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Pest Dynamics under Conservation Agriculture based Cereal Systems of South Asia

SAROJ JAIPAL[1, 3]*, H.S. JAT[2], S.K. KAKRALIYA[2], M.K. GORA[2,3], M. KAKRALIYA[2,3], MADHU CHOUDHARY[2], A.S. TETARWAL[4], P.C. SHARMA[2] AND M.L. JAT[1]*

[1]*International Maize and Wheat Improvement Center (CIMMYT), NASC Complex, Pusa, New Delhi-110012*
[2]*ICAR- Central Soil Salinity Research Institute (CSSRI), Karnal-132001, Haryana*
[3]*CCS Haryana Agricultural University, Hisar, Haryana*
[4]*ICAR-Central Arid Zone Research Institute (CAZRI), KVK, Bhuj, Gujrat*

ABSTRACT

Pests are the key yield limiting factors in agricultural production systems around the world. Their population dynamics are shown to vary with the modifications in agro-ecosystem, cropping system and management practices. Plentiful information is available on assessment of their seasonal population fluctuations mainly due to abiotic factors in conventional tillage (CT) based cereal production systems. However, while transitioning from CT based production systems to a more stable and ecologically sustainable conservation agriculture (CA)- based systems, the pest dynamics particularly in relation to biotic factors are not clearly understood. Therefore, we conducted a systematic study on pest dynamics under long-term CA in major cropping systems of North-West Indo-Gangetic plains. In our study, crop rotations, no-tillage and residue retention led to more diverse aerial and epigeic arthropod communities which seemingly increased biological control of pests through predation by natural enemies, that subsequently resulted in no significant increase of pests in the CA-based cereal systems. CA-based rice-wheat (RW) system had the highest insect diversity than respective CT system and maize-wheat (MW) systems. In RW system, stem borers (+7.0% and -11.2%), leaf folders (15.6% and 4.8%), leafhoppers (-2.9% and -3.6%) and grain sucking insects (0% and -2.0%) were observed at tillering and grain filling stage, respectively under CA- based system compared to CT- system. Similarly, in MW system, stem and silk borers (-14.8% and -14.0%), defoliators (-4.6% and -36.8%), beetles (-22.9% and -4.2%), shoot fly (-9.2% and 0%) were recorded. The parasitoids and predators density under CA-based RW system was about 20 folds at tillering stage and 3.5 folds at grain filling stage, while, under CA-based MW system it was 6.4 times (at tillering stage) and 3.9 times (at grain filling stage) as compared to their CT counterparts. The increased density of both aerial and epigeic beneficial arthropod diversity perhaps yields in increased niche differentiation and consequently reduced herbivory in CA systems. The CA systems naturally conserve and foster beneficial biodiversity that potentially helps mitigating the populations of several detrimental arthropods by making production systems more amenable to biocontrol.

Key words: Pests, population dynamics, biodiversity, cropping systems, crop residues, Indo-Gangetic plains

*Corresponding author,
Email: jaipalsaroj@gmail.com; M.Jat@cgiar.org

Introduction

In conventional tillage (CT) based systems, inappropriate use of critical production inputs and improper management of land, water and agro-biodiversity in major agri-food systems of the region have led to the multiple challenges of resource degradation, increased biotic and abiotic stresses, biodiversity erosion and decelerating productivity of cereal crops resulting in fragile agro-ecosystems (Kakraliya *et al.*, 2018; Kakraliya *et al.*, 2018a). Meeting the projected 40% increase in food demand by 2050 coupled with climate change and restricted scope for expansion of acreage under crop production will be a daunting task under the business usual management and policy paradigm. Therefore, there is no option other than designing agri-food systems which not only produce more from less but are also sustainable (Jat *et al.*, 2016; Jat *et al.*, 2021). Healthy soil is key to developing sustainable crop production systems that minimize the environmental externalities (Jat *et al.*, 2020a) and are resilient to biotic stresses. To this effect, maintaining a good balance of natural eco-system is one of the key strategies. Host of studies on the impact of long term CA practices on soil have established that CA improves its physical properties (reduced bulk density, soil penetration resistance and higher water content, infiltration, soil penetration resistance and aggregation-Gathala *et al.*, 2011; Njaimwe *et al.*, 2018; Jat *et al.*, 2019a), chemical properties (available macro and micronutrients; Jat *et al.*, 2018; Nandan *et al.*, 2019; Njaimwe *et al.*, 2018; Piazza *et al.*, 2020) as also biochemical properties like microbial biomass carbon (MBC), enzymatic activities like dehydrogenase, acid and alkaline phosphatase and beta glucosidase activity (Chaudhary *et al.*, 2018a; Jat *et al.*, 2019a, 2019b; Piazza *et al.*, 2020). CA-based systems also contain a diverse community of organisms that help to control pest populations (Jaipal *et al.*, 2002, 2005).

However, under CT-based agricultural systems, intensive tillage, imbalanced use of fertilizers and agro-chemicals resulted in huge ecological losses, making crop production systems more vulnerable. Monotonous cereal systems with the overuse of conventional crop production and protection practices have resulted in several micro- and macrofaunal and floral consequences (Choudhary *et al.*, 2018a, b). Therefore, a paradigm shift in farming practices through eliminating unsustainable elements of intensive agriculture is crucial for future productivity gains while sustaining the natural resources (Jat *et al.*, 2021). Conservation agriculture (CA), a concept that evolved as a response to concerns of sustainability of agricultural systems with the aim to gain production intensification and stable yields while protecting the natural resources and increased biodiversity through compliance with three interrelated principles of minimum tillage, residue recycling and efficient crop diversification (Jat *et al.*, 2019; Jat *et al.*, 2020b).

Insects are the most diverse group of animals living on earth. The majority of insects are directly relevant to humans and their environment (several species are parasitoids, predators, pollinators, decomposers and producers). Only less than 0.5% of the known species are considered pests, inflicting damage to humans, farm animals and crops (Muthaiyan, 2009). Of these, herbivorous insects cause injury to plants either directly or indirectly in their attempts to secure food (Atwal and Dhaliwal, 2015) inflicting about 13 percent losses to crop yields (Kaul and Cuperus, 2007). Pests have remained one of the critical agronomic interventions in intensive cereal systems. Cereal crops, throughout their crop growth stages, are susceptible to a wide array of insect pests and diseases (Schwartz and Mohan, 2008). The productivity of major cropping systems of the world largely depends on successful field pest management. Pest problems are occasionally being reported from around the world as the yield limiting factor especially during the transition to CA systems. The abandonment of plough in CA raises some apprehensions and unwarranted fears in the minds of plant protection functionaries and farmers regarding pest management as conventional tillage in intensive cropping systems was adjusted useful in controlling not only weeds but also was considered a subtle cultural practice to reduce insects and disease incidences. There is no denying the fact that the change in climate and cropping environments may result in perceptible changes in pest status on several crops. Circumstantially, some pest problems have been encountered especially in partial and or short-term CA systems or during the initial phase of transition to long term CA.

Conservation Agriculture (CA), based crop production system maintains macrofaunal diversity while improving crop yields (Mashavakure *et al*., 2019a,b; Jat *et al.,* 2020c). Short-term CA systems in South Asia have occasionally and circumstantially been reported to also bring some negative impact in status of some insects, diseases and weeds (Howard *et al.*, 2003; Hobbs *et al.*, 2008). Within the framework of our earlier research (Jaipal *et al*., 2002, 2005) done in the north west India, albeit no dramatic surge in detrimental arthropod populations in RW system under partial CA was seen between 1998-99 and 2005-2006. However, there have been a few specific incidences of situational flare ups that appeared to be more related to crop intensification, cultivar susceptibility, climate and increased use of N fertilizer than the tillage treatment alone. There is evidence that ecologically specialized (monophagous) species have been favoured by crop intensification that involves changes in cultural practices such as (a) an increase in the number of crops grown per year, (b) an increase in the use of agricultural chemicals (fertilizer and pesticides), (c) increased area under irrigation and (d) increased plant densities. The natural decay and decomposition of stubbles brings out mortality of the hibernating larvae of these stem borers (Jaipal *et al*., 2005; Hobbs, 2007). The fall in winter temperature further results in reducing their number in soil. Heavy winter rains during January and February in North India have shown to bring out even cent per cent mortality of the yellow stem borer larvae lying in soil around the root zone of wheat hills (Jaipal *et al*., 2002). The apprehensions of field crop functionaries and farmers regarding carryover of specialist monophagus species in large numbers to next crop might be due to some specific factors or conditions and hence could not be generalized. In semi-arid environments of Central Queensland, Robertson *et al.* (1994) and Wilson-Rummerie (1999) also did not find any increase in pest density under conservation tillage (CT) system.

Systematic studies on pest dynamic under CA- based management practices are largely lacking. Given the increasing role of CA in sustainability of agriculture and addressing the challenges of climate change, a sound understanding of pest dynamics (beneficial as well as harmful) under altered soil environments and micro-climates is felt required for its accelerated adoption and realizing the potential benefits.

Materials and Methods

A study was conducted during *kharif* 2020 in the on-going long-term (10 years) farmer-scale CA research trials set up in 2009-10 at ICAR-Central Soil Salinity Research Institute (29°70′ N, 76°96′ E,), Karnal, India. The basic objectives of the study were to quantitatively assess the diversity and populations dynamics of both epigeic and aerial insects (detrimental and beneficial both) in the major cereal based systems under CA in cereal systems in a sub-tropical and semi-arid climate. The experiment with six management scenarios (Table 1), differed by tillage, crop establishment methods, crop diversification and residue, water and nutrient management practices. The entire scenarios were replicated thrice in a completely randomised block design. The scenarios were designed keeping in view of present as well as future drivers of agricultural changes in the region and their details can be obtained from earlier publication (Gathala *et al.*, 2013; Jat *et al.*, 2019). The CA based scenarios involved three levels of rotations in both rice (rice-wheat-mugbean) and maize (maize-wheat-mungbean) as against two in CT (rice-wheat; maize-wheat). CT based maize-wheat was grown in the adjacent plot. Sampling for aerial and epigeic insects as also those occupying the crop parts was done as per standard methods and procedures at weekly to fortnightly intervals.

Table 1. Drivers of agricultural change towards sustainability of cereal systems, crop rotation, tillage, crop establishment and residue management practices applied to different scenarios

Scenario	Crop Rotations	Tillage	Crop Establishment Method	ResidueManagement	Water Management
I	Rice-Wheat-Fallow	CT-CT	Rice: Transplanting Wheat: Broadcast	All residue removed	Flood irrigation
II	Rice-Wheat-Mungbean	CT-ZT-ZT	Rice: Transplanting Wheat: Drill seeding Mungbean: Drill/relay	Full (100%) rice and anchored wheat residue retained on soil surface; full mungbean residue incorporated	Flood irrigation
III	Rice-Wheat-Mungbean	ZT-ZT-ZT	Rice: Drill seeding Wheat: Drill seeding Mungbean: Drill/relay	Full (100%) rice and Mungbean; anchored wheat residue retained on soil surface	Flood irrigation
IV	Maize-wheat-Mungbean	ZT-ZT-ZT	Maize: Drill seeding Wheat: Drill seeding Mungbean: Drill/relay	Maize (65%) and full mungbean; anchored wheat residue retained on soil surface	Flood irrigation
V	Rice-Wheat-Mungbean	ZT-ZT-ZT	Same as in scenario 3	Same as in scenario 3	Sub-surface drip irrigation (SDI)
VI	Maize-wheat-Mungbean	ZT-ZT-ZT	Same as in scenario 4	Same as in scenario 4	SDI

Where: CT- conventional tillage; ZT- zero till; CA- conservation agriculture; SI- sustainable intensification; SSD- sub surface drip; SDI- sub-surface drip irrigation;

Results and Discussion

In our study, 76 species of insects and spiders were recorded from the various scenarios in rice and maize crops. Of the 21 detrimental insect species belonging to orders Lepidoptera, Hemiptera, Hymenoptera Coleoptera, Neuroptera, Orthoptera, Odonata, Diptera and Isoptera, only six were of major economic significance while an additional 15 species were of minor importance to the crops. The detrimental insects were classified into various guilds such as root feeders (termites, grubs and root weevils), stem/stalk borers (yellow-, white-, striped- dark headed- and pink stem borers, maize stem borer and semilooper), leaf folders, plant hoppers and leafhoppers, foliage or grain sucking insects and defoliators, armyworms and cutworms, sap suckers leaf eaters (e.g. elegant grasshoppers, blister beetle, leaf miner and leaf beetles) based on their infestation pattern and damage to the crops. The appearance of these herbivores was crop specific e.g. fall army worm, silk corn worm, maize stem borer, blister and florescent beetles (detrimental) appeared specifically in maize crop only while, leaf folders and leaf hoppers, yellow and white stem borers, and stink bugs in rice crop only. Some of these herbivores also attracted specific parasitoids and predators e.g. the appearance of predatory pentatomids and coreids was noticed in maize crop only while *Microvellia* bug was restricted to rice crop alone. The odonates (dragon and damsel flies) initially appeared in flood irrigated rice and gradually spread to all rice crop scenarios and also to maize crop scenarios, though to a lesser extent. The highest odonates density was recorded at panicle initiation which then subsequently declined and seen migrating to the more aquatic environment such as neighbouring water bodies. The differential appearance of arthropod species is majorly determined by their preference for food, shelter and ambient abiotic conditions to grow and survive.

Our results further revealed that relative to the CT scenario, the CA based scenarios had higher arthropod diversity and abundance in both rice (rice-wheat-mungbean) and maize (maize-wheat-mungbean) crops. Of the detrimental guilds, the incidence of stem borers, leafhoppers, grain bugs, termites, cutworms, armyworms and grasshoppers though remained below economic injury levels irrespective of the treatments, was not similar in the rice crop scenarios. The leaf folders infestation, on the other hand, was significant and relatively much higher throughout the crop period in CA based direct seeded rice (rice-wheat-mungbean) than CT (rice-wheat). The pink stem borer which appeared at reproductive stage of rice crop predominantly occupied the rice crop at grain filling and its population density was also slightly higher in flood irrigated DSR than CT. The incidences of specialist stem borer (*S. incertulas*, *S. Innotata*) and dark headed stem *Chilo* species, leafhopper *Nephotettix virescens* and grain stink bugs were recorded comparatively higher at tillering as well as grain ripening stages in CT rice (Fig. 1). Guilds such as Isoptera (termites) appeared in direct seeded rice and maize plots at the initial stage of crop establishment only and not in others.

In maize crop, significant infestation by stem and silk borers, and defoliators was recorded in both CA and CT scenarios, however, in both sub-surface drip irrigated (SDI) and flood irrigated maize (maize-wheat-mungbean) scenarios, the infestation of herbivore guilds such as stem and silk borers (*Chilo partellus*, *Sesamia inferens*, *Helicoverpa species*) defoliating worms (*S. frugiperdes*, *S. litura*) and beetles remained lower than the CT throughout the crop growth stages (Fig. 2). Surprisingly, no perceptible changes in termite (*Odontotermes* amd *Microtermes* spp.), armyworm and cutworms (*Mythimna separata*, *Agrotis* spp.) infestation in CA from CT maize were evident. The introduction of green crops such as sunhemp may help break the life cycles and alleviate the increased damages when

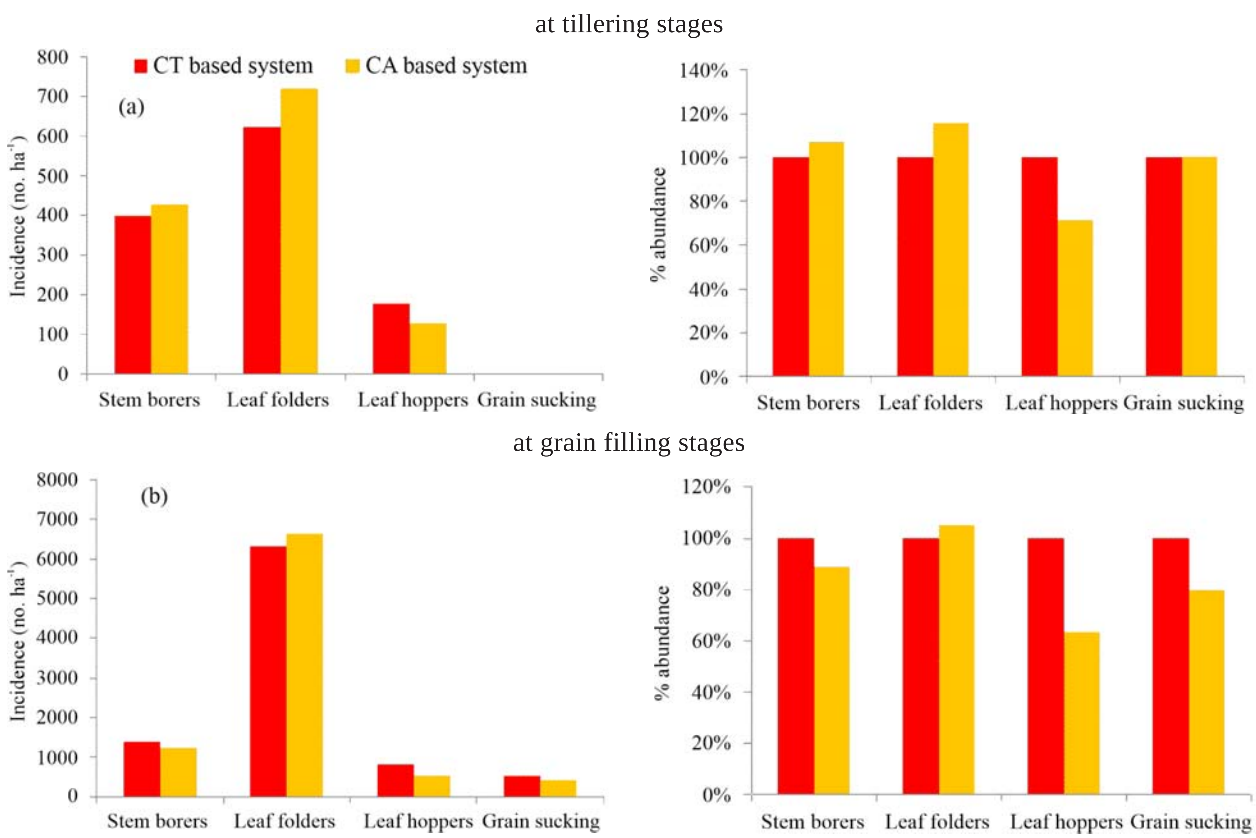

Fig. 1. Herbivores incidence levels and relative abundance of herbivore guilds in CA and CT based rice at tillering (a) and grain filling stages (b)

Fig. 2. Herbivores incidence levels and relative abundance of herbivore guilds in CA and CT based maize at vegetative (a) and grain filling stages (b)

elevated above the threshold injury levels (Muoni *et al.*, 2019).

In both CA based rice and maize crops, a very high faunal density comprising of a wide range of natural enemies was recorded (Figs. 3 & 4). Among the potentially beneficial fauna, thirteen were ground and webbing spider species, nine parasitic and predatory wasps species, ten damsel and dragonflies species, four parasitic and predatory bug species, six beetles species, three tachinid flies species, two cricket and one each of earwig, ant, and grasshopper species. The epigeic fauna mainly consisted of scarabids, carabids, earwigs, ants, ground spiders and root weevil and aerial and soil surface detrivores such as euryphid, chironomids, tachinids flies, millipedes, snails and dung beetles. The remaining species were 'neutral' simply taking shelter in the crop and a few of them serving as food for some spiders and bugs. The beneûcial arthropod groups were grouped as pollinators (e.g. bees, wasps), predators of detrimental arthropods (e.g. ladybird, wasps, praying mantis and spiders), and decomposers (e.g. termites), parasitoids of eggs, larvae/pupae/nymph of stem borers and leaf folders and entomopathogens.

In general, beneûcial arthropods increased in numbers as the crops reached to maturity except for some guilds such as the Odonata (damsel and dragon flies) which gradually declined in number as the crop progressed to maturity. The faunal density, species richness and relative abundance of beneficial insects were highly significant in CA than CT (Fig. 3). The abundance of some arthropod guilds appeared to differ more conspicuously in cropping scenarios. Among the dominant guilds, Hymenoptera, Coloptera, Diptera and Odonata were important that appeared in fairly high relative abundance across the scenarios and crops.

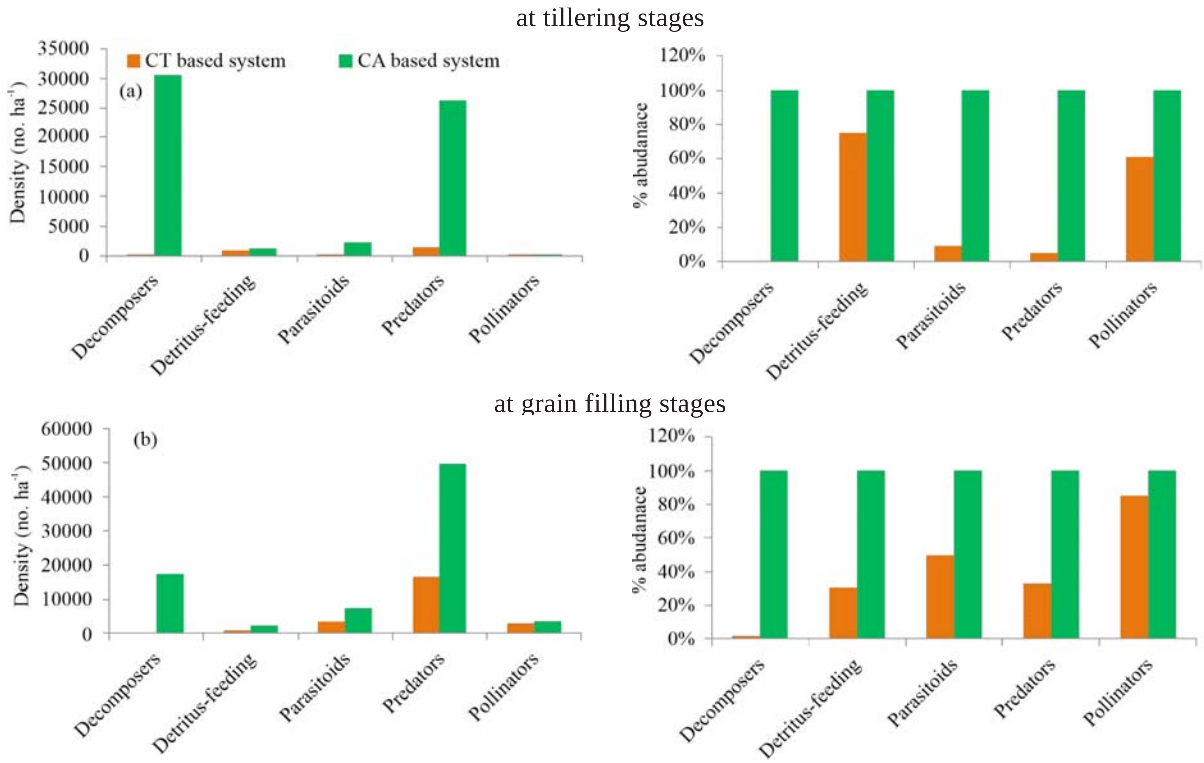

Fig. 3. Population density and relative abundance of beneficials in CA & CT based rice at tillering and grain filling stages

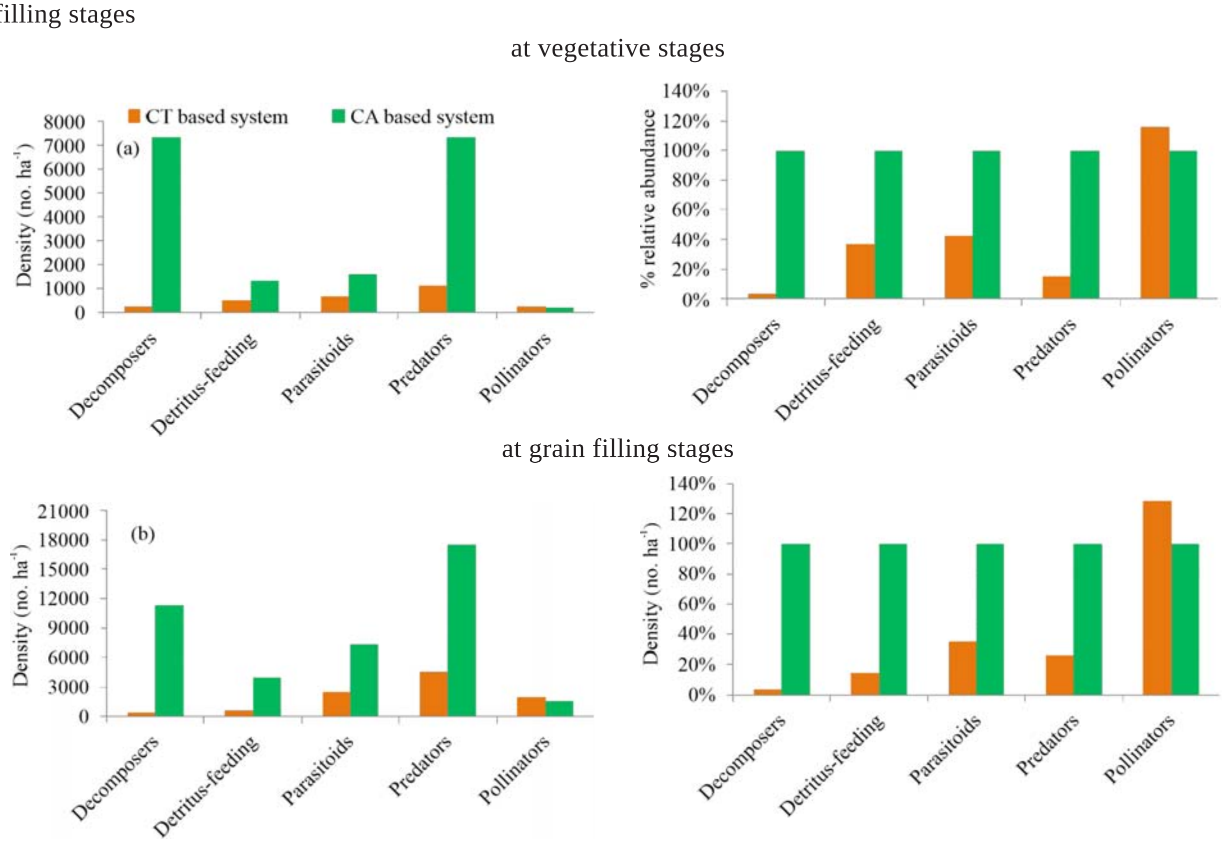

Fig. 4. Population density and relative abundance of beneficials in CA & CT based maize at tillering and grain filling stages

In both rice and maize crops grown in rotation with wheat and moongbean, the induced agronomic changes resulted in remarkably higher beneficial arthropods density as compared to CT treatments. A divese range of insects populations dominated by decomposers, detrivores and predators that feed on adults and life stages of detrimental species were evident. Adult and larvae of carnivorous Odonata are considered efficient predators in rice fields (Siregar *et al*., 2010). Retention of crop residues and diversification ensure conditions favourable to survival and carry over of predatory arthropods such as spiders, coccinellids, earwigs, crickets, grasshoppers etc (Mhlanga *et al*., 2020) and hence their conservation and abundance in CA systems. It is crucially important that key natural enemies should appear as early as the crop colonises the pests. The availability of predators in abundance during early stages of pest infestation in CA crops helps curtail the detrimental species populations. Similarly, emergence of *Glyptomorpha deesae*, *Chelonus* sp. Isotima spp. and *Bracon chinensis* from the overwintering larvae generally coincides with the emergence of the pests. This synchronisation could be quite advantageous for the management of the stem borer damage. Almost all the larvae and pupae parasitoids of stem borers in rice remain in the crop residues. In CT crops, however, there seems minimal chance for early predation and parasitism as a result of disruption of microhabitat due to tillage operations.

Based on the available evidence from our study, the reductions in the number of herbivorous insects also appear to be caused, in large part, by the increase in numbers of their natural enemies. Conservation agriculture provides considerably more complex habitats and food webs compared to conventional tillage, due to residue retention and higher plant diversity – which may also include some economically important weeds. This complexity provides additional resources in the form of alternative prey and shelter to a variety of biological control agents. Cover crops and residues are mostly beneficial for breaking pest cycles and enhancing the effectiveness of natural enemies. Residues of various cover crop species were found to contain higher natural enemies densities and reduced pest abundance in cabbage fields (Bottenberg *et al*., 1997; Xu *et al*., 2011). Residue retention creates favourable microhabitats for beneficial insects specially the epigeic carabids, staphylinids, ants, spiders (Altieri and Schmidt, 1985). Besides, more balanced soil fertility due to soil conservation efforts and increased diversity of cropping systems under CA should also be helpful in minimising herbivores incidence.

Concurrently, the self-reliance of stable CA systems (Fig. 5) naturally fosters beneficial

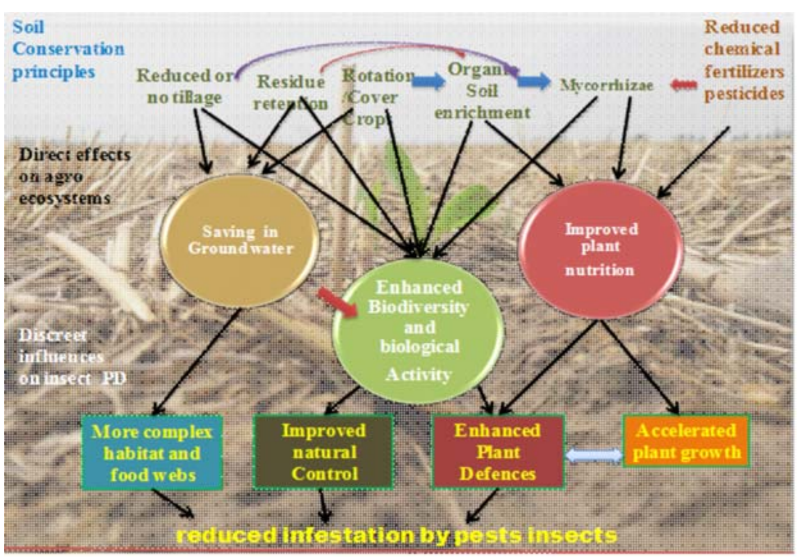

Fig. 5. Systematic presentation of a self-reliant CA system that leads to reduced pest problems

biodiversity that potentially leads to increased biocontrol, thus, mitigating the populations of several detrimental arthropods (Jaipal *et al*., 2002; Hobbs *et al*., 2008; Chenu *et al*., 2011; Harrison *et al*., 2019; Mashavakure *et al*., 2019a, b; Mhlanga *et al*., 2020) and makes CA more amenable for the implementation of IPM principles and approaches (Ehler, 2006; *Owenya et al.*, 2011).

Conclusions and Future Research Needs

The potential benefits of conservation agriculture-based management systems on crop yields, water productivity, economic profitability, soil health as well as increased adaptive capacity to climatic risks and mitigating GHGs across diverse production systems and growing environments are well documented. However, there has been a large skepticism on pest dynamics due to lack of scientific evidence as there are barely any systematic research on this. In this article, we provide some science based evidence on pest dynamics under long-term conservation agriculture in major cereal based rotations of south Asia. The arthropod species community diversity and richness seems to be influenced by changes in tillage, crop establishment methods, residues, agronomic management practices and crop diversification. The CA with rice, wheat and mungbean in rotation consistently had the highest diversity while, the conventional tillage (CT) based management practices showed the least species diversity. The CA systems comprising of reduced tillage, plant residue retention and crop rotation did not show any increased incidence of detrimental arthropods across all treatments and cropping systems. For realising economically viable yields, herbivores in CA systems need to be effectively managed at the appropriate times if they exceed an economic threshold level. With its key elements, CA itself is consistently reported to maintain both aerial and epigeic beneficial arthropod diversity. Being more diversified, CA systems (e.g. with crop residues, rotations/ intercrops/cover crops) lead to increased niche differentiation and also provide shelter and hunting grounds for predators.

The economical and ecosystem benefits of CA principles in terms of enhanced biological activity especially the natural enemies of pests consistently being reported from all regions of the world and must achieve a greater consensus among international and national scientific communities and policy-planners in order to satisfy the apprehensions on pests to promote adoption of CA in smallholder production systems. We need to enhance fundamental research for the conservation and utilization of useful biodiversity in agricultural systems. Employing biodiversity for a sustainable agricultural production that produces diverse and nutritious foods will contribute to the conservation of these bio-resources to make them available to address the future global climate scenarios. Some CA based agricultural changes targeted to attain sustainability goals may sometimes also lead to elevated pest levels especially during initial stages or transitory period of change. This will require assessment of the damages and the economic threshold levels and development of CA specific cost effective and eco-biologically IPM packages and their applications.

Author Contributions

M.L. Jat, HS Jat and PC Sharma designed and established the long-term CA research . HS Jat and S.K. Kakraliya managed the experiment and data. M.K. Gora and M.K. Kakraliya helped in collecting the data and study material. Saroj Jaipal scouted experiment for insect population dynamic, guided and supervised collection of data, analysed the data and wrote the manuscript. All authors contributed in writing and editing of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial or personal interests involved.

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Ethical Approval

This article does not contain any studies with human participants or animals carried out by any of the authors.

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