of H' in the year 2007-2008. This indicated the presence of some rare species such as Plexippus paykulli and Plexippus petersi in the spider community during monsoon and post-monsoon seasons of the study period in
the paddy field. The value of λ was higher in the monsoon of the 2007-2008, summer of 2008-2009 and pre-monsoon of 2009-2010, which indicated higher spider species number in these seasons.

Species-wise diversity indices for the paddy field revealed that Shannon-Wiener index (H') value was higher in the post-monsoon season of 2007-2008 and monsoon season of 2008-2009 and 2009-2010, which indicated that the species were more evenly found during these seasons (vide table 5.9). This trend indicated that the abundance of spiders varied in different seasons. This might be due to the differences in the insect prey availability during different seasons of the study period as earlier studies (Bhatnagar et al., 1982; Peter, 1988) reported that the crops having more insects and insect visitors always had more spiders and the insect (aphid) populations to establish in cereal fields in particular seasons viz., late spring and early summer (Wiktelius et al., 1990). DelaGuz and Litsinger (1986) also observed that as the main crop matured, insect (hopper) populations declined naturally because of outward migration and natural enemy activity in the rice field. An unambiguous and straightforward index of species richness would be Margalef richness index (R), which shows the total number of species in a community. Species richness examines the number of species occurring in a habitat. Overall species richness is the most widely adopted diversity measure. However, since R depends on the sample size, it limits comparative index. Hence, a number of indices have been proposed to measure species richness that is independent of the sample size. They are based on the relationship between R and total number of individuals observed, (n), which increases with increasing sample size. When all species in a sample are equally abundant an evenness index will be at its maximum. Probably most common
evenness index used by ecologists is ‘E’. An evenness index should be independent of the number of species in the sample. It has been shown that the addition of rare species to the sample that contains only a few species greatly changes the value of ‘E’. In the present study values of richness and evenness (E) were more during post-monsoon seasons except in 2007-2008. In 2007-2008 the evenness value (E) was high during summer. The species-wise result also showed the same pattern. During the post-monsoon seasons of the present study period the crops attained tillering, flowering and ripened stages. This might be the reason for higher richness and evenness values during the post-monsoon seasons of the present study period.

From the family-wise dendrogram, it is evident that the post-monsoon and pre-monsoon periods formed one group and summer and monsoon formed another group in the cluster analysis (vide fig. 5.50). This result indicated that the post-monsoon and pre-monsoon seasons had highest similarity in the occurrence of spider species, while the lowest similarity was found between pre-monsoon and summer. The species-wise result showed that post-monsoon and monsoon seasons had the highest similarity while the lowest similarity was recorded between pre-monsoon and monsoon seasons. This may be due to commencement of cultivation in late summer. This result also suggested that seasonal segregation of spiders might promote species co-existence (e.g., Breymeyer, 1966; Buddle and Draney, 2004).

6.2.2. Crop season and crop stages

There were crop season and crop stage-wise variations in the distribution of spiders in the paddy field during the present study period (vide table 5.11 and 5.16). The present study found overall significant differences in the density of the families Eresidae, Oxyopidae, Salticidae, Tetragnathidae and Theridiidae in the two crop
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seasons viz., Kuruvai and Thaladi (vide table 5.13). Species-wise analysis indicated that *A. inustus* and *A. formosana* were found in all the stages of the two crop seasons viz., Kuruvai and Thaladi (vide table 5.16). Comparison of mean densities in different crop seasons showed that *Neoscona* sp. (2) *P. pseudoannulata*, *O. javana*, *T. javanus*, *T. cochinensis* and *Achaearanea* sp. had significant differences between crop seasons (vide table 5.18). It might be due to the climatic changes associated with the changes in the crop seasons which could influence the abundance of spiders (Kato *et al.*, 1995). There was no significant difference in the densities of families Araneidae, Lycosidae and Linyphiidae between crop seasons (*p* >0.05). The family Araneidae, Lycosidae and Linyphiidae were the common spiders in all the stages of both the crop seasons. Heong *et al.* (1992) also found the relative abundance of Lycosidae at five rice sights in Philippines to be stable across the seasons. In the present study, it was found that the family Sparassidae was found only in the *Thaladi* crop. The *O. mites* was the only spider recorded under the Sparassidae and it prefers the warmer seasons and as such it was found only in the *Thaladi* crop season which occurs during the warmer months of an year at the present study area.

The crop stage-wise results revealed that the population of Araneidae gradually increased with the crop growth in both the crop seasons (vide table 5.11). Spider density were reported to increase with development of crop in many seasonal crops including paddy (Royer and Walgenbach, 1991; Duffield and Reddy, 1997; Pekar, 2005; Sudhikumar *et al.*, 2005). In the present study the populations of Linyphiidae, Lycosidae and Tetragnathidae were more in the early stages (from seedling to flowering) of the crop in both the seasons. This was in accordance with the reports of Satpathi (2004) and Sudhikumar *et al.* (2005). They found that the
distribution of Lycosidae and Tetragnathidae were more in the early stages of paddy cultivation. In the first 35 days after transplantation the dominant predators in irrigated rice were the Lycosidae and Linyphiidae spiders Philippines and Northern Bihar, India respectively (Sigsgaard et al., 1999, Sahu et al., 1996). The presence of abundant detritivores early in the season had been attributed to be one of the keys to the success of spider population (Sigsgaard, 2000).

Multiple comparisons (Tukey’s test) of mean densities of spider families in different stages of the crop revealed that Linyphiidae, Lycosidae, Tetragnathidae and Theridiidae were significantly higher during transplantation (vide table 5.12). Species-wise results also indicated that *P. pseudoannulata*, *A. formosana*, *T. javanus* and *Achaearanea* sp. were higher during transplantation. Studies on the biology of spiders indicated that the family Lycosidae, Tetragnathidae, Linyphiidae prefer and colonize the newly prepared wetlands (Satpathi, 2004; Sebastian and Peter, 2009). Rajeswaran et al. (2005), recorded more number of Lycosidae during the nursery stages. In the present study, Araneidae, the orb web weaver was recorded more in the ripened stage when compared to others. This was in accordance with the report of Sudhikumar et al. (2005). They found a peak of Araneidae in 90 days after transplantation. Other researchers have also found the availability of specific structural features to limit the habitats occupied by various web builders (Duffey, 1962).

Significance of diversity analysis in defining the observed differences in community structure between different crop stages and seasons based on the species abundance distributions (Solow, 1993) had been discussed in this text already. In the present study, it was found that in Kuruvai the value of $H'$ was high in the seedling
stage, while in *Thaladi* it was high in the transplantation stage (vide tables 5.14 and 5.19). This result indicated the presence of some rare species in the spider community in the early crop stages. The value of Simpson index ($\lambda$) increased as crop growth advanced. This indicated the dominance of some families of spiders like Araneidae, Oxyopidae in the later stage of crop growth. The value of richness was high in the flowering stage of *Kuruvai* and transplantation stage of *Thaladi*. The evenness (E) was high in the tillering stage of *Kuruvai* and flowering stage of *Thaladi*. Species-wise analyses revealed that the value of Shannon-Wiener index ($H'$) was higher in the flowering stages of *Kuruvai* and Ripened stage of *Thaladi*. The value of Simpson index ($\lambda$) was high in the tillering stage of *Kuruvai* and Seedling stages of *Thaladi*. Like wise the richness and evenness also varied among the crop seasons (vide table 5.19). Studies of Russell - Smith (2002) established the importance of rainfall in the regional spider diversity. In general, different species have varying humidity and temperature preferences and are limited to those seasons, which offer a microclimate within the range of their physiological tolerance.

The similarity co-efficient matrix indicated that the transplantation and tillering stages of paddy showed higher similarity in the occurrence of spider species, while the lowest similarity was recorded in the seedling and ripened stages. The species-wise result also showed the same trend (vide table 5.20). Structurally complex crops have been reported to provide a wider assortment of resources that would support a more diverse spider assemblage, thus increasing the chances of establishing the ‘best’ match between spiders and insect pests (Marc et al., 1999). The results of the present study also indicated the influence of vegetation structure on the similarity of spider community.
6.2.3. Variations in the density of different guilds of spiders

Spiders are generalist predators that use a variety of prey-capture techniques (Tikader, 1987; Satpathi, 2004; Sebastian and Peter, 2009). Assemblage of Spider species is more effective in reducing prey densities than a single species of spiders (Greenstone, 1999; Sunderland, 1999; Marc et al., 1999). Assemblage of spiders has usually been described within the ecological framework of guilds (Uetz et al., 1999). The way that foraging guilds are arranged in the community has much to do with stabilizing effect that spiders have on prey populations. However, there is no consensus on which guild is more effective in checking the pest population.

The total population of web-weavers was significantly higher than the non web-weavers in all the crop stages in the paddy fields of the present study. The same pattern of results was recorded by earlier in the paddy fields (Choi and Nankung, 1976; Stratton et al., 1979; Mason, 1992; Lee et al., 1993a, 1993b). The present study also indicated that among the web builders orb-web weavers were more in numbers and among the non-web weavers ground runner was recorded more up to tillering stage and stalker population was high during the later stage of crop. Barrion and Litsinger (1995) reported that three guilds of spiders viz., orb weavers, hunting spiders and space-web weavers were found more in irrigated rice at South East Asian Countries. Orb weavers include the family Araneidae and Tetragnathidae and the most common orb weaver genera were Tetragnatha, Araneus and Argiope. Lycosids were the dominant ones in the guild of hunters, while the guild of space-web spiders contain three families i.e., Theridiidae, Linyphiidae and Agelenidae. The most common explanation for the observed pattern of spider guild structure is that the host crop induces micro environment or the level of disturbance that influence the spider
populations (Luczak, 1979; Young and Edwards, 1990). The experimental evidences suggest that habitat structure maintains a diverse spider assemblage (Uetz, 1991; Wise, 1993) and may be critical to successful insect pest suppression. The structural complexity may determine guild composition of a crop’s spider fauna and indirectly influence the level of herbivore damage. Downie et al. (1999) and New (1999) had demonstrated that the spiders were extremely sensitive to small changes in the habitat structure, including habitat complexity and microclimate characteristics. Thus the physical structure of the environments has an important influence on the habitat preference of the spider species especially the web-building species (Hurd and Fagan, 1992). The results of the present study also indicated the orb-weavers population increases as the crops grow. The space web, funnel web and sheet web weavers required moist habitat and as such they were reported more in the transplantation stage during the present study. The doom web was the complex one and the spiders prefer undisturbed habitat because of their larger investment for the web construction. The early stages of the crop had more disturbances with regard to the farm management and so the dome-webs were lesser during these stages. Thus vegetation structure might be perhaps a more important determinant than the seasonal variations in spider population guild structure (Greenstone, 1984; Scheidler, 1990). Differences in the vegetative architecture during crop growth stages influenced the different spider community in the present study also.

6.2.4. Weeding operations and spider population variations

The density of families Araneidae, Lycosidae and Salticidae were significantly lesser in the paddy field after the weeding operations (vide table 5.22). This result was in accordance with earlier research reports. For e.g., Afun et al.
(1999) stated that in the tropical rice cropping system, weed residues have been shown to result increased spider density. Increased weed densities enhanced the number of web weavers (Balfour and Rypstra, 1998). Motobayashi et al. (2006) recorded that the population abundance of Lycosid and Salticid spiders were larger in the untilled paddy fields than in the tilled paddy fields. In the present study the density of Oxyopidae got increased significantly after weeding. Cardenas et al. (2006) reported that an intermediate disturbance level in the olive orchards favoured the family Oxyopidae. Annual crop systems are frequently disturbed, which can make it difficult for predators to remain in the fields. For example, cultivation methods such as ploughing and harrowing can cause predator mortality and emigration (Marc et al., 1999; Holland and Reynolds, 2003; Thorbek and Bilde, 2004). Thorbek and Bilde (2004) also found that spiders were more sensitive to such mechanical crop treatments.

The diversity data revealed that the value of Shannon-Wiener index ($H'$), Shannon-Wiener evenness index ($H'$) and richness index (R) got increased after the weeding operations. This was in accordance with Lenz et al. (2004) and Cardenas et al. (2006). They reported that an intermediate disturbance in the field increased spider diversity. However, Diekotter et al. (2010) reported that spider and decomposer diversity were not significantly affected by farming system or landscape context. A decline in the value of Simpson index ($\lambda$) after the weeding operation in the present study, may be due to significant decline of Araneidae, which was the dominant group in the spider community. Riechert and Lockley (1984) stated that the harvest and tillage contributed in reduction of spider abundance and diversity.
Species-wise results indicated that the density of all species of Araneidae declined and especially that of *A. catenulata* got reduced drastically (p<0.001) after weeding. This might be due to *A. catenulata* constructed the vertical orb-web between the leaves and the weeds in the field supported the construction of such webs during the study period. The number of *T. javana* and *T. cohinensis* densities which built horizontal orb webs increased after weeding. Hence it is recommended that weeding operations should be in such a way to provide enough space for webs. *A. formosana* also had increased density after weeding operations. This result was similar to that of Thorbek *et al.* (2004). They stated that Linyphiids showed rapid population recovery after crop management disturbance. Diversity studies revealed that the value of Simpson index (λ) was higher after weeding operations. This indicated the dominance of some species like *A. formosana*, *T. javana*, *T. cochinensis*, *O. javanus* in the spider community after the weeding operations.

### 6.2.5. Fertilizer applications and spider population

With regard to fertilizer application on spiders, all the spider families got reduced after fertilizer application with the decrease being statistically significant for Araneidae, Lycosidae and Tetragnathidae (vide table 5.26). Cardenas *et al.* (2006) studied the spider population in olive orchards in the province of Granada (Southern Spain) under different management systems; organic, integrated and conventional. They recorded significantly higher abundance of spiders in the organic than the conventional orchards. The study by Bengtsson *et al.* (2005) also revealed the positive effects of organic farming on the abundance or richness of soil organisms. With regard to diversity the value (H'), evenness (H') and richness index (R)
increased after fertilizer applications. This indicated the presence of more number of rare species in the field after fertilizer application.

Species-wise analysis indicated that *A. catenulata* was completely absent and *Neoscona* sp.1 and *T. cochinensis* also reduced significantly (p<0.05) after fertilizer application (vide table 5.28). Application of fertilizer is one of the mechanical disturbances, because by hand spraying the fertilizer was applied in the field of the present study area. This might be one of the reasons for the reduction of the spider density. With regard to diversity value the Simpson index increased after fertilizer application. This might, perhaps, be the most abundance of species like *T. javana*, *P. pseudoannulata* were recorded more after fertilizer application. Agricultural management practices were reported to affect a variety of soil organisms like earthworms (Birkhofer *et al.*, 2008a), ground beetles (Doring and Kromp, 2003; Purtauf *et al.*, 2005) and spiders (Birkhofer *et al.*, 2008b). The population of natural enemies was dependent on the availability of suitable host / prey (Sigsgaard, 2000). Sigsgaard (2000) also reported that abundant detritivores were one of the key factors to the success of the spiders in the rice field. Settle *et al.* (1996) recorded more number of detritus feeders, such as Collembola and other insects adding organic materials in the rice field. But in the present study only inorganic fertilizers were applied in the fields. This might be another reason for the decline of spider population after application of fertilizers in the present study.

6.2.6. Pesticide applications and spider population variations

Pesticide applications in the paddy fields influenced the density of spider families and species (vide tables 5.30, 5.31, 5.32 and 5.33). The family Eresidae and Sparassidae disappeared totally from the paddy fields. However, both were very
meager before pesticide application. The eradication of Eresidae was not only influenced by the pesticide effect, but also by the pruning activities in the field. The densities of all the other families except Tetragnathidae decreased significantly after pesticide application. Several earlier studies have also shown that the application of pesticide reduces the population density of spiders in rice fields (Park et al., 1972; Kim, 1992). Intensive application of insecticides during the growing seasons was also reported to eliminate most arthropods including spiders (Young and Lockley, 1994). The family Salticidae showed the greatest sensitivity to synthetic pesticide (Cardenas et al., 2006). However, Theridiidae family was sensitive to certain pesticide only (Cardenas et al., 2006). Similar responses were observed for Lycosidae by Marc et al. (1999) and Hummel et al., (2002), for Araneidae by Samu, et al. (1992) and Marc, et al. (1999) and for Linyphiidae by Marc et al., (1999) as well.

The diversity data revealed that Shannon – Wiener index (H') and Margalef richness index (R) got reduced after application of pesticides, while the value of Simpson index was high in the post application period in the paddy field. This indicated that some common species of spiders withstand the effect of pesticides in the field. Many studies had also shown that the use of chemicals to decrease the diversity of spiders in orchards (Specht and Dondale, 1960; Bogya and Marko, 1999), in cotton fields of China (Zhao et al., 1980), in the cereal fields of France (Fischer, 1987) and in paddy (Lee et al., 1993a, 1993b).

Influence of pesticide on spiders indicated that all the spider species except *A. inustus, P. pseudoannulata* and *T. cochinensis* were significantly reduced after application of pesticides in the paddy field. Diversity data revealed that the value of
Simpson index and evenness index (E) were increased after application of pesticides. This indicated that the predominant species in the spider community like *A. inustus*, *P. pseudoannulata* and *T. cochinensis* maintained a more or less stable population in the field while some other spider species seem to be more sensitive to chemical treatment than the others. In fact, the spiders’ hunting strategy, behaviour and localization in the vegetation influence their response to chemicals. Samu *et al.* (1992) demonstrated that the webs of orb-web spiders contained large quantities of chemicals, because these spiders eat their web daily and then build new webs and they end up ingesting the accumulated chemicals. Thus they suggested that these orb-web weavers were more affected by such chemical treatments in the crop fields.

In contrast, Pekar (1999) and Hose *et al.,* (2002) stated that, the web acted as collectors of harmful products, protecting the spider from contact with chemicals. The wandering spiders appear to be more affected than web weavers (Specht and Dondale, 1960; Bostanian *et al.,* 1984). The Wolf spider *P. pseudoannulata* are highly tolerant to botanical insecticides such as neem – based chemicals (Markandeya and Divakar, 1999). They are also generally more tolerant to organophosphates and carbamates, than to pyrethroids, organichlorines and various acaricides, although this tolerance might be due to genetic resistance over a period of continuous exposure (Yardim and Edwards, 1998; Marc *et al.,* 1999; Tanaka *et al.,* 2000). Van Den Berg *et al.* (1990) reported that spiders were tolerant to pyrethroids also. During the present study the most commonly used chemicals in the present study fields are organophosphates, carbamates and pyrethroids. The concentration and the types of solvents used in such applications are one of the important factors to be taken into account when speaking about toxicity of treatments (Mansour *et al.,*
1986). In the present study it was observed that water was generally used as a solvent, eventhough the final concentration of the chemicals varies depending on the individual farmers, for the same fields. Moreover the farmers did not follow the recommended dosage. Majority of them applied more concentrated chemicals to the field. This is because of lack of awareness with regard to natural enemies. This might be one of the reasons for the decline of population of spiders in the field after application of pesticides. The application method is another reason. It produces different effects depending on the location of the spiders in the vegetation, which is linked to the functional group to which they belong. For example, Cocquempot et al. (1991) noted that, the quantity of chemical product reaching the different levels of vegetation in wheat fields decreased from the top of the plant to the first leaves and became very low on the ground. The bunds surrounding the rice fields provide refugia during farm operations and bunds were the sources of colonization by ground dispersing predators, such as *P. pseudonnullata* and *Linyphiids* like *A. formosana* (Sigsgaard, 2000). These earlier reports supported the results of the present study.

The present study area is also surrounded by medium sized bunds and pave way for the directional movement of the *P. pseudonnullata*, the active hunter between the rice field and the bunds. This perhaps might be the reason for the increase in the population of *P. pseudonnullata* recorded immediately after the application of insecticides in the present study. However, more studies are necessary to assess the effects of noted chemical substances commonly used in different agro eco systems that might affect the spiders.
6.3. Spiders of Brinjal field

Twenty one species of spiders belonging to nine families were recorded during the study period in the brinjal fields. Earlier Satpathi (1999; 2004) reported the occurrence of predatory spiders in the brinjal field of West Bengal, India. Rajeswaran et al., (2005) observed thirteen species of spiders in the vegetable crops including brinjal. Vayssieres et al., (2001) recorded thirteen species of spiders belonging to eight families in the vegetable crops belonging to the families of Solanaceae, Cucurbitaceae, Brassicaceae and Liliaceae. Faragalla and AL-Ghamdi (2001) also observed spiders in the vegetable fields in Western Saudi Arabia.

6.3.1. Climatic season-wise variations

Variations in the density of different families of the spiders in the brinjal fields of the present study area during different climatic seasons indicated that the family Lycosidae and Oxyopidae were found in all the seasons of the study period (vide table 5.35). Moreover the family Oxyopidae was the most predominant spider followed by the Lycosidae, in the brinjal fields in all the seasons of the study period. Satpathi (1999; 2004) also found that Lycosidae, Oxyopidae and Tetragnathidae were the common spiders in the brinjal field of West Bengal, India. Faragalla and AL-Ghamdi (2001) recorded the Lycosidae to be the predominant family in the vegetable habitats. During the present study, the family Araneidae was not recorded in the summer seasons of all the years of the study period. This might be due to the reason that the Araneidae required a vertical space of at least 25 – 30cm² (Cherret, 1964) and the brinjal cultivation started at late summer, i.e., in June in the present study area during the study period. The family Tetragnathidae was also absent in the summer of 2008-2009 and 2009-2010. Generally the Tetragnathids are water or
moisture loving animals (Tikader, 1987). In the summer the irrigation water to the brinjal field was limited because the crop was in the seedlings stage. This result coincided with Faragalla and AL-Ghamdi (2001) who pointed out that the population densities of spiders declined throughout summer season especially due to unfavourable weather conditions. In the present study the Theridiidae occurred only in the monsoon seasons of the year 2008-2009 and 2009-2010. The density of Tetragnathidae was more in the monsoon seasons, while the densities of Oxyopidae, Salticidae, Thomisidae and Erisidae were more in the pre-monsoon seasons. Species-wise results indicated that *P. pseudoannulata*, *H. agelenoides*, *O. javanus* and *O. sunandae* were found during all the stages of the brinjal during the present study period (vide table 5.39). Multiple comparisons test revealed that *P. pseudoannulata*, *O. liniatipus*, and *O. shweta* showed peak densities in the pre-monsoon seasons, while *O. javanus* was found more in the monsoon seasons. The pronounced peak coincided with the prevalence of prey and abundant hosts during the growing season. During the pre-monsoon and monsoon seasons the crop attained the vegetative, flowering and ripened stages. During these stages the population of fruit and shoot borer, bud worms, weevils, aphids were high and they cause damage to the crop (SUSVEG-Asia Brinjal IMP.2009.). Bhatnagar *et al.*, (1982) and Peter (1988) reported that the crop having more insects always had more spiders. Arango *et al.*, (2000) stated that the foraging and feeding of *P. viridana* (Oxyopidae) were more intense between July and September, when their prey, the flower visitors were more abundant. The family Lycosidae and Linyphiidae were more in summer. The funnel web weavers, *H. agelenoides*, were also more in summer. This is because the newly prepared field had loose soil and it was more suitable for construction of webs in the edges (Satpathi, 2004).
Variations were found in the diversity, richness and evenness of spider families in the brinjal fields of the present study area during different climatic seasons of the study (vide table 5.37). The value of Shannon-Wiener index ($H'$) and Margalef richness index ($R$) were high in the monsoon seasons of the year 2008-2009 and 2009-2010. In 2007-2008 the value of Shannon-Wiener index ($H'$) and Margalef richness index ($R$) were higher during pre-monsoon seasons. These results indicated that pre-monsoon and monsoon seasons had more species of spiders including some rare species viz. *M. orientales, S. sarasinorum*. The value of Simpson index ($\lambda$) was higher in the summer of 2007-2008 and 2008-2009 and pre-monsoon season of 2009-2010. This trend indicated that the abundance of spiders varied in different years; moreover it also indicated the dominance of Lycosidae and Linyphiidae in the summer season. Species-wise variations in the diversity of spiders indicated that the composition of species also varied during different years and seasons of the study period (vide table 5.41). The value of Simpson index ($\lambda$) was higher in the summer of all the years studied. This indicated the dominance of *H. agealenoides* and *O. sunandae* in the summer season. The Shannon-Wiener index ($H'$) was higher in the monsoon season of 2008-2009 and 2009-2010, while it was higher in the pre-monsoon of 2007-2008. This indicated some of the species like *O. lineatipes* and *O. shweta* which were not observed in the monsoon of 2007-2008, occurred in the monsoon of 2008-2009 and 2009-2010.

Both family-wise and species-wise similarity co-efficient matrices indicated that the pre-monsoon and monsoon seasons had higher similarity in the occurrence of spider species, while the lowest similarity was recorded between the monsoon and summer (vide tables 5.38; 5.42). This may be due to commencement of cultivation
in the late summer in the present study and the number and species of spiders less during summer seasons of the present study.

6.3.2. Crop stage-wise variations

Analysis of the crop stage-wise variations in the spider population in the brinjal fields revealed that the families Araneidae and Tetragnathidae were found only from the vegetative stage onwards. This might be due to the factors such as plant height (Cherret, 1964), structural complexity and the plant community (Chew, 1961; Riechert and Reeder, 1970; Rovner and Barth, 1981; Uetz and Stratton, 1982; Uetz, 1991). The family Eresidae was found only in the seedling and flowering stages. This might be due to the pruning activities of the shrubs in the bunds. In general the density of spiders except Araneidae declined in the ripened stage. The reason may be the occurrence of more mechanical disturbance due to harvest in the ripened brinjal field. In the present study area the harvests were made in alternative days or atleast once in two days. The density of Araneidae was recorded more during ripened stage. This might be due to the presence of Neoscona sp. (1) (vide table 5.2). This species is nocturnal in habit. Hence the Araneidae were found more in ripened stage. The multiple comparisons (Tukey’s test) indicated that the Lycosidae population was significantly more (p<0.001) in the seedling stage. The density of Linyphiidae was significantly higher in the transplantation stages. Both these spider families prefer newly prepared wetlands (Satpathi, 2004; Sebastian and Peter, 2009). The Theridiidae and Thomisidae were also found more in the transplantation stage while the Tetragnathidae was more in vegetative stage. The species-wise results also revealed the same trend. Except H. ageleoides all other spiders were higher in the later stage of the brinjal crop. This might be due to the
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The presence of more pest population during these stages (SUSVEG-Asia Brinjal IPM.2009). Riechert (1974) observed that the aggregational behaviour of spiders increased with a local abundance of prey where as Turnbull (1964) established that for the Theridiids *Achaearanea tepidariorum* selection of the site for construction of the web is a random choice and is made before prey abundance. Although the structure of the site is apparently the only criterion used to choose a web site, Turnbull (1964) demonstrated that if prey abundance proves to be insufficient, the spider will then move out and build its trap elsewhere. This behaviour inevitably leads to grouping of the individuals of the species in places were prey is more numerous. The same behaviour has been confirmed by Morse (1979) for an ambush species of the Thomisidae family which leaves its hunting site when the prey density is unsatisfactory.

Family-wise diversity data revealed that Shannon-Wiener index ($H'$) and Margalef richness index ($R$) were more in the flowering stages (vide table 5.45). This indicated that more number of spider species including some rare species was recorded during the flowering stages. The Simpson index ($\lambda$) and evenness ($E$) were high during seedling stages. This indicated that spider densities including that of common species were evenly distributed in the seedling stages (vide table 5.45). The species-wise result also indicated that the flowering stages had more species of spiders including some rare species, while the common spider species were higher during transplantation stages (vide table 5.49).

Family-wise Bray-Curtis similarity values indicated that the highest similarity was found between transplantation and vegetative stages, while the lowest similarity was observed between the seedling and the ripened stages (vide table 5.46). The
species-wise data revealed that the highest similarity was observed among the vegetative and flowering stages, while the lowest similarity was found between transplantation and ripened stages. This might be due to the structural variations or similarities in the plants and variations in the prey availability (SUSVEG-Asian Brinjal IPM. 2009.).

6.3.3. Variations in the density of different guilds of spiders

The total population of non-web weavers was significantly higher than the web weavers in all the crop stages in the brinjal fields in the present study period (vide table 5.51). The most common explanation for the observed pattern of spider guild structure is the micro environment or the level of disturbance (Luczak, 1979; Young and Edwards, 1990). The result also indicated that both the web weavers and non-web weavers declined in the ripened stages. The ripened stages of the crop had more disturbance with regard to harvest. This may be one of the reasons for the decline in the population during the ripened stages. The funnel-web weavers required loose soil for their webs and before seedlings were raised the land was ploughed. Thus they were more in the seedling stages, while the space-web and sheet-web weavers required moist habitat and they were more during transplantation stages. The orb-web weavers were higher in flowering stages. They required space and height for the construction of the web (Cherret, 1964). Thus vegetative structure is found to be more important than the seasonal variations in determining spider guild structure in the brinjal fields (Greenstone, 1984; Scheidler, 1990) as well.
6.3.4. Weeding operations and spider population variations

The density of families Araneidae, Theridiidae and Salticidae were significantly higher in the brinjal field after weeding operations, while the density of Linyphiidae and Tetragnathidae declined significantly after weeding (vide table 5.52). This result was in accordance with that of Thorbek and Bilde (2004). They found the spiders were more sensitive to mechanical crop treatment. On the other hand, cultivation methods, such as ploughing and harvesting can cause predatory mortality and emigration (Marc et al., 1999; Holland and Reynolds, 2003). In the present study the population of Araneidae increased after weeding. The density of orb-weavers, *G. geminata*, a species of Araneidae, which constructs a large horizontal web in between the plants, was more after weeding. Thus the weeding operations seemed to have encouraged the building of webs in *G. geminata*. Species-wise results indicated that the population of *O. lineatipes* and *O. shweta* also increased after weeding operations (vide table 5.54). Cardenas et al. (2006) also reported that an intermediate disturbance level in the olive orchards favoured the family Oxyopidae.

The family-wise diversity data revealed that the Shannon-Wiener index (H'), Shannon-Wiener evenness (H') and evenness index (E) got reduced after weeding operations. This may be due to decline of some rare species in the community. The Simpson index (λ) and Margalef richness index (R) got increased after weeding operations. Species-wise diversity data revealed that Simpson index and evenness index (E) decreased after weeding operations, while the Shannon-Wiener index (H'), Shannon-Wiener evenness index (H') and Margalef richness (R) got increased after weeding operations. Teodoro et al. (2011) reported that local environmental
variables were important drivers for species richness and abundance in arthropods and the community structure of arthropods was sensitive to land use management. They also reported that the spider abundance was the highest in the managed coffee agro forests than in the unmanaged habitats i.e. forests and abandoned coffee. Perner and Malt (2003) assessed the effect of changing agricultural land use on vegetation, spiders and beetle assemblage. They recorded spiders' species richness to increase with decreasing management impact and the evenness to increase with decreasing management impact for beetles, although for spiders such relationships were not significant. Topping and Lovei (1997) assessed the spider assemblages in different management regimes in New Zealand. They reported that the density and species diversity increased with decreasing frequency or intensity of disturbance. Thus the observed impact of weeding operations on the spider species in the brinjal fields of the present study might be due to alteration of the structural complexity.

6.3.5. Fertilizer applications and the spider population variations

The family-wise data indicated that the population of Eresidae and Linyphiidae were completely absent after fertilizer applications in the brinjal fields (vide table 5.56). Population of the other families of spiders except Oxyopidae and Theridiidae also got reduced significantly after fertilizer applications (vide table 5.56). Species-wise data analysis revealed that the density of *O. javanus* got significantly reduced after the application of fertilizers, while the densities of *O. lineatipes, O. shweta* and *P. pseudoannulata* increased after the fertilizer applications. Supply of nitrogen fertilizer during the study period, might have enriched the food value of the leaves, causing the larvae of some general defoliators to feed more and increase their population. Bhatnagar *et al.* (1982) and Peter (1988)
reported that the crop having more insect pest always had more spiders. Thus increased pest numbers in the field might be the reason for the increased spider populations after fertilizer applications. This finding is also similar to that report of Shapard et al. (1995), who reported the leaf folders become more prevalent with high level of fertilizer application.

The family-wise diversity data revealed that the Shannon-Wiener index (H') and Margalef richness index (R) got reduced after fertilizer applications (vide table 5.57). Likewise the species-wise data indicated that the Shannon-Wiener index (H'), Margalef richness index (R) and evenness index (E) got reduced (vide table 5.59). These results were in accordance with that of Chapin et al. (1997) and Vitousek et al. (1997), who reported that changes in land use, habitat fragmentation, nutritional enrichment and environmental stress often affect species diversity in the ecosystems.

6.3.6. Pesticide applications and spider population variations

Variations in the population densities of different families of spiders in the brinjal fields of the present study, before and after pesticide applications indicated that population of all the spider families decreased after the application of pesticides (vide table 5.60). Among these families Eresidae and Linyphiidae disappeared totally from the brinjal fields. After the pesticide applications except Oxyopidae and Theridiidae all the other families decreased significantly in their number (vide table 5.60). Species-wise variations indicated that the population of *P. pseudoannulata*, *O. javanus*, *O. shweta* decreased significantly after pesticides application ('t' test; p<0.05) (vide table 5.62). This result coincides with many workers in various habitats. In agro-ecosystem, Benitez and Mendez, (2011) also reported that insecticide spraying to affect spider abundance negatively. Luczak (1979) observed
the insecticides destroy spider fauna and Thomas and Jepson (1997) found the insecticide applications to reduce spider abundance.

Family-wise variations in the diversity of spiders revealed that the Shannon-Wiener index (H'), Shannon-Wiener evenness index (H') and Margalef richness index (R) values got reduced after pesticide applications in the brinjal fields (vide table 5.61). The same trend was also recorded in the species-wise variations. These results were similar to that of Pekar and Kocourek (2004). They reported that insecticides seem to affect spider diversity. Teodoro et al. (2011) pointed out that the local environmental variables to be important drivers of arthropods species richness and their abundance in the field. Thus it is inferred that the application of insecticide, might result in changes in the assemblage structure of spider species in the agricultural fields.

6.4. Spiders of groundnut field

Twenty two species of spiders belonging to nine families were recorded in the groundnut fields of the present study area during the study period (vide table 5.2). Earlier, Agnew et al. (1985) reported 134 species belonging to 18 families in the groundnut fields in the Texas West cross-timber region. Sahayaraj and Martin (2003) observed spiders were one of the predators in the groundnut fields of Tirunelveli District, Tamil Nadu, India. Rajeswaran et al. (2005) reported 18 species in oil seed fields. Sahayaraj and Jeya Parvathi (2011) recorded 31 spider species belonging to 9 families in two different seasons at Tirunelveli and Thoothukudi, Tamil Nadu, India. *Lycosa pseudoannulata* and *Oxyopes* species were recorded in the groundnut field of Uganda and Democratic Republic of Congo (Munyuli et al., 2008).
6.4.1. Climatic season-wise variations

Variations in the density of different families of spiders during different climatic seasons in the groundnut fields of the present study area indicated that the families Lycosidae, Oxyopidae, Tetragnathidae and Salticidae were recorded in both monsoon and pre-monsoon seasons of the three years of study (vide table 5.65). This result is almost similar to the reports of Agnew et al. (1985), who recorded Araneidae, Clubionidae, Dictynidae, Gnaphosidae, Linyphiidae, Lycosidae, Philodromidae, Theridiidae, Salticidae and Oxyopidae in the groundnut fields in the Texas West Cross – Timbers. During monsoon season of 2007-2008 there were seven species of spiders in the groundnut fields, while in both 2008-2009 and 2009-2010 only five species of spiders were recorded in the same groundnut field. This might be due to variations in the cultivation periods as in 2007-2008, the cultivation started at the last week of November, while in 2008-2009 and 2009-2010 the cultivation started only in the second week of December in present study area. Among the nine families observed, Oxyopidae recorded maximum number in both seasons viz., post-monsoon and monsoon followed by Lycosidae, Tetragnathidae and Salticidae (vide table 5.65). This finding was similar to that of Sahayaraj and Jeya Parvathi (2011), who found that the Oxyopidae had maximum number of species in all the nine sites in two districts of Tamil Nadu. Agnew et al. (1985) also reported the Oxyopidae to be abundant in the groundnut fields.

Species-wise density data revealed that *O. javanus* was recorded more among the Oxyopidae and *P. pseudoannulata* was more among Lycosidae (vide table 5.68). This result was in accordance with that of Venugopal Rao (2001), who reported that *Lycosa* sp. and *Theridid* sp. play a prominent role in decreasing the pest complex in
groundnut ecosystems. Sahayaraj and Jeya Parvathi, (2011) also observed that *P. viridana* population to be significantly higher in the groundnut fields.

Variations in the diversity of different families during different climatic seasons of the study period indicated that the diversity, richness and evenness differed among different years and seasons (vide table 5.66). The result also indicated that different climatic seasons of the present study period showed different species compositions. It might be expected that climatic changes could influence the abundance of the spiders (Kato *et al.*, 1995). In the present study the value of $H'$ and Margalef richness index ($R$) were higher in the post-monsoon season of all the three years of the study. This indicated the presence of more species including some rare species *S. sarasinorum* and *S. fusca* in the spider community. During the post-monsoon season of the study period, the Simpson index ($\lambda$) and evenness index ($E$) were recorded more in the monsoon season of the 2007-2008 and 2009-2010 and post-monsoon season in the year 2008-2009. Species-wise data also revealed that the species richness was higher in the post-monsoon seasons of all the three years (vide table 5.69). The Simpson index was higher in the monsoon season except 2009-2010. In 2009-2010, the post-monsoon had the higher value of Simpson index. These trends indicated that the abundance of some common spiders *viz.*, *O. javanus* and *O. lineatipes* varied in the different seasons.

6.4.2. Crop stage- wise variations

Crop stage – wise variations revealed that the family Eresidae was found only in the ripened stage, while the family Scytodidae was recorded only in the flowering and ripened stages of the crop (vide table 5.71). The occurrence of the Eresidae was
fully dependent on shrubs in the bunds. The branches of the shrubs are removed by cutting them periodically by the agriculturalist when it offered shade to the crop, or in certain periods the branches are removed which would supplement the food for the cattle. Probably this might be one of the reasons for the occurrence of the spiders in the restricted seasons or stages of the crop. Studies on the biology of the spiders indicated that the family Scytodidae preferred dry dark places underneath houses and live in leaf litters (Sebastian and Peter, 2009). This may be one of the reasons for some spiders are occurring only from the flowering stages. Like-wise the family Araneidae was seen only from vegetative stages. *C. citricola*, the dome-web weaver and *Neoscona* sp. (2), Orb-web weaver were recorded in the family Araneidae. The *C. citricola* usually construct their web in the bushy vegetation and *Neoscona* sp. construct their orb webs usually if the plant had a minimum height. These may be the reasons for the occurrence of Araneidae from the vegetative stages onwards. This observation was similar to the findings of earlier reports. Greenstone (1984) and White and Hassall (1994) demonstrated that vegetation structure (height and density) is important for spiders. In the present study Oxyopidae was the predominant family in the groundnut in all the stages of the crop. This results was consistent with the findings of Agnew *et al.* (1985). They reported the family Oxyopidae were abundant in the groundnut field throughout the growing season.

Multiple comparisons revealed that the differences in the density of Oxyopidae during different stages of the crop was not statistically significant, even though they had higher populations in the ripened stage of the crop (vide table 5.72). Thomisidae was more significantly high in the ripened stage (vide table 5.72). The Termite, *Microdermis* sp. was higher during the ripened stage of the groundnut field
in the present study area. The Oxyopide could be found on both foliage and ground (Agnew et al., 1985). The density of Araneidae and Tetragnathidae were less in the groundnut fields and their maximum population was observed in the flowering stages. This result was also in accordance with that of Agnew et al. (1985), who reported that *Tetragnatha laboriosa* was collected in the last stages of the crop and all the spider families except Salticidae were recorded more in the last stage of the crop. Species-wise results indicated that *O. javanus*, *O. lineatipes* and *O. sunandae* maintained a consistent population throughout the crop growth. The *P. viridana* population was higher during seedling stages. Like-wise the density of *H. agelenoides* was also higher in the seedling stages (vide table 5.76). The funnel web-weavers *H. agelenoides* required loose soil for their web in the groundnut field of the present study and the land was ploughed before seedlings were raised. Hence they were more in the seedling stages. The density of *P. pseudoannulata* was significantly higher in the ripened stage (vide table 5.76). This might be due to the presence of more pests in the fields (Batnagar et al. 1982; Peter, 1988). Dhir et al. (1992) reported the occurrence of one *S. litura* per plant at the seedling and flowering stages in the groundnut fields. The results of the present study also revealed that more number of *Euprotics* sp. (Lepidoptera) and *Helicoverba armigera* were found in the flowering stages while *Microdermis* sp. (Termites) was more in the ripened stages.

Data on the diversity of spiders in the groundnut fields revealed that the value of Simpson index ($\lambda$) was higher in the ripened stages for both family-wise and species-wise diversity (vide table 5.77). This indicated that some common species of spiders viz., Oxyopidae, Lycosidae especially the species *O. javanus* and *P.*
pseudoannulata were more in the ripened stages in the spider community structure. The family-wise analysis indicated that the value of Shannon-Wiener index (H') and Margalef richness index (R) were also higher in the ripened stages. This indicated that some rare species such as Oxyptila sp., Thomisus sp. and S. fusca are found in the ripened stages and they enrich the richness of the spider community. Even distribution of spiders was recorded in the vegetative and flowering stages. The species-wise analysis indicated that the value of Shannon-Wiener index (H') and Margalef richness index were higher in the flowering stages. This might be due to the structural complexity (Chew, 1961; Riechert and Reeder, 1970) and prey availability (Marc, 1993) during that stage of the crop.

The family-wise similarity coefficient results indicated that the highest similarity was observed between the vegetative and flowering stages, while the lowest similarity was recorded between the vegetative and ripened stages (vide table 5.74). The species-wise similarity values indicated that the vegetative and flowering stages of the groundnut showed highest similarity in the occurrence of the species, while the lowest similarity was recorded between the seedling and ripened stages (vide table 5.78). These results of this study also indicated that the variations in the structural complexity of crop, influences greatly the similarity/dissimilarity of spider community between different seasons and stages of the crops.

6.4.3. Variations in the density of different guilds of spiders

The total population of non-web weavers were significantly higher in all the stages of the crop except seedling stage (vide table 5.79). The same pattern was recorded by Sahayaraj and Jeya Parvathi (2011) as well in the groundnut fields of Thirunelveli and Thoothukudi. Among the web weavers, funnel-web weavers were
more in all the stages of groundnut except the ripened stage. The orb weavers were higher in the ripened stage. These results are also similar to that of Sahayaraj and Jeya Parvathi (2011).

6.4.4. Weeding operations and spider population variations

The spiders of the family Tetragnathidae totally disappeared from the groundnut fields of the present study area after weeding operations (vide table 5.80). The population of orb-web weavers (Araneidae) and irregular space-web weaver (Theridiidae) declined after weeding operations. Earlier reports also showed that cultivation method such as ploughing can cause predator mortality and emigration (Marc et al., 1999; Holland and Reynolds, 2003; Thorbek and Bilde, 2004). Afan et al. (1999) stated that in tropical rice cropping system, presence of weed resulted in the increase of spider density. Higher weed density was reported to increase the number of web weavers by Balfour and Rypstra, (1998) as well. In the present study, it was found that the population of Scytodidae got significantly increased in the groundnut field after weeding operations. The population of spiders belonging to the family Salticidae, Lycosidae and Thomisidae also got increased in their densities after weeding operations. Species-wise results indicated that all the predominant spiders except O. sunandae were not affected by the weeding operations. O. sunandae totally disappeared from the groundnut fields of the present study area after weeding operations. Other spiders either maintained their population consistently or increased after weeding operations. On the other hand Cardenas et al. (2006) reported that an intermediate disturbance level in the Olive orchards favoured the family Oxyopidae.
The family-wise and species-wise diversity data revealed that the value of Shannon-Wiener index (H') and Margalef richness index (R) got declined, while the value of Simpson index (λ), Evenness index (E) and Shannon-Wiener evenness index (H') got increased after weeding operations. Cardenas et al. (2006) reported that an intermediate disturbance in the field might increase the spider diversity also. A decline in the value of Simpson index after weeding operations in the present study may be due to the significant decline of *O. sunandae* which was the dominant group in the spider community. Campos and Civantos, (2000) also stated that different types of orchard managements including planting methods, irrigation, pruning, harvesting and soil treatment could have a diverse effect positive or negative on useful arthropod groups.

6.4.5. **Fertilizer applications and spider population variations**

With regard to fertilizer application on groundnut fields the family Oxyopidae and Scytodidae got increased significantly after fertilizer applications (vide table 5.84). The population density of Salticidae and Thomisidae also increased. Species-wise data also revealed that *O. javanus, P. viridana* population increased after fertilizer application. Supply of nitrogen fertilizer during the study period might have enriched the food value of the leaves, causing the larvae of some general defoliators to feed more and increase in their population. Bhatnagar et al. (1982) and Peter (1988) reported that the crops having more insect pests always had more spiders. Increased pest in the field may be the reason for increased spider population after fertilizer applications. Similar views were expressed by Shapard et al. (1995). They reported that leaf folders become more prevalent with high level of fertilizers. An increase in the spider population depended on prey availability and if
the density of prey becomes higher, spiders are expected to increase proportionally to some extent. Kiritani et al. (1972) also stated that the peak in population density of spider coincided with an increase of insect pest. The family Tetragnathiae got significantly reduced in their population after fertilizer applications. Like wise the other web weavers i.e., Araneidae, Therididae also got reduced in their population after fertilizer applications (vide table 5.84). In Lycosidae, the population of funnel web-weavers *H. agelenoides* declined after fertilizer application (vide table 5.84 and 5.86). Application of fertilizer is one of the mechanical disturbances because by using pick axe and hand spreading, the fertilizer was applied in the groundnut field of the present study area. This might be one of the reasons for the reduction of the spider density especially the web weavers. This reason may be applicable for *P. pseudoanmulla* also, which was totally absent after the fertilizer applications, since they are ground runners and their population is usually high at the base of the plant and ground (Sebastian and Peter, 2009).

The family-wise and species-wise diversity data revealed that the value of Shannon-Wiener index (H') got reduced after the application of fertilizers (vide tables 5.85 and 5.87). This indicated some rare families in the groundnut field viz., Araneidae Therididae and Tetragnathidae declined after application of fertilizer. The Simpson index (λ) value was higher after fertilizer application. This might be due to the abundance of some common spiders like *O. javanus* and *P. viridana* in the spider community. Chapin et al. (1997) and Vitousek et al. (1997) also stated that the changes in land use, habitat fragmentation, nutritional enrichment and environmental stress often affected species diversity in the ecosystem.
6.4.6. Pesticide applications and spider population variations

In the present study it was found that the pesticide application influenced the density of spider families and species in the groundnut field (vide tables 5.88 and 5.90). The families Scytodidae, Tetragnathidae and Therididae disappeared totally from the groundnut fields, after pesticide applications. The density of all the other families except that of Araneidae declined significantly after pesticide applications. The species-wise result indicated that *H. agelenoides* was not affected by the pesticide applications. All Oxyopidae spiders decreased significantly (‘t’ test; p<0.01) after pesticide application. In fact the spiders’ hunting strategy, behaviour and localization in the vegetation influence their response to chemicals. Samu *et al.* (1992) suggested that these orb-web weavers were more affected by such treatments. The wandering spiders appear to be more affected by pesticides than the web weavers (Specht and Dondale, 1960; Bostanian *et al.*, 1984). Munyuli *et al.* (2008) recorded insecticide sprays to significantly reduce the number of Lycosidae in groundnut fields.

Both family-wise and species-wise diversity variations revealed that the value of Shannon-Wiener (H'), Shannon-Wiener evenness index (H') and Margalef index (R) got reduced after pesticide application (vide tables 5.89 and 5.91). The value of Simpson index (λ) and evenness index (E) were higher after application of pesticides. This might be due to the abundance of a few species *viz.*, *P. pseudoannulata* and *H. agelenoides* after pesticide applications. Pekar and Kocourek (2004) reported that insecticides seem to affect spider diversity. Teodoro *et al.* (2011) pointed out that the local environmental variables were important drivers of arthropods species richness and their abundance in the field. Thus the application of
insecticides seemed to have changed the community structure of spider species in the groundnut field of the present study area.

6.5. Spiders of Garden

Twenty four species of spiders belonging to nine families were recorded in the garden of the present study during the study period. The report of Satpathi (1995) supported this finding, who recorded twenty one species of spiders belonging to eight families on different flowering plants at 1000 to 1500m above mean sea level in the Eastern Himalayas. Taxonomically diverse plant habitats often provide microclimates, greater availability of food sources, alternative hosts that encourage the natural enemies (Coll and Bottrell, 1995; Munyuli et al., 2008).

6.5.1. Climatic season-wise variations

Variations in the densities (No./plant) of different families of spiders during different climatic seasons revealed that the major families viz., Araneidae, Lycosidae, Oxyopidae, Salticidae, Sparassidae and Thomisidae, were present during all the seasons in the study period in the garden (vide table 5.93). Among the eight most predominant spiders that were taken for further analysis all spiders except *L. decorata* were found during all the seasons of the study period. The Tetragnathid *L. decorata* was absent in the pre-monsoon seasons of 2008-2009 and summer of 2009-2010 (vide table 5.97). Tetragnathidae are moisture loving animals (Satpathi, 2004; Sebastian and Peter, 2009). During summer and pre-monsoon seasons the weather condition was unfavorable for these spiders. Gillespie (1987) pointed out that *T. elongata* is associated exclusively with riparian habitats. In general, in the garden selected for the present study the management practice were few and limited. The
grassing and pruning were done at the maximum thrice a year. Plants were irrigated periodically by a small canal and no chemicals were used either as fertilizers or pesticides. These may be reasons for the occurrence of spiders throughout the study period. Multiple comparisons (Tukey's test) indicated that the post-monsoon season had more densities of Tetragnathidae, Araneidae, Theridiidae and Oxyopidae. This result was similar to the findings of Gillespie (1987), who recorded more *T. elongata* where the higher humidity was high. The monsoon seasons had higher densities of the families Lycosidae, Salticidae, Sparassidae and Thomisidae. This result was in accordance with Faragalla and AL-Ghamdi (2001). They reported that the Lycosidae population was higher in the monsoon and post-monsoon seasons (November to March) in the crop ecosystem and the natural habitat in Western Saudi Arabia.

### 6.5.2. Plant type-wise variations

Variations in the densities (No./Plant) of different spiders indicated that the family Araneidae was found in all the plants except *H. rosa sinensis* and they were more in *Cycas* sp. (vide table 5.101 and 5.102). *A. anasuja* and *C. citricola* were the representatives of the family Araneidae and the *C. citricola* which makes dome web was recorded more in the *Cycas* sp. The dome-web is a complex one and the spiders that make dome-webs prefer undisturbed habitats because of their larger investment in web constructions. There was no mechanical disturbance in the *Cycas* plant during the study period in the study area because of their uniform and slow growth. This may be one of the reasons for the abundance of *C. citricola* in the *Cycas* sp. Hersilidae was restricted only in the *Codiaeum* sp. Studies on the biology of the spiders indicate that, Hersilidae prefer dry land habitats, especially the walls and old tree trunks (Sinha, 1951). In Lycosidae the ground runner *P. sumatrana* and funnel-
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web weaver *H. agelenoides* were the common spiders in the garden (vide table 5.101 and 5.105). Family-wise multiple comparisons revealed that ground had more density of Lycosidae spiders (Vide table 5.102). The specie-wise results revealed that *P. sumatrana* was found more in the ground. This result was similar to the findings of Faragalla and AL-Ghamdi (2001), who reported that the wandering spiders were more abundant in the open roaming spaces. The higher population density of *H. agelenoides* was recorded in the *Ixora coccinea* (vide table 5.106). It constructed funnel-web and did not retreat daily. It preferred undisturbed place. The family Tetragnathidae was recorded in all the plants studied except *I. coccinea* and their maximum density was observed in *Codiaeum* sp. *L. decorata* was also observed in the same pattern of distribution. The *Codiaeum* sp. have high vertical stratification and thus they may offer more physical structure for web attachment. This result was similar to the findings of Faragalla and AL-Ghamdi (2001), who found that more of web spinning spiders dwell in the stable habitats characterized by thick canopy and vegetation. Uetz (1991) reported that environmental characteristics exert a strong influence on habitat selection in spiders. For example, spiders depend on the structure of the environment because: (1). they need attachment sites for their webs and (2) their sensory organs are based on the recognition of tactile vibrations of the substrate (Rovner and Barth, 1981; Uetz and Stratton, 1982). Spider populations showed certain association between their structure and heterogeneity and / or structural complexity of the plant community (Chew, 1961; Riechert and Reeder, 1970). The family Oxyopidae was recorded in all the plants studied, and their maximum densities were found in *Codiaeum* sp. Salticidae was absent in *T. coronaria*. Their higher population was recorded in *H. rosa sinensis*. The Thomisidae was recorded only in *H. rosa sinensis* and *T. coronaria*. Multiple
comparisons (Tukey's test) indicated that *T. coronaria* had higher density of Thomisidae, Theridiidae and Sparassidae (vide table 5.101 and 5.102). Lycosidae was the only family found in the ground of the garden studied. The species-wise results indicated that *O. javanus* was found in all the plants studied and their maximum population was recorded in *I. coccinia*. *O. shweta* and *T. dimidiata* were restricted to the *H. rosa sinensis*, *Cycas* sp. and *Codiaeum* sp. and their highest population density was recorded in *Codiaeum* sp. *T. pugilis* was recorded only from *H. rosa sinensis* and *T. coronaria* with their population density being higher in *T. coronaria* (vide table 5.105 and 5.106). Studies on the biology of spiders indicated that the Thomisidae prefer warm habitats (Nyffeler and Sunderland, 2003), with more inflorescence (Tikader, 1987). Morse (1991) demonstrated that *Misumena vatia* actively chooses its territory, moving from poor to high quality inflorescences. Crab spiders do not spin web, instead they use camouflage. Their colours bend with the colour of the plant, flowers they live on, making them practically unnoticeable (Satpathi, 2004). Crab spiders do not seem to respond to unopened flowers, instead, they direct their response to the number of insect attracted to plants (Morse, 1988). The population density of both the spider families and the species varied among the plants studied. This might be related to the differences in the prevalence of insects on the host plants. This result is in agreement with Faragalla and AL-Ghamdi (2001), who reported that different densities were recorded in three different habitats viz., vegetable, date-Palm and mixed weed habitat in Western Saudi Arabia. Henschel and Lubin (1997) reported that spider density correlated with habitat quality. Among the major characteristic to be taken into account by spiders in a given environment are the habitat structure (Marc, 1993), microclimatic conditions (Canard, 1990) and availability of prey (Turnbull, 1964; Marc, 1993);
The family-wise data analyses revealed that Shannon-Wiener index ($H'$) was higher in the plant *H. rosa sinensis*. This indicated some rare species found in this plant. The value of Simpson index ($\lambda$) was more in ground; this may be due to the presence of common species Lycosidae in the spider community in the ground. The richness value was higher in *T. coronaria* (vide table 5.13). One of the possible reasons for this might be the presence of complex architecture *i.e.*, flowers attracting insect visitors and the capability of plant, supporting a large number of spider species. Moretti *et al.* (2002) recorded a rich mosaic of microclimatic conditions which supported the spider species. Species-wise diversity indicated that the Shannon-Wiener index ($H'$) was higher in *H. rosa sinensis* while the value of Simpson index ($\lambda$) was higher in *I. coccinea*. This result indicated that rare species *O. milleti* and *T. dimidiata* in the spider community preferred *H. rosa sinensis* and common species in the community preferred *I. coccinea*. The species richness value was higher in the *Codiaeum* sp. Shannon-Wiener evenness index ($H'$) was higher in *I. coccinea* and *Cycas* sp. had more evenness index (E) value (vide table 5.107). Horse and Uniyal (2008) also reported that species composition to be not similar in different vegetation types of Terai conservation area, India. Downie *et al.* (1999) and New (1999) had demonstrated that the spiders were extremely sensitive to small changes in the habitat structure, including habitat complexity and microclimatic characteristics. The physical structure of the environment has an important influence on the habitat preference of the spider species especially the web building spiders (Hurd and Fagan, 1992). The vegetation structure may be more important determinant than the seasonal variations (Greenstone, 1984; Scheidler, 1990). Murdoch *et al.* (1972) also reported that insect diversity highly correlated with plants’structure diversity. As such it might be concluded that difference in
vegetation architecture exert the major influence in shaping the different community structure of spiders in the garden of the present study.

Both family-wise and species-wise Bray-Curtis similarity coefficient matrix values indicated that the *Cycas* sp. and ground had the lowest similarity in the occurrence of the spider species, while the highest similarity is found between *H. rosa sinensis* and *Codiaeum* sp. The architecture of *H. rosa sinensis* and *Codiaeum* sp. were similar. Thus it is evident that the plants having similar architecture had more similarity in the spider species occurrence.

### 6.6. Spiders of Godown

Variations in the density of different families of spiders during different climatic seasons indicated that all the families except Sparassidae were found in all the seasons of the study period. Multiple comparisons (Tukey’s test) result indicated that the population of Araneidae was higher in the post-monsoon seasons. The monsoon had more densities of Scytodidae and Sparassidae. The population of Pholcidae and Salticidae were higher in summer seasons. Species-wise result indicated that all the six spider species were found in all the seasons of the study period. The *C. citricola* was higher in the post-monsoon season, while the other species were found more in summer seasons. This might be due to the differences in the availability of insect prey. In the present study, paddy and rice are the main storage products in the godown. The stored paddy and rice are infected by many pests *viz.*, Grain moth, *Sitotroge cerealella*, Grain weevil, *Sitophilus granaries* and *S.oryzae* and Red flour beetle, *Tridolium cestaneum* (Foliarflo, et al., 2011) where populations will be more in the high temperature and low humidity condition (Herbert, 2011) as is prevalent in the godown.
Grains produced in fields may be stored for periods of few weeks to few years before they are fed or processed. The profitability of such storage depends not only upon marketing concerns but also upon maintaining grain quality. The harvest and storage of grains do not signal an end to the possibility of losses caused by insects and pathogens (Weinzierl and Higgins, 2008). Direct-feeding damage caused by insects reduces grain weight, nutritional value, and germination of stored grain. Infestations also cause contamination, odor, mold, and heat-damage problems that reduce the quality of the grain and may make it unfit for processing into food for humans or animals. Commercial grain buyers may refuse to accept delivery of insect contaminated grain, or may pay a reduced price (Mason and Obermeyer, 2010).

Several species of insects may infest grain in storage. The principal pests that cause damage are the adult and larval stages of beetles, and the larval stage of moths. All these pests may cause a problem by their presence, either alive or dead, in grain that is to be processed for food (Mason and Obermeyer, 2010).

Over 60 species of insects infest stored grains. They are the grain borer, rice weevils, maize weevils, cadelle beetles, flat grain beetles, rusty grain beetles, sawtoothed grain beetles, foreign grain beetles, mealworm beetles, red flour beetles and confused flour beetles. Indian meal moths, book lice, and grain mites are considered to be the 14 main pests. Of the 14 pests listed, Indian meal moths are the most common. Damage by stored-grain insects usually goes unnoticed until the grain is removed from the storage facility (Herbert, 2011). Most infestations of stored-grain insects originate from immigration of the insects into the bin from outside. Some stored-grain insects infest maturing grain in the field. Although some field infestations probably occur in fields, the extent of field-originated storage
problems is minor (Weinzierl and Higgins, 2008). Successful management of stored-grain insects is possible only when proper storage practices are implemented. Insecticides and fumigants should be viewed as supplements to, not replacements for, sound storage methods. When used properly, insecticides and fumigants limit insect losses in stored grains without endangering the pesticide applicator or resulting in excessive pesticide residues that threaten the health of consumers (live-stock or humans) of treated grain or grain products (Weinzierl and Higgins, 2008).

If grain is stored on the farm, one goal should be to keep it relatively insect-free, preferably without using insecticides or fumigants. Taking steps to prevent a build up of insect numbers requires time and planning, but the outcome is grain that is not infested with insects and will not be docked. Certain insect-management tactics should be considered for preventing infestations of insects in stored grains. They are Sanitation (cleanup of old grain and grain debris), Empty-bin spray with an insecticide, Empty-bin fumigation, primarily to control insects by storing clean and dry grain, treating grain with a protective insecticide, Aeration to cool the grain to prevent insect feeding and reproduction. Insecticide resistance is an important worldwide problem that is especially common (on an international scale) in stored product insects. In fields, resistance to Malathion is widespread among Indian – meal moth populations. Some field populations of the red flour beetle are resistant to Malathion, but the range and intensity of this resistance problem are not well known. Populations of the hairy fungus beetle may be resistant to both Actellic and Malathion; the geographical range of resistant populations of this species is now known (Weinzierl and Higgins, 2008).
Tamil Nadu Agricultural University (TNAU) has developed devices that exploit the wandering behaviour of the insects and help in timely detection of insects in stored products leading to timely control. These include TNAU probe trap, TNAU pit fall trap, two in one model trap, indicator device, automatic insect removal bin, UV-light trap technology, egg removal device and stack Trap (TNAU, 2011).

One or more companies market programs that call for periodic releases of beneficial insects (predators and parasitoids of pest species) for pest management in stored grains. Although considerable research has been directed at this practice, questions remain unanswered concerning the ability of releases of beneficial insects to lower pest populations to levels required by current grading standards. Where management efforts must be limited to “nonchemical” methods of control, sound cultural practices (sanitation, adequate drying, cleaning, aeration and annual rotation of the commodity) outperform the release beneficial insects (Weinzierl and Higgins, 2008).

Even though the present study was attempted to record the predatory spiders in the godown, the results clearly indicated that the density, diversity and richness of spiders differed in different seasons of the years studied. In the present study area, the paddy harvest was done in two seasons, viz., in the monsoon and post-monsoon seasons. The overall results indicated that the density of spiders in the godown studied was more in summer and post-monsoon seasons, while the diversity and richness were recorded more in the summer and pre-monsoon seasons. This indicated that the population and composition of spiders were directly related to the availability of insects in the godown. Herbert (2011) and Knodel (2011) reported that, grain harvested and stored in the hottest time of the year stand a greater chance
of becoming infested, since, insect reproduce rapidly at the temperature in the range of 60° - 90° F. Farm-stored wheat, rye, barley, oats are more likely to have insect problems than corn or beans, which are harvested during cooler months of the year. Spiders belonging to Araneidae and one of the prominent spiders in the Araneidae, C. citricola were recorded more in the godown studied during the post-monsoon seasons. This might be due to the storage of paddy immediately after harvest (post-monsoon season). Weinzierl and Higgins (2008) reported that, some stored grain insects infest maturing grain in the field and insects originate from immigration of insects into the godown from outside. Hence, the present study clearly indicated that the spiders might have acted as important predators to reduce insect pests in the godown studied.

6.7. Prey preference

6.7.1. No-choice Tests

Some degree of specialization or monophagy by a predator on prey is assumed to be necessary for the predator to reduce populations of that particular prey. Spiders are more specialized on particular prey than is often realized. It is common that when spiders have an excess of prey they become more selective (Riechert and Harp, 1987). The literature suggests that, in general, hunting spiders have a greater diet breadth than web-weavers (Nyffeler, 1999).

Results of the no-choice tests of the present study indicated that P. pseudoannulata could prey upon more number of prey viz., Microdermis sp. and Helicoverpa sp. than that of O. javanus and O. lineatipes. This findings are in accordance with a previous study (Samiayyan and Chandrasekharan, 1998), in which
the *Pardosa* species could prey upon twice the number of plant and leafhoppers as that of *Tetragnatha* and *Oxyopes*.

There was a significant difference (ANOVA; p<0.05) between the intake of *Microdermis* sp. over other pests in terms of number of individuals consumed (vide table 5.119). Wise (1993), Nyffeler *et al.* (1994), Marc *et al.* (1999) reported that spiders usually eat prey that is 50% to 80% of their own size. The size of the *Microdermis* sp. is small when compared to others and that might perhaps be the reason for its higher consumption rate when compared to the other two prey types tested. However, with regard to the mean weight consumption of prey *Helicoverpa* sp. was consumed more by *P. pseudoannulata* and *Euprotics* sp. was consumed more by both *O. javanus* and *O. lineatipes*. The higher mean consumption of the larval forms of Lepidoptera i.e., *Helicoverpa* sp. and *Euprotics* sp. might be due to the fact that they might provide more juicy materials for the spiders. Jackson and Pollard (1996), also reported that spiders preferred soft bodied animal. They also reported that Salticidae species prey upon a diverse assortment of arthropods, but seem biased towards flies and Lepidoptera larvae.

### 6.7.2. Bi-Choice Tests

Prey preference over a mixed population of *Microdermis* sp. and *Helicoverpa* sp. indicated that all the three spiders consumed more number of *Microdermis* sp. than *Helicoverpa* sp. in terms of numbers of individual consumption (vide table 5.127). However, mean weight consumption rate indicated that *P. pseudoannulata* preferred *Helicoverpa* sp., while the *O. javanus* and *O. lineatipes* preyed more of *Microdermis* sp. (vide table 5.122). In the other bi-choice tests, when the spider was offered combination of *Microdermis* sp. and *Euprotics* sp. *Microdermis* sp. was
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preferred by all the spiders (vide table 5.123). Mean weight consumption rates indicated that Microdermis sp. was preferred by \textit{P. pseudoannulata} while \textit{Euprotics} sp. was preyed upon more by \textit{O. javanus} and \textit{O. lineatipes} (vide table 5.124). When the three spider species tested were caged with the population of \textit{Helicoverpa} sp. and \textit{Euprotics} sp. \textit{P. pseudoannulata} consumed more number of \textit{Helicoverpa} sp. while the \textit{O. javanus} and \textit{O. lineatipes} consumed more number of \textit{Euprotics} sp. (vide tables 5.125 and 5.126). From the results of all the bi-choice tests it is inferred that the \textit{Microdermis} sp. were consumed more in numbers by all the three spiders. On the other hand more mean weight (mg) of \textit{Helicoverpa} sp. was preyed by \textit{P. pseudoannulata} and \textit{Euprotics} sp. was consumed more by \textit{O. javanus} and \textit{O. lineatipes}. Such differences might, perhaps the due to differences in moving habits of insects, as according to traditional foraging theory, spiders are considered to be predators of live, moving preys (Turnbull, 1960; 1973).

6.7.3. Multiple Choice tests

The multiple choice tests also indicated that more numbers of \textit{Microdermis} sp. were consumed by all the three species of spiders tested. However, result of mean weight prey consumptions indicated that \textit{P. pseudoannulata} preyed more amount of \textit{Microdermis} sp. while \textit{O. javanus} and \textit{O. lineatipes} consumed more quantity of \textit{Euprotics} sp. This could be attributed to the differences in the habitats of the spider species also. \textit{P. pseudoannulata} inhabits the lower parts of the crops and that might explain why it preys more on \textit{Microdermis} sp. The \textit{Oxyopes javanus} and \textit{O. lineatipes} inhabit the upper canopy and this might, perhaps, account for their preference for \textit{Euprotics} species. The earlier reports also support these present findings, as Marc and Canard (1997), Marc \textit{et al.} (1999) and Nyffeler (1999)
reported that although spiders are polyphagous predators, their hunting strategies and microhabitat preference cause each species to be specialized. Nyffeler and Benz (1988b) reported that wolf spiders to be abundant in field crops were they forage on small soft bodied arthropods, while Nyffeler et al. (1992) found the Lynx spiders to capture a wide variety of small sized arthropods and show considerable flexibility in switching their dietary composition in response to prey availability (Nyffeler et al., 1992). Indeed, spiders show behavioural specializations and prey preferences that make them able to effectively limit certain prey populations. However, Satpathi (2004) viewed the prey preference of spiders on their biochemical requirements and stated that most spiders have qualitatively similar food requirements since the basic chemical composition of their tissues and their metabolic processes are generally similar and these requirements are normally met by the diet. Greenstone (1979) also stated that some species of spiders select insect preys that balance their amino acid requirements.

6.8. Significance of spider web types and their architecture

In the present study different kinds of webs viz., orb webs, funnel web, dome web, irregular sheet web, irregular space web and social web had been encountered with regard to spider species recorded (vide table 5.2). Their web architecture varied widely (vide tables 5.129 and 5.130). Further the types, placement and size of webs also varied in different microclimatic conditions. All these have shown that there is a high diversity of spiders with a variety of prey capture methods. Such a diversity of species with many foraging tactics might maximize the number of encounters that spiders have with potential prey and ultimately might prove to be the most effective
6.9. General Discussion

6.9.1. Insect pest control by spiders

A rich diversity of spiders had been revealed in the agricultural crop fields during the present study (vide table 5.2). Since all spiders are carnivorous and prey chiefly on insects and are adapted variously to capture and utilize various types of insects, they could effectively play the role of bio-control agents for insect pests in the agricultural crop fields.

According to traditional foraging theory, spiders are considered to be predators of live, moving prey only (e.g., Turnbull, 1960; 1973). Later this view was modified when evidence was found that spiders adopt and utilize a much broader range of foraging strategies, including feeding on arthropod eggs (Nyffeler et al., 1990). Most spider species forage on multiple prey species (generalist predators) (Greenstone, 1979). Savory (1928) stated that spiders will eat all kinds of flies, as well as wasps, bees, ant, beetles, earwings, butterflies, moths, harvestmen, woodlice and other spiders whenever the opportunities occurs.

Many studies have demonstrated that spiders can significantly reduce insect (prey) densities. High feeding frequencies were observed in field population of certain larger – sized orb-weavers (Araneidae) that rebuild their webs daily (Nyffeler, 1982). Large orb weavers often kill prey in excess of their energy requirements. Sheet-web weavers, mesh-web weavers and funnel-web weavers that do not renew their web daily, feed less frequently (Nyffeler et al., 1994). Low
feeding frequency was observed in four families of hunters viz., Wolf spider, lynx spiders, crab spiders and jumping spiders (Nyffeler and Breene, 1990).

The orb-web weaver *Tetragnatha laboriosa* trap insects predominantly of the orders Diptera and Homoptera. Leafhoppers (Cicadellidae) represented an essential component in the prey of *T. laboriosa* in soybean fields in Illinois and Kentucky (Leasar and Umzicker, 1978; Culin and Yeargan, 1982). In a cotton field in Texas, the prey of this species was composed largely of aphids (75% of total) (Nyffeler, *et al.*, 1989). *Tetragnatha* sp. is very common in almost all rice fields and they feed *Nephotettix nigropictus, Nephotettix virescens, Nilaparvata lugens* and moth of *Cnaphalocrosis medinalis* and *Scirpophaga incertulas* (Satpathi, 2004). *Tetragnatha maxillosa* were reported to feed 3-5 aphids per day in the brinjal field (Satpathi, 1999). Large orb weavers of the genus *Argiope* were found to frequently kill grasshoppers (Orthoptera) (Nyffeler and Breene, 1991). *Argiope* sp. were reported to capture larger grasshopper like *Ceracris nigricornis, Chondracris rosea, Oxyahyl ahyla* and moths of stemborers and leaf rollers in the rice field (Satpathi, 2004). *Araneus inustus* was found to prey on small insects like leafhoppers, planthoppers and flies in the rice field (Satpathi, 2004). *Argiope* sp. consumed Tagar leaf folder, Flea and Aphids in the flowering shrubs of Eastern Himalayas (Satpathi, 1995). Several species of orb weavers spin highly modified orb webs that function as effective moth traps (Foelix, 1982; Eberhard, 1990).

The family of sheet-web weavers (Linyphiidae) were reported to kill numerous small insects primarily from the orders Diptera, Hymenoptera, Homoptera and Heteroptera (Nyffeler and Benz, 1981). *Atypena formosana* directly consumed 4 to 5 jassids, young leafhoppers and planthoppers daily (Satpathi, 2004).
Agriculturally harmful cereal aphids formed a significant portion (12-40%) in the prey of the dwarf spiders in European winter wheat fields (Nyffeler and Benz, 1988a). Green rice leafhoppers; *Nephotettix cincticeps* (Uhler) and brown plant hopper, *Nillaparvata lugens* (stal), composed 60% of the prey of Linphyiidae in the rice fields in Asia (Kiritani *et al.*, 1972). The Theridiidae constructed irregular mesh type web and preyed more on ants than other insects (Nyffeler and Benz, 1981). The funnel-web weavers were found to capture a wide variety of different insect groups (Nyffeler, 1982).

Wolf spiders (Lycosidae) are abundant in field crops and grasslands where they forage on small soft bodied arthropods. Their diet includes springtails (Collembola), small dipterans, and homopterans (Nyffeler and Breene, 1990). Aphids constituted an essential portion in the diet of *Pardosa* spp. in European winter wheat fields (Nyffeler and Benz, 1988b). Wolf spiders also reduced densities of sucking herbivores (Delphacidae and Cicadellidae) in tropical paddy fields (Fagan *et al.*, 1998). Singh and Dhaliwal (1994) reported the presence of the predatory spiders *i.e.*, *Lycosa pseudoannulata* checked the population of brown planthopper and whitebacked planthopper in the rice fields. *Lycosa pseudoannulata* and *Pardosa* sp. were reported to consume 3-5 aphids per day in the brinjal field of west Bengal, India (Satpathi, 1999). *Hippasa* sp., *Pardosa* sp., *Pardosa sumatrana* found in the plants of Eastern Himalaya controlled the pests like Hopper, aphid, whitefly, mired bug etc. (Satpathi, 1995). The green rice leafhoppers *N. cincticeps* and brown planthoppers, *N. lugens* composed 80% of the diet of wolf spiders (Kiritani *et al.*, 1972).
Lynx spiders (Oxyopidae) actively search the plant surface for prey and they capture a wide variety of small-sized arthropods including small bugs (Heteroptera) (Nyffeler et.al., 1992). In a cotton agroecosystem in Texas, *Oxyopes salticus* preyed heavily on cotton leafhoppers boll weevil (Nyffeler et.al., 1992). *Oxyopes lineatipes* was reported to consumed 5-8 aphids per day in the brinjal field (Satpathi, 1999). *Oxyopes salticus* was found to consume an average of 1.14 soyabean looper larvae per day in the soyabean field (Richman et al., 1980). *Oxyopes lineatipes* controlled the *Henosepitachna vigintioctopunctata* (F) in the brinjal field (Satpathi, 1995). *Oxyopes* sp. controlled the pest viz., hopper, aphid, mired bug in the flowering plants of Eastern Himalaya (Satpathi, 1995).

Crab spiders (Thomisidae) are among the most abundant spider predators in the grasslands and agricultural crops. They feed on small winged Hymenoptera and Diptera (Nyffeler, 1982). *Misumenops celer* was found to feed on various bugs in field crops (Dean et.al., 1987; Agnew and Smith, 1989; Breene, et.al., 1990). Jumping spiders (Salticidae), particularly *Plexippus paykuli* is cosmopolitan species and it feeds on a wide variety of arthropod taxa including odonata, orthoptera, Homoptera, Lepidoptera, Diptera, Hymenoptera (Jackson and MacNab, 1989).

As generalist predators, spiders destroy pest insects, insects of a neutral economic status and beneficials alike (Nyffeler, 1982). They might be expected to exert considerable influence in their coexistence with insect prey population. Thus the availability of spiders in any locality depends upon the occurrence of insects in the area (Bristowe, 1941). Although the ecological significance of spiders in the balance of nature is still largely unexplored, they generally are considered to be important natural enemies of insects (Young and Edwards, 1990). Turnbull (1973)
surveyed 37 published censuses of spider numbers in a wide variety of natural and modified environments. The report found that an overall mean density of 130.8 spiders per square meter (range, 0.6-842/m²) and concluded that spiders must-have an enormous predation impact on insect populations. The prey kill by the spiders of such ecosystems was estimated at 50-200kg/ fresh weight per hectare per year (Van Hook, 1971). The Study of Baldev (1983) reported the quantitative assessment of food taken by different spiders, and found who reported that in the family Lycosidae, a female of Lycosa kupupa consumed, on an average, 4.1. moths of Corycyra cephalonica, 2.2. houseflies and 6.4 cotton jassids, and the most common spider of cotton crop, Oxyopes species fed, on an average, 5 months of Coreyra, 3.1. houseflies and 9.8 Cotton jassids in 24 hours. Form the forgoing discussion it could be clearly inferred that spiders play an important roll in the agricultural crop fields as natural enemies of agricultural insect pests.

6.9.2. Effects of pesticides on Non-target animals such as spiders

Fertilizers and pesticides have modified traditional rice-growing environments. There is indirect evidence that crop intensification has decreased species diversity in rice fields (Roger et al., 1991). The greatest pressure exerted on the microbial, faunal, and floral communities of rice fields is due to fertilizer and pesticide use (Roger et al., 1994). Both have significant impact on population composition and dynamics. There is also concern about the increased use of pesticides, which may cause (i) environmental hazards such as water table and water body contamination, (ii) biological imbalance in rice field populations, and (iii) reduced efficiency because of shifts toward soil microorganisms more efficient in pesticide degradation.(Roger et al., 1994) Pesticides are a major factor affecting
biological diversity, along with habitat loss and climate change. They can have toxic effects in the short term in directly exposed organisms, or long-term effects by causing changes in habitat and the food chain.

Agricultural pesticides can reduce the abundance of weeds and insects which are important food sources for many species. Herbicides can change habitats by altering vegetation structure, ultimately leading to population decline. Fungicide use has also allowed farmers to stop growing ‘break crops’ like grass or roots. Pesticides are an integral part of agriculture as Indian climate fosters an environment conducive to major pest outbreaks throughout the entire year. The environment also is favorable for the development and presence of beneficial organisms that positively affect the agricultural production and enhance the plant communities. A side effect of usage of some pesticides results in unfortunate consequences to the non target organisms including spiders (Isenring, 2010).

Many pesticides are toxic to beneficial insects, birds, mammals, amphibians, or fish. In the UK, of the 95 incidents of bee poisoning (where the cause could be identified) between 1995 and 2001, organophosphates caused 42%, carbamates 29%, and pyrethroids 14% of cases (Fletcher and Barnett 2003). In the last decade in the UK, insecticides which poisoned bee colonies included bendiocarb (a carbamate) and three pyrethroids : cypermethrin, deltamethrin and permethrin (PSD 2001-7). Synergistic effects between pyrethroids and EBI fungicides (imidazole or triazole fungicides) can increase the risk to honeybees (Pilling and Jepson, 2006).

One-third of 6,000 amphibian species worldwide are threatened. Besides habitat loss, over-exploitation or introduced species, amphibians are affected by the pollution of surface waters with fertilizers and pesticides from agriculture (IUCN
In the USA, spray drift of hexazinone, a triazine herbicide, was considered “likely to adversely affect” the endangered red-legged California frog and its habitat (US EPA 2008). The insecticides chlorpyrifos and endosulfan was highly toxic to cause serious damage to amphibians at concentrations occurring in the environment under normal conditions of use (Sparling and Feller 2009). Surface water is frequently contaminated with insecticides. Through normal use at leaves, these insecticides affect fish and aquatic invertebrates such as daphnia or shrimp. For example, this was observed for levels of azinphos-methyl, chlorpyrifos, and endosulfan in the aquatic environment (Schulz, 2004).

Nitrogen-fixing microorganisms and BNF were more affected by pesticides than other populations and activities. Soil and water invertebrates dominant in rice fields are ostracods, copepods, cladocerans, rotifers, insect larvae, aquatic insects, mollusks, oligochaetes and nematodes (Roger and Kurihara, 1991). They have agricultural impact as nutrient recyclers, rice pests, and rice pest predators. Zooplanktons are more affected by fertilizer than by pesticides (Simpson et al., 1994). Insecticides are the most active pesticides on floodwater invertebrates. Herbicides and fungicides appear to possess limited toxicity to invertebrates at field concentrations (Georghiou 1987). A field study by Takamura and Yasuno (1986) showed the development of large populations of chironomids and ostracods in herbicide and insecticide treated fields. Lim and Wong (1986) attributed the dominance of ostracods in treated fields to their resistance to pesticides and the large number of eggs produced parthenogenetically.

Broad-spectrum insecticides (e.g. carbamates, organophosphates and pyrethroids) can cause population declines of beneficial insects such as bees, spiders,
or beetles. Many of these species play an important role in the food web or as natural enemies of pest insects. Since 1970, insect numbers in the cereal fields in Sussex have dropped by half (GCT, 2004). Numbers of bugs, spiders and beetles were considerably higher in untreated fields (Moreby and Southway 1999).

Agricultural fields that are frequently sprayed with pesticides often affect the spider population (Bogya and Marko, 1999; Amalin et al., 2001; Holland et al., 2000). In general spiders are more sensitive than many pests to some pesticides, such as the synthetic pyrethroids, cypermethrin and deltamethrin; the organophosphate, dimethoate and malathion; and the carbamate, carbaryl (Marc et al., 1999; Holland et al., 2000; Tanaka et al., 2000). In alfalfa, imidacloprid affected the number and species diversity in communities of arthropods (natural enemies such as spiders) more strongly than among target pest insects (Liu et al. 2008). A decrease in spider population as a result of pesticide use can result in an outbreak of pest populations (Yardim and Edwards, 1998; Marc et al., 1999; Holland et al., 2000; Tanaka et al., 2000). In the literature, methods by which predator numbers in an agro ecosystem could be increased are discussed (Nyffeler, 1982; Young and Edwards, 1990; Wise, 1993). They suggested several management strategies (e.g., reduction of pesticide usage and cultivation frequencies) that could enhance the spider numbers in field crops and adjacent habitat resulting in increased predation activities.

Results of the present study clearly showed that many spider species disappeared from the crop fields immediately after pesticide applications (vide tables 5.30, 5.32, 5.60, 5.63, 5.88 and 5.90). As such the use of pesticides should be minimized or totally stopped in order to enhance the population of natural enemy
insect pests such as spiders, which are one among the many non-target organisms that got affected by the indiscriminate use of pesticides in the agricultural fields.

6.10. Recommendations for field management of spiders

1. Steps must be taken to reduce the use of chemical fertilizers and synthetic pesticides in the agricultural crop fields in order to prevent elimination of natural enemies of insect pests such as spiders.

2. Bunds of agricultural fields should be properly maintained to the needs of both field crops and beneficial arthropods such as spiders by minimizing grassing in the bunds and regulating the pruning of the shrubs in the bunds.

3. Adequate attention should be given to the non-cultivated lands nearer the crop fields so as to improve the biodiversity of beneficial arthropods such as spiders.

4. An awareness campaign must be undertaken so that the local people can realize the significance of the spiders in terms of predatory behaviour and need to utilize them sustainably for mutual benefit.