Journal of Biodiversity and Conservation Research

ISSN: xxxx-xxxx Vol. 1 (1),
pp. 001-008, December, 2013. ©
Global Science Research Journals

Review

Potential impacts of recent climate change on biological control agents in agro-ecosystem: A review

S. Selvaraj[1]*, P. Ganeshamoorthi[2] and T. Pandiaraj[3]

[1]Department of Entomology, G.B. Pant University of Agricultural and Technology, Pantnagar, India. [2]Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi, India.
[3]Department of Agronomy, G.B. Pant University of Agricultural and Technology, Pantnagar, India.

Accepted 10 September, 2013

Global climate change is a change in the long-term weather patterns that characterize the regions of the world. It is evident from increase in global average temperature, changes in the rainfall pattern and extreme climatic events. The impacts of warming can already be observed in many places, from rising sea levels to melting snow and ice to changing weather patterns. Climate change is already affecting agro-ecosystems, freshwater supplies and human health. These seasonal and long term changes would affect the fauna, flora and population dynamics of insect pests, activity and abundance of natural enemies, species extinction and efficacy of crop protection technologies. The abiotic parameters are known to have direct impact on insect population dynamics and direct and indirect impact on biocontrol agents through modulation of developmental rates, survival, fecundity, parasitism and dispersal. The abundance and activity of natural enemies will be altered through adaptive management strategies adopted by farmers to cope with climate change. These strategies may lead to a mismatch between pests and enemies in space and time, decreasing their effectiveness for biological control. Climate change will also reduce the effectiveness of host plant resistance; transgenic plants used for pest management. Hence, there is a need to generate information on the likely effects of climate change on natural enemies to develop robust technologies that will be effective in future pest management strategies.

Key words: Climate change, biological control, predator, parasitoids, fitness, mitigation.

INTRODUCTION

Crop plants used as a food by human beings are damaged by over 10,000 species of insects, and cause an estimated annual loss of 13.6% globally and 23.3% in India (Dhaliwal et al., 2010). In India, the average annual losses have been estimated to be 17.5% valued at US$17.28 billion in eight major field crops (cotton, rice, maize, sugarcane, rapeseed-mustard, groundnut, pulses, coarse cereals and wheat). These losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming. The global CO_2 concentration, which was about 180-200 ppm after the last glaciation and 270 ppm in early industrial times rose up to the present 320-350 ppm, amounting to an approximately 25-30% increase during the last 100-120 years. Similar tendencies were registered for other main “greenhouse” gases (CH_4, NO_x and carbohalogenides) as well (VijayaVenkataRaman et al., 2012). This may lead to a rise in global temperature with a rate of 0.1-0.8°C per decade. Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1°C by 2025 and 3°C by the end of the next century

*Corresponding author. E-mail: selvas84@gmail.com. Tel: 7417016018

(IPCC, 1990). In agriculture, weather affects crop yield and quality as well as the dynamics of pests and their regulation by natural enemies. Weather is perhaps the most important overall cause of pest insect outbreaks in agroecosystems through its influence on insect physiological development, migration and dispersal (Risch, 1987).

Apart from having direct effects on plant productivity, climate change can also influence productivity through indirect effects mediated by changes in pests and diseases. There is abundant evidence that climate change can influence the distribution of phytophagous (Parmesan et al., 1999; Batalden et al., 2007; Trnka et al., 2007) and also influence the phenology of insects including arrival times (Parmesan, 2007), emergence time of insects (Dewar and Watt, 1992) and predatory potential of natural ene-mies (Stireman et al., 2005). Plants growing under increased CO_2 and temperature extremes as well as decreased precipitation will provide different nutritional resources for invertebrate hosts, indirectly influencing the fitness of predators and parasitoids feeding on these hosts. There is also the potential for climate change to influence over-lap between the appearance and abundance of natural enemies at times when crops are under pressure from herbivores.

The ability of natural enemies to track their hosts will depend on their tolerance of environmental extremes relative to their herbivore hosts as well as their movement rates. Under climate change, the effectiveness of some biological control agents (BCAs) may change. Stireman et al. (2005) predicted that the frequency and intensity of pest outbreaks will increase as climate be-comes more variable and disrupts the stability of existing biological control systems. These changes will have major implications for crop protection mainly on biological control, particularly in the developing countries. Keeping these facts in view the topic, the potential impacts of climate change on bio control agents is discussed.

RECENT CLIMATE CHANGE vs. INSECT PESTS

The abiotic parameters are known to have direct impact on insect population dynamics through modulation of developmental rates, survival, fecundity, voltinism and dispersal. Among the climatic factors, temperature is an important factor. Warmer conditions are likely to increase the importance of some existing pests (although possibly decrease the pest status of some species) and also encourage other insect species, which may themselves become new pests (Cammell and Knight, 1992). The response of insect herbivores to elevated levels of atmospheric CO_2 will depend on their feeding strategy (Bezemer and Jones, 1998) and how their host plant responds. Leaf chewing insects reared on plants grown in elevated CO_2 typically show an increase in foliage consumption, (Williams et al., 1994; Lindroth, 1996; Stiling et al., 1999), reduced weight (Lindroth, 1996) and slower development rate (Johnson and Lincoln, 1991).

Increases in foliage consumption will be detrimental to crop plants, especially if the herbivores are not otherwise adversely affected by the CO_2 induced changes within the plant (Williams et al., 1994; Lindroth, 1996). Increased CO_2 may also cause a slight decrease in nitrogen-based defenses (e.g., alkaloids) and a slight increase in carbon-based defenses (e.g., tannins). Acidification of water bodies by carbonic acid (due to high CO_2) will also affect the floral and faunal diversity. Lower foliar nitrogen content due to CO_2 causes an increase in food consumption by the herbivores up to 40% (Sharma et al., 2010). Phloem feeding insects, such as aphids, have been shown to benefit from CO_2 enriched foliage (Stacey and Fellowes, 2002). For instance, cotton is attacked by aphids, *Aphis gossypii*, which are in turn attacked by the ladybird beetle. Under elevated CO_2, cotton aphid survival significantly increased but ladybird larval development took significantly longer time (Gao et al., 2009). Therefore, the aphids may become pests that are more serious in the future.

Effect of climate change on transgenic crops

Soil moisture, soil fertility and temperature have strong influence on the expression of *Bacillus thuringiensis* (Bt) toxin proteins deployed in transgenic plants (Sachs et al., 1998). Cotton bollworm, *Heliothis virescens* (F.) destroyed *Bt*-transgenic cottons due to high temperatures in Texas, USA because of reduced production of Bt toxins (Kaiser, 1996). Cry1Ac levels in transgenic plants decrease with the plant age, resulting in greater susceptibility of the crop to insect pests during the later stages of crop growth (Sachs et al., 1998; Adamczyk et al., 2001; Kranthi et al., 2005).

The increased consumption rates by pest insects, brought about by warmer conditions or changes in leaf quality caused by CO_2 enrichment, will lead to a greater intake of pathogens such as *B. thuringiensis* (Bt) (Coviella and Trumble, 2000). Interestingly, Coviella et al. (2002) found that the changes in the C : N ratio caused by elevated CO_2 reduced the efficacy of Bt toxin expression in transgenic cotton leaves. Possible causes for the failure of insect control in transgenic crops may be due to inadequate production of the toxin protein, effect of environment on transgene expression, *Bt*-resistant insect populations, and development of resistance due to inadequate management (Adamczyk et al., 2001). It is therefore important to understand the effects of climate change on the efficacy of transgenic plants for pest management.

WHY BIOLOGICAL CONTROL IS IMPORTANT?

An important ecosystem service provided by biodiversity is natural pest control (Wilby and Thomas, 2002). Pest species destroy 25-50% of the world’s crops, either before or after those crops are harvested. The amount spent globally on pesticides is perhaps the best indicator of how much we value pest control: World pesticide expenditure reaches more than $30 billion annually, with insecticides alone accounting for nearly one-third of the total amount (Kiely et al., 2004). Furthermore, pesticide usage is expected to triple by 2050 (Tilman et al., 2001). Chemical pesticides, and the strategies by which they are applied to fight crop pests, can have harmful unintended consequences. Pests can develop resistance, which means higher doses of pesticides. Resistance is now found in more than 500 insect and mite pests, over 100 weeds, and in about 150 plant pathogens (WRI, 1994). Populations of the natural enemies of pests are also being decimated by heavy use of pesticides. Natural predators are often more susceptible to synthetic poisons than are the pests. The result is that destruction of non-natural predator populations leads to blooms in prey numbers, not only freeing target pests from natural controls but often promoting non-pest species to pest status. Therefore, biological controls employ a significant role in the control of insect pests and also reduce development of resistance.

Fortunately, approximately 99% of potential crop pests are controlled by natural enemies, including vertebrates, spiders, parasitic wasps and flies, lady bugs, and other numerous types of organisms (DeBach, 1974). These natural biological control agents save farmers billions of dollars annually by protecting crops and reducing the need for chemical control (Naylor and Ehrlich, 1997). These biocontrol agents are expected to establish permanently to reproduce and spread. Important properties for natural enemies to be used in this classical biocontrol approach are good host location ability, high reproductive rate to its prey, specificity to the target pests and the ability to tolerate the required climatic conditions (Coppel and Mertins, 1977; Stacey, 2003). The diversity and stability of biocontrol species within an agro-ecosystem depend on the diversity of plant species within the field, the surrounding plant communities, the type of crop grown and how all these factors interact with prevailing climatic conditions.

Effects of climate change on biological control agents

Climate change vs. natural enemies prey location

Plants growing under increased CO_2 and temperature extremes as well as decreased precipitation will provide different nutritional resources for invertebrate hosts, indirectly influencing the fitness of predators and parasitoids feeding on these hosts. The fitness of predators and parasitoids will decline as the quality of their herbivore hosts decreases (Wang et al., 2007). The coccinellid predator, *Leis axyridis* Pallas (Coleoptera: Coccinellidae), of an aphid herbivore, *Aphis gossypii* Glover (Hemiptera: Aphididae), consumed more prey under conditions of higher CO_2 (Chen et al., 2005). Chen et al. (2007) found a negligible impact of elevated CO_2 on its coccinellid predator, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), but increased abundance of the braconid parasitoid, *Aphidius picipes* (Nees) (Hymenoptera: Braconidae), resulting in increased aphid parasitism in elevated CO_2 as compared to ambient CO_2. In this case, the biocontrol efficiency of the parasitoid against aphid hosts may be enhanced in elevated CO_2. These results suggest that higher CO_2 could make generalist predators more effective in controlling pests. However, the searching time needed by predators to locate prey could be increased as a consequence of extra plant foliage due to increased growth.

In cassava *Manihot esculenta* Crantz, parasitism of mealybugs is reduced under conditions of water stress associated with drought conditions. Appa-rently, the immune response of mealybugs is improved when these insects are grown on water stressed plants, leading to an increased rate of encapsulation ranging from 30 to 50% in three different species of encyrtid mealybug parasitoids (Calatayud et al., 2002). Increases in herbivore develop-ment time due to changes in plant nutrition can make herbivore prey more susceptible to predation due to the longer window of opportunity availa-ble to predators. The development of the willow feeding leaf beetle, *Galerucella lineola* F. (Coleoptera: Chrysomelidae), is longer on different hosts, predation by a range of taxa including heteropteran families Penta-tomidae and Nabidae, and spiders is higher (Haggstrom and Larsson, 1995). Chan-ges in host development can also influence parasitoid activity and fitness; an increase in development time makes hosts more susceptible to parasitism, particularly if it leads to parasitoids encoun-tering instar stages of the host that are relatively more susceptible to parasitism (Sequeira and Mackauer, 1994).

Consequently, the foraging efficiency and consumption rates of many insect predators apparently improves much more than the metabolic efficiency of their prey as temperature increases (Skirvin et al., 1997; Perdikis et al., 1999), leading to increasingly successful biological control. Other climatic factors predicted to occur in the future are likely to adversely affect predator or parasitoid activity, for example increased cloud cover (Barbosa and Frongillo, 1977), wind speed (Casas, 1989), atmospheric pressure (Marchand and McNeil, 2000) and rainfall (Juillet, 1964). Also, some natural enemies will decrease their periods of activity if conditions get too hot or dry. Spiders are more susceptible to drought than many insect species because of their nonsclerotized abdomens (Riechert, 1998) so their activity may become spatially or temporally restricted in future summers, and perhaps more so than insect predators occupying the same feeding niche. If those insect predators are able to take over in the absence of the spiders, then pest populations will continue to be kept in check, but this is dependent on how each species reacts to the changes.

Climate change vs. physiology of natural enemies

Climate change factors will act directly on the physiological processes of insect natural enemies, greatly affecting their functioning (Jervis and Kidd, 1996) and thus their ability to control pest insects. It has been suggested that the immune response to parasitoid attack of host insects should be correlated with temperature (Stacey and Fellowes, 2002). Beneficial insects will be influenced by warmer conditions in similar ways to that of pest insects, with faster growth rates, smaller body sizes and reduced longevity (Atkinson, 1994; Saona and Miller, 1999). The number of frost days will also significantly influence insect survival, as well as increase weather variability and sudden extreme changes in temperature (Parmesan et al., 2000).

Fewer frost days will aid in the winter survival of in-sects, and even allow introduced species to establish perma-nent populations. This will be of greater benefit to farmers using inoculative biocontrol agents. Greater variability in weather will be a disadvantage though. Many insects need periods of slow cooling to survive the winter (Bale, 1993) so rapid temperature fluctuations may negatively impact on their survival. Most crops will have been har-vested by this period in the year, but natural enemies are still relied upon during this time to suppress pest numbers and reduce their impact in the following spring.

Climate change vs. geographic range shifts

Modifications in the geographical distribution of plants, hosts, and parasitoids may result from a number of processes, including differences in migratory potential of insects (and their host plants), the appearance of green bridges (new plant species providing favourable overwintering sites), and the destabilization of resident ecosystems (Cannon, 1998). Increased temperatures may be expected to extend poleward the range of species currently limited by low temperature and frosts or increase altitude at which they can survive. Climate warming will affect not only plant yield, but also the densities of mealybug and its natural enemies over their entire geographic range.

With increases of 2 and 3°C in average daily temperatures, the geographic distribution of the mealybug remains relatively unchanged, but the areas favorable for its development shift increasingly with population levels generally increasing everywhere due to increasing failure of biological control (Gutierrez et al., 2008). Cold-limited species may be able to increase their geographic range in the future. For example, warming will allow the cold intolerant pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), to expand its range on cotton into formerly inhospitable areas affected by heavy frosts, and damage rates will increase throughout its current range (Gutierrez et al., 2006).

These expansions of herbivores may lead to escape from natural enemies. For instance, the braconid parasitoid of European corn borer, *Macrocentrus gifuensis* Ashmead (Hymenoptera: Braconidae), killed 53% of larvae overwintering on mugwort *Artemisia vulgaris* L. but none overwintering on maize (Thomas et al., 2010). Diamondback moth can travel large distances to new cruciferous crop plantings; due to the low numbers of effective natural enemies and especially parasitoids, the moth is better than its natural enemy complex to become established and increase population density (Talekar and Shelton, 1993). The capacity of parasitoids to increase their geographical distribution following a climate change is limited by how their hosts react to these changes. The distribution of the eulophid *Chrysocharis gemma* is limited by cold temperature and its host *Phytomyza ilicis* is more cold hardy (Klok et al., 2003).

Hence, the crop plants might sometimes escape herbivores but it is more likely that herbivores will escape natural enemies. Movements of invasive species often involve large distances across continents or regions, whereas with range expansion under climate change distribution shifts will often be incremental. When this occurs, natural enemies might be able to track their hosts as long as movement rates are adequate. Where herbivores move into new areas, a resi-dent community of natural enemies might also provide some control of the herbivore.

Climate change vs. host and natural enemy synchrony

In addition to affecting biological characters, climate change may cause temporal asynchrony between interacting populations. Although natural selection will tend to increase synchrony between hosts and parasitoids, asynchrony may occur if host and parasitoid respond differentially to changes in weather patterns (Karuppaiah and Sujayanad, 2012). Asynchrony may introduce a partial refuge effect that can reduce parasitism. However, the lack of temporal coincidence between searching parasitoids and hosts can contribute to stability.

In a stable biocontrol system, the level of regulation is such that sufficient hosts and natural enemies survive to the next year to allow similar ongoing regulation in the next. In populations where host and natural enemy have multiple discrete generations a year, imperfect phenological synchronisation allowing some hosts to escape can stabilize an otherwise unstable interaction (Godfray et al., 1994).

The parasitoid *Campoletis chlorideae* developed successfully over the temperature range of 12-37°C. However, the developmental period was found to be inversely correlated with temperature in the range of 12-37°C. The percentage pupal mortality of *C. chlorideae* increased above and below 22°C, with the highest mortality rate occurring at 37°C. As temperature increased, longevity decreased accordingly. The highest longevity of parental females (17.2 ± 3.6 days) was recorded at 12°C and longevity decreased continuously with rising temperature, with the longevity of adult female parasitoids being less than four days at 37°C. The pattern of daily reproduction and the estimates of other life-table statistics of *C. chlorideae* demonstrate that its performance decreased below and above 22°C (Pandey and Tripathi, 2008).

Diapause in insects is typically associated with an interaction between day length and temperature (Denlinger, 2002) and altered patterns of diapause could influence generation number. Diapause in the lacewing *Chrysopa carnea* is induced and maintained by photoperiod. After diapause ends, activity only resumes above 4°C, and mating and oviposition above 8°C. If the rate of warming from winter to spring increases, rather than a general increase in mean temperatures over the winter-spring period, then the time between adult emergence and ovi-position will be reduced, allowing the lacewing population to begin growing earlier (Tauber and Tauber, 1973). Poor synchrony between a parasitoid and its host has been documented in cases of hibernating parasitoids of leaf miners emerge at a time when no hosts are available, and this results in a low level of parasitism of the first generation of horse chestnut leafminers, *Cameraria ohridella* Deschka and Dimic (Lepidoptera: Gracillariidae), in the field (Grabenweger et al., 2007). The parasitoid *Lydella grisescens* (Diptera: Tachinidae) emerges in spring when its pest host the European corn borer *Ostrinia nubilalis* larvae are too young to attack (Hsiao and Holdaway, 1966). Parasitoids emerge earlier than hosts because their development shows a sharper response to temperature. A disconnect between host and parasi-toid can arise because of increased climate variability. Naturally occurring parasitoids often require different hosts at different times of the year (Damman, 1993) so it is important to study all the hosts of a biocontrol agent when predicting how successful it will be in the future.

Climate change vs. interspecific population interaction

Natural enemies with very narrow and specific host ranges, a highly desirable attribute for classical biocontrol programmes, may be more sensitive to climate change than generalist herbivores and predators. The interactions between plants, herbivorous insects and parasitoids result from a long co-evolution in a particular environment. Parasitoids are more likely to be affected by climate change than plant herbivores because they depend on the capacity of the lower trophic levels to adapt to these changes. Those that kill their hosts only when their development is completed (koinobiont) are particularly vulnerable, as their hosts must remain alive throughout their development. They rely on and may influence the behaviour of the parasitised host so that it seeks locations where survival is more probable.

Population dynamics theory predicts that the extent to which a predator population suppresses its prey population is determined by the ratio of the predator's generation time to that of its prey (Godfray et al., 1994, Kindlmann and Dixon, 1999). First, insects generally have a minimum temperature required for development, and this development threshold can differ between bio-control agents and their hosts. When the threshold is lower in the host than in the enemy, then pest suppression should increase with warming (GTR declines). If the thermal development threshold is higher in the host than in the enemy, then warming may reduce pest suppression (GTR increases). While the GTR has been shown to be a strong predictor of prey suppression by predators (Kindlmann and Dixon, 1999), the theory has also been applied to parasitoid-host systems (Mills, 2006).

Temperature can also able to affect competition between two natural enemy species (Inglis et al., 1999). If temperature acts on the development rate of two natural enemy species, resulting in a temperature by species interaction, then the competitive outcome of those two species will change in warmer conditions. For example, Contreras et al. (1998) showed that interspecific competition between a parasitoid and a pathogenic fungus, both attacking the aphid *Sitobion avenae*, depended on the timing of parasitoid oviposition and fungal infection. When attacking the aphid simultaneously, the fungus had the competitive advantage over the parasitoid based on the shorter development time of the fungus. The development times of the two natural enemy species change differentially if temperatures increase, it may be the parasitoid that wins. Of course, from a pest control viewpoint the aphid will still be killed, but this will not automatically equate to no change in overall pest control effectiveness. The parasitoid could be more effective at dispersing within and between aphid populations, aphid resistance to it could be different, and other factors such as the overwintering ability of the two natural enemies could differ, all resulting in a net change in pest control.

Effect of climate on pest population via natural enemies

Shifts in climate can differentially affect the development rates of pest and natural enemy population. Hence, in biological control systems of insect pests utilising parasitoids, the temperature response of the parasitoids determines their success in controlling the pest population. The egg predator *Cyrtorhinus lividipennis* of brown plant hopper (BPH) had increased instantaneous attack rates and decreased handling times with increasing temperatures until 32°C. At 35°C, the attack rate and handling time decreased drastically. This implies that predator acti-vity is likely to increase with increasing temperatures up to a critical temperature of about 35°C (Karuppaiah and Sujayanad, 2012).

Indirect effects of climate change on natural enemies via host plants

The natural enemies of pest insects interact with plants, even if they do not rely on them directly for survival, therefore changes in plant biology will act on the natural enemies as well as the herbivores. What these changes mean in terms of net increases or reductions in pest control will depend on the climatic factor, plant species and the environment the plant is growing in. Increases in atmospheric CO_2, shifts in precipitation and particularly increases in temperature will alter plant phenology, influencing herbivore growth and abundance, and indirectly affecting the abundance of prey and hosts for natural enemies. Many natural enemies using plant chemical signals to locate their prey, and higher temperatures and elevated levels of CO_2 (Stiling et al., 2002) could interfere with host location. For example, *Diaeretiella rapae* parasitoids were shown to be attracted to mustard oils from the host plant of their prey aphid *Myzus persicae* and warmer temperatures increasing the volatility of these chemicals should aid the parasitoids in finding their hosts.

The physical structure of a plant is also heavily influenced by CO_2 (Stacey and Fellowes, 2002), and such changes to the plant will have impact on its interacting organisms. For example predatory mites prefer smooth leaves to hairy ones, and are able to eat more prey on them (Rasmy, 1977). Coccinellid foraging success is dependent on plant architecture (Clark and Messina, 1998), which influences the propensity for the beetle to fly away, the difficulty it has in walking on the leaves and its frequency of falling off the plant, as well as the availability of prey refuges.

Climate variability

Most biocontrol agents perform best under a stable environment. However, in addition to the forecast increase in mean temperature, CO_2 and shifts in rainfall distribution, climate variability is expected to increase. Extreme weather events such as droughts, flood and even unseasonal frosts are predicted to occur more frequently (Gerald et al., 2012). While many species have mechanisms to cope with extremes, they require time to acclimatize and/or enter the resistant state. For example, parasitoids are exposed to low temperature, their development is stopped, when the insects are returned to temperatures above their base temperature, development should resume normally if no damage occurred, as in the trichogrammatid *Trichogramma nerudai* (Tezze and Botto, 2004), exposure to temperature extremes induces lethal and sublethal damage to prasitoids (Hance et al., 2006).

In generally, it decreases longevity, fecundity and mobility when exposed to low temperature. For instance, *Trichogramma carverae* size decreases when exposed to 10°C or below in the early pupal stage (Rundle et al., 2004), adult Scelionidae longevity decreased (Foerster and Doetzer, 2006), adult parasitoids scelionid, *Telenomus podisi* fecundity was reduced up to 80% (Bayram et al., 2005), *Anagyrus ananatis* (Hymenoptera: Encyrtidae) produced only male progeny (Pandey and Johnson, 2005). Extreme temperatures can also affect behaviours linked to host location and evaluation. In the parasitoid *Microplitis demolitor* (Braconidae), females emerging from chilled pupae were unable to respond to an attractive odour source (volatile semiochemicals), even after only four days of chilling (Herard et al., 1988). The wolbachia bacterial endosymbionts that facilitate parthenogensis can be eliminated by short exposure to high temperature (Hurst et al., 2001). Extreme weather events such as droughts are followed by pest population explosions because of the loss of natural enemies. Generally, the host is more resistant to extreme in climate variability/events than natural enemy. Therefore, after local extinctions due to an extreme climatic event, the pest reintroduces more rapidly than the biocontrol agents.

Mitigation through farming practices

New adaptive management strategies have the following potential impacts on natural enemies:

1. Changes in agricultural practices have led to the widespread adoption of no-tillage or low tillage plantings and the use of mulches for water retention in a wide variety of crops. For example, aphid pests are suppressed in mulched cereal fields due to improved parasitoid and predator biocontrol (Schmidt et al., 2004). The abundance of carabids, parasitoid Hymenoptera and spiders, predatory and parasitic Diptera and predatory Hemiptera increased in following applications of straw and compost as mulches to reduce water loss (Thomson et al., 2010).
2. Crop land mitigation measures are: soil management practices that reduce fertilizer use and increase crop diversification; promotion of legumes in crop rotations; increasing biodiversity, the availability of quality seeds and integrated crop/livestock systems; promotion of low energy production systems and avoiding burning of crop residues; and promoting efficient biocontrol agents use by commercial agriculture and agro-industries.
3. Flowering (usually alien) ground cover plants can have positive effects on predator and parasitoid abundance with resultant benefits on pest control (Gurr et al., 2003).
4. Environmental changes lead to interest in maintaining remnant vegetation and revegetating areas on farms for a variety of reasons including salinity reduction and carbon capture. There are potential benefits of vegetated areas for pest control because these areas can support a high abundance and diversity of predators and parasitoids (Olson and Wackers, 2007).

CONCLUSION AND RECOMMENDATIONS

The climate change, as realized through trends of temperature rise and increased CO_2 concentration, is a major concern. Effect of climate change is more in temperate areas; it can affect the range expansion, host and enemy synchrony and interspecific competition. Among the

the various abiotic factors, temperature is an important force to drive the natural enemy population. It can cause the direct effects like survival, growth and development, voltinism, longevity, parasitism and dis-persal of natural enemies. The CO_2 cause indirect effect through host nutrient alteration and it has both positive and negative effects. Climate change will also alter the interactions between the insect pests and their host plants. As result, some of the cultivars that are resistant to insect pests, may exhibit susceptible reaction under global warming. Adverse effects of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programs. On the other hand, higher temperature would affect the change of agro-ecosystem in a region, and the cultural system and natural enemy population would also be changed following the global warming. Therefore, there is a need to have a concerted look at the likely effects of climate change on crop protection and long-term conservation bio control agents, which need greater attention to understand and address these issues through more research.

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