IPM ISSUES IN ZERO-TILLAGE SYSTEM IN RICE-WHEAT CROPPING SEQUENCE

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Citation

Saroj Jaipal, R. K. Malik, Ashok Yadav and Raj Gupta. 2005. IPM Issues in Zero-tillage System in Rice-Wheat Cropping Sequence. Technical Bulletin (8). CCS Haryana Agricultural University, Hisar-125 004, India, pp. 32.

Cover

Rice Crop

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The production of this publication has been supported by the National Agricultural Technology Project (NATP), Indian Council of Agricultural Research through its Special Research Sub-project on “Accelerating the Adoption of Resource Conservation Technologies (RCTs) for Farm-level Impact on Sustainability of Rice-Wheat Systems of the Indo-Gangetic Plains” in the PSR mode.

IPM Issues in Zero-tillage System in Rice-wheat Cropping Sequence

Rice and wheat on which human population mainly subsists is critical to food security. India already has a population of over one billion people. If the human growth rate continues at the current pace, the population by 2020 is expected to be 50 per cent greater than it is today, requiring about 50 per cent more food. The desire for an ever increasing food demand has resulted in highly productive rice and wheat systems expanding over 10 million hectares in India. However, presently the systems are seemingly on a declining path in terms of factor productivity, soil fertility, water quality as well as supplies and increased costs of production, problems of pests, sodicity, salinity and environmental pollution. Because of these sustainability and other issues the burgeoning population seems to be at risk. The zero or reduced tillage or in broad terms the conservation tillage systems are optimal in terms of productivity, sustainability and cost effectiveness of most grain cropping systems. The practices have improved yields, soil organic matter and input use efficiency, while lowering the production costs.

The zero or reduced tillage system in rice-wheat cropping sequence (RWCS) is relatively a new concept under Indo-Gangetic plains of South Asia. In India, this has transformed wheat cultivation across much of North-West states in the recent past. There are several reasons for the current dramatic spur in acreage under the system in states like Haryana, Punjab, Uttar Pradesh and Bihar. The revolution entails wide spread adoption of wheat sowing method that involves direct drilling of wheat seeds into rice residues after the harvest of rice crop. This has virtually culminated in major changes in wheat crop environment ranging from minimum soil disturbance to location of rice stubble and weed ecology which in turn may influence the soil properties as also the species diversity, status, biology, ecology and carry over of insects, diseases and beneficials. The probable shift we have been assuming in the composition of the pest fauna and flora or the associated natural biotic mortality factors as the tillage practice evolved during the past five years was followed particularly in reference to the rising and falling fortunes of insects, because it is in the periods of rapid agricultural change that one might expect the effects of changed cultural environment to be more clearly highlighted. In practice, however, such an assessment may not be a simple process as many aspects of the environment typically vary together and their separate effects seem difficult to unravel. This current attempt to come to grip with the challenges of insect-pest management in the zero/reduced tillage system of rice-wheat with surface managed crop residues draws on a series of observations we recorded on farmers fields located at five different sites in North-West Haryana. The bulletin principally documents the changes in the population densities of key insect-pests of rice and wheat and their natural enemies associated with the reduced tillage or raised bed methods of wheat planting as also outlines the probable IPM issues in context with the changed system and the solutions thereof.

Many species of arthropods inhabit rice and wheat fields, albeit most are not truly noxious to the crops. For instance, some 500 species of insects and spiders may appear in a rice field in a particular season. Of these only few are potential threat. The rest are either beneficial in the form of a wide range of predators and parasites that contribute to keeping insect-pest organisms in check or innocent immigrants (neutral species) living on weeds or on organisms and under certain conditions serving as general prey for some beneficials. However, the status of these different categories of organisms is not permanent in crops and may shift or change in response to natural or artificial (induced externally) modification of the habitat of cropping systems. The latter mainly entails the alterations in crop environment through cultural practices.

The herbivores variously attack all the parts of rice and wheat plants during the different stages of their growth. The feeding guilds in rice mainly entail –

Root feeders – termites and root weevils

Stem borers – yellow-, white-, striped- dark headed- and pink stem borers

Leaf folders

Plant hoppers and leafhoppers

Grain sucking insects and

Defoliators

Root feeders

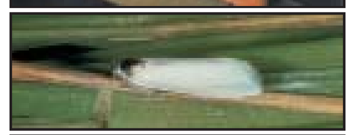
Termite incidence in rice fields is noticed in patches especially under conditions of scanty rainfall. Termites often kill the plants, reducing their number. The root weevil is active in irrigated rice during early crop stage, the larvae feeding on the roots. Damaged plants grow poorly and have low yields.

Stem borers

The stem borers are the serious pests of rice crop, causing significant reductions in yield during certain outbreak years. Both noctuids and pyralids (Lepidoptera) constitute the main rice stem borers. Important species causing damage to rice plants in India are –

Yellow stem borer (YSB), *Scirpophaga excerptalis* (Walker)
Pyralidae, Lepidoppera

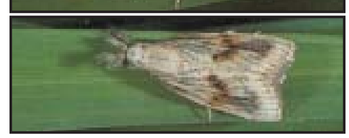
White stem borer (WSB), *S. innotata* (Walker)
Pyralidae, Lepidoppera



Striped stem borer (SSB), *Chilo suppressalis* (Walker)
Pyralidae, Lepidoppera

Pink stem borer (PSB), *Sesamia inferens* (Walker)
Noctuidae, Lepidoppera

Dark headed stem borer, *Chilo polychrysus* (Meyrick)
Pyralidae, Lepidoppera



A few less destructive and less abundant species of localized importance are –

Golden fringed stem borer, *C. auricilius* Ddgn. Pyralidae, Lepidoppera

Spotted stem borer, *C. partellus* (Swinhoe) Pyralidae, Lepidoppera **and**

Top shoot borer, *S. nivella* Fabr. Pyralidae, Lepidoppera

Apart from these *Ancylolomia chrysographella* Koll., *S. gilviberbis* Zell. and *Maliarpha separatella* Ragon have also been recorded damaging rice crop in the country.

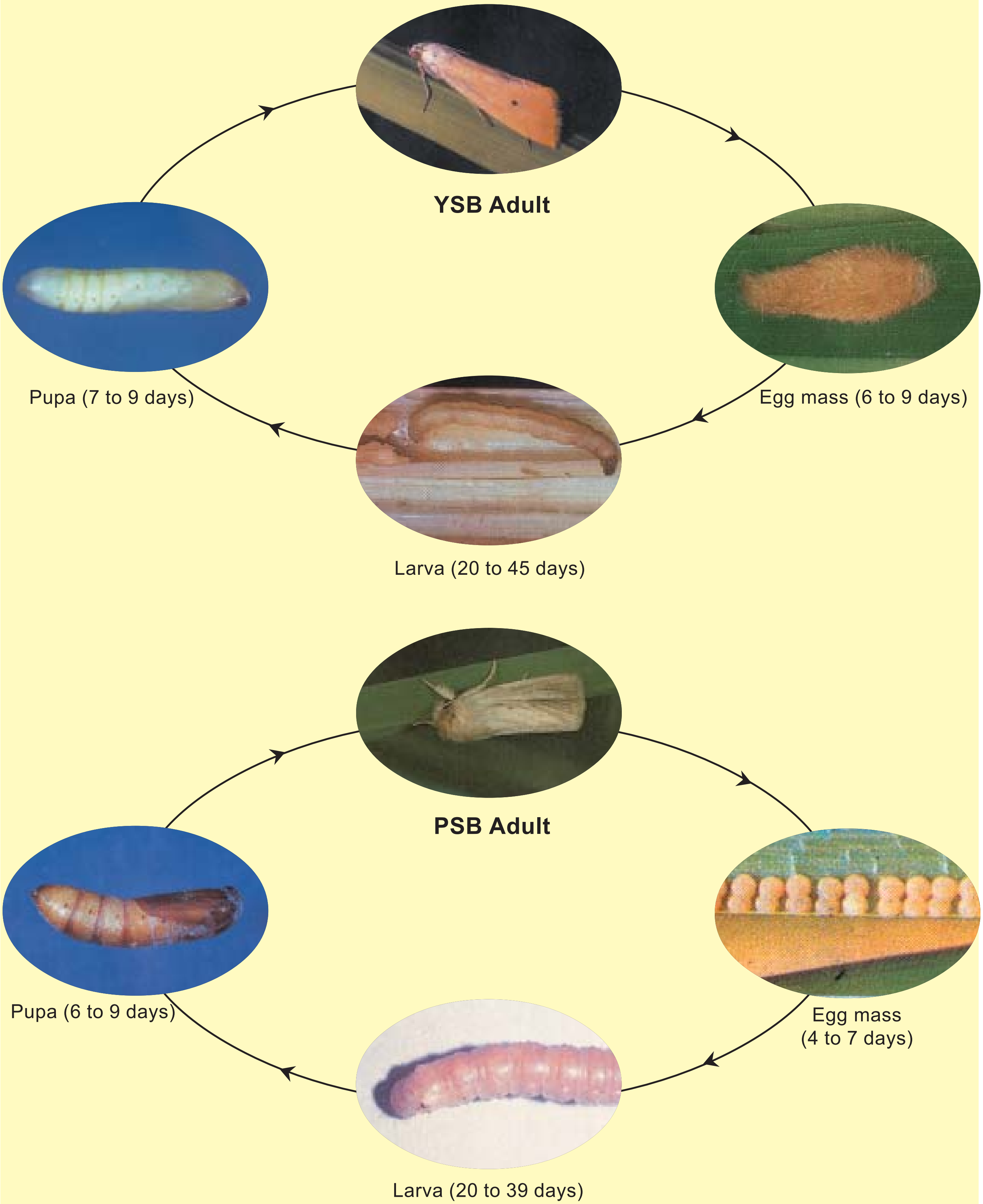


Fig. 1. Life cycle of yellow stem borer and pink stem borer.

Rice stem borers are recorded from all the rice ecosystems, *viz*. upland, medium land, rainfed lowland and irrigated conditions but severe damage is usually limited to irrigated rice grown both in wet and summer seasons. The specialist species, *S. incertulas* is the most destructive and dominant species of rice crop in India and is reported to occur throughout the country. It has been shown to be more severe in lowland cultures coupled with moderating effects of irrigation on microclimate and in crops planted in staggered manner with scented rice. Both *C. suppressalis* and *C. polychrysus* are also widely distributed in the country in low to moderate proportion, while the white stem borer is a localized species and also occurs in low to moderate abundance. The striped stem borer is more abundant in temperate and subtropical regions. The pink borer, *S. inferens* is an extremely polyphagous species. It is also recorded to inhabit sugarcane, maize, wheat, barley, millet and some species of wild grasses. Under Orissa conditions, yellow stem borer is the only species noticed at vegetative phase. At grain ripening the population densities of this along with *C. suppressalis* often exceed 50 per cent of the stem borer population. Here, the pink borer also becomes most active at grain ripening when it is recorded to constitute about 15-35 per cent population of stem borers as against about 20 per cent of striped borer and 45-60 per cent of yellow stem borer. Although only a few species cause sufficient yield reduction to require intensive control measures, all the five widely distributed species are frequently cited as major constraints to rice production. Rice stem borers can infest the crop at any stage of crop growth, from seedling to maturity. The larvae which hatch from the eggs, initially feed on the plant tissue under the leaf sheaths. Damage is inflicted during the course of larvae feeding and burrowing in the stems. Injury at seedling stage results in drying of the central shoot forming a characteristic "dead hearts". Feeding inside the stems of grown up plants results in panicle failure and white earhead. As a result the panicle is unfilled and whitish in colour, rather than filled with grain and brownish in colour. Such empty panicles are called "whiteheads". Shriveled grains are formed when at dough stage the panicles are severed off from the base of plants.

"Dead heart" due to stem borer damage

"White heart" due to stem borer damage

Since both larvae and pupae of these borers live within the stems of plants, the straw in any form may help spread the borers from one place to another. Adults emerge from the pupae through the exit holes and can fly several kilometers, if, assisted by wind. Rice stem borers complete several generations in a year, the actual number depending largely on the availability of food and suitable climatic conditions.

Under diversified cropping system, generalist species like *S. inferens*, *C. auricilius*, *C. partellus* and *S. nivella* may inhabit wheat, rice, sorghum, barley, millet or some wild grasses and other weeds before or after the harvest of rice crop. The specialist species, *S. incertulas* and *S. innotata* are, however, reported strictly monophagous in habit. An estimate made at Central Rice Research Institute (CRRI), Cuttack suggests that every one per cent increase in stem borers incidence at the vegetative phase registered a loss of 0.28 per cent in yield which at heading stage was shown 0.62 per cent. The potential losses of 40-50 per cent stems before harvest have been estimated due to yellow stem borer alone. In deep water rice, stem borers have been shown to cause even upto 95 per cent damage to shoots and stems in a few farmers fields during the years of outbreaks. In semi-deep waters of Orissa, every one per cent increase in stem borer population density causes a reduction of 0.28 per cent in yield when the damages occur at shoot stage and 0.62 per cent when stems are damaged at grain filling stage. In another similar report every one per cent stem damage is shown to cause a reduction of 0.1 to 0.16 per cent reduction in grain yield. However, we believe that the losses due to stem borers are misrepresented because in several instances these also include the losses to crop by other pests like weeds, diseases as well as other insects. At vegetative stage, plant tolerance plays a vital role in reducing the losses to a great extent, the damaged plants throwing new tillers a lot more vigorously than the normal shoots which compensate for the lost ones. At early growth stage, the plants are able to make up loss of even upto 40 per cent tillers through this phenomenon of compensatory tillering. This mechanism of pest damage tolerance by the crop to some degree also works even during panicle formation and grain filling stage.

Leaf folders and caseworms

The widely distributed leaf folding species *Cnaphalocrosis medinalis* has assumed the status of major pest with the introduction of high yielding varieties and excessive fertilizer and pesticide usage. Apart from the main leaf rolling *Marasmia exigua* a number of other species have lately been recorded on rice crop, but *M. exigua* and *C. medinalis* cause serious damage to rice crop in India. The leaf folders infest the crop mainly during crop growth stages. The damage to leaves is more particularly during the vegetative stage. The larvae roll the leaves around their bodies, scrapping them between the veins. Damaged leaves become papery white, dry up and turn brown. Damage to the flag leaf results in highest yield loss.

The leaf rollers inflict damage to rice crop in the same way as leaf folders, however, the infestation tends to increase in the older crop. The case worms are the problems of irrigated and rainfed wet land environments. *Nymphula depunctalis* (Guen.) is the main damaging species at vegetative stage. The incidence of case worms is generally high in dwarf, compact, heavy tillering high yielding varieties.

The leafhoppers and planthoppers

The leafhoppers and planthoppers (Hemiptera) are the sucking bugs which remove plant sap from the xylem and phloem tissues of the plant. In general, the leafhoppers attack all the aerial parts of the plant, whereas the planthoppers attack the basal portions (stems). Severely damaged plant dry and take on the brownish appearance of plants that have been damaged by fire. Hence, hopper damage is called "hopper burn". These bugs are also the vectors of serious virus diseases of rice e.g. tungro virus transmitted by the green leafhopper, *Nephotettix virescens* and the grassy stunt virus transmitted by the brown planthopper, *Nilaparvata lugens.*

Grain sucking insects

The stink bugs (Hemiptera), known for the foul odour produced by the scent glands on their abdomen, penetrate the developing grain and their sucking mouthparts and remove the white fluid referred to as "milk". Damage early in the development of the grain prevents the filling of the grain. Later attack results in "pecky rice" which is referred to as the condition of the grain after being sucked by stink bugs and the grain being subsequently stained by the bacteria or fungi which enter the punctured wounds.

Defoliators

A large group of insects belonging to several insect orders feed on rice leaves. Most common are the larvae and adults of beetles, larvae of lepidopterans and nymph and adults of grasshoppers. Defoliation reduces the photosynthetic activity of the plant and thereby decreases yields. However, when feeding damage occurs early in the crop growth, plants have an ability to compensate for the damage by producing new tillers. Thus, rice plants in the actively tillering stage of growth can tolerate a certain level of leaf damage without any yield loss.

Insect-pests of wheat crop

The common insect-pests of wheat crop are termites, shoot flies, aphids, cutworms, armyworm, flea beetles, Gujhia weevil, thrips and mites. The white ants *Microtermes obesi* Homl. and Odont*otermes obesus* Ramb. are important soil pests of the crop. With the introduction of modern wheat varieties, shoot fly has also emerged as a major pest of wheat. The species, *Atherigona naqvii* and *A. oryzae* are generally common to wheat, the former being the dominant one. The damage is shown by a characteristic dead heart formed out of drying of central shoot. Infestation during early crop stage causes economic loss. At tillering, the yield loss is significant when the damage occurrences are more than 20 per cent in the crop. Sometimes grown up tillers are also attacked resulting into white ears similar to those caused by pink borer. The aphid species of frequent occurrence in wheat are *Macrosiphum miscanthi* Takahashi and *Rhopalosiphum maidis* Fitch. Late sown crops of high yielding varieties are more prone to infestation than the early sown. Cloudy weather is another factor influencing its incidence in the crop. The sucking by nymphs and adults results in loss of yield depending on the population intensity. The pink borer, *Sesamia inferens* is an extremely polyphagous pest particularly of cereal crops. The boring of larvae into shoots results in dead hearts. The caterpillar being highly migratory, injures several plants in its life. The infestation increases during dry pre-monsoon periods. The cutworms, *Agrotis* and *Euxoa* sp. which generally cut the young wheat seedlings near the ground level are also highly polyphagous pest. They are of frequent occurrence in vegetable, oilseed and cereal crops. The armyworm, *Mythimna separata* is again a polyphagous pest of many graminaceous crops. The introduction of Mexican varieties has accentuated its incidence in the crop.

Losses due to insects in rice and wheat crops

Insects reduce yields substantially depending on their population densities in the crops. The estimation of overall damages due to insects alone is a complicated matter because their activity and population densities are determined by many other biotic and abiotic factors. Since these natural factors as also the several agronomic practices (cropping pattern, cultivars, biodiversity, fertilizer and irrigation management, etc.) differ from region to region so is the abundance and activity of insects in the crop. In India, the average losses to rice crop due to insect damage have ranged from 10 to 30 per cent in the last three decades. According to Dhariwal and Arora (1996), the average estimated loss of yield in rice is above 25 per cent measuring a monetary value of more than 94,500 million rupees. Fortunately, the losses in wheat are far sparse. On an averages wheat is recorded to lose approx. 5 per cent amount of its total production to insects, the monetary value of which is measured about eight times less than rice. However, there is an additional loss of about 12.7 million tonnes of food grains during storage. The importance of insects and other pests is indicated by the fact that only a 10 per cent rise or fall in rice and wheat production on a global scale can make the difference between a glut and acute scarcity.

Zero tillage and IPM issues in rice-wheat cropping system

Although insects in rice crop have been a problem since ages, outbreaks have increased and the pest complex has changed with change in agricultural practices. With change in cultural environment of crops, some insects have increased in severity, while others have declined in importance. In Karnal and Kurukshetra districts of Haryana, incidence of some 13 rice pests has progressively increased in a span of 15 years (1977- 80 and 1993-95, Table 1).The outbreaks of brown plant hopper (BPH), white backed plant hopper (WBPH) and stem borers may be attributed to intensive planting and abundant use of N fertilizer and pesticides. The most visible effects of the cultural changes have been in specialist species like BPH and the YSB. The increased use of resurgence inducing insecticides has been identified as the major cause of BPH outbreaks.

Table 1. Trends of intensity of stem borers in rice under RWCS in Haryana (1977-95)

Stem borer species	1977-80	1981-84	1985-88	1989-92	1993-95
Scirpophaga incertulas	*	*	*	***	***
Sesamia inferens	*	*	*	**	**

Source : Dhiman *et al.* (1995). *low, **medium, ***severe

The photoperiod insensitivity and the reduced growth duration of the modern varieties have made it possible to grow two or even three crops of rice in a year, sometimes even at the cost of natural resources. Continuous cropping in staggered manner and monocultures has caused shifts in the composition of pest fauna. The problems of whorl maggot, *Hydrellia* and caseworm *Nymphula* have increased with the increase in area under irrigated rice.

Conservation tillage in forms of minimum tillage, no tillage, stubble mulch, chisel-plant or till-plant bring about a profound change in the cultural environment of crops. Under RWCS there seems to be six main ways in which zero/reduced tillage may bring out biotic changes.

- The huge amounts of surface residues over large areas in the region resulting from zero/ reduced tillage may ensure survival of a number of insects both destructive and beneficial.
- The cutting height of the crops at harvest and the management of stubbles by the farmers in various ways may also influence the levels of pest inoculum.
- The decomposition of residues alongwith several interrelated factors like climate, crop geometry, irrigation and fertilization, cultural practices and pesticides may affect the survival of insects in crop residues.

- The decomposition of residues brings out a chemical change in the composition of soil which in turn may affect the host's reaction to pests. Secondly, the reduced or no tillage system may affect the population densities of insects which otherwise becomes reduced in number with each tillage operation.
- A change in weed ecology is expected to influence the survival of several of those insects which tend to develop on weeds particularly during fallow and
- Since the zero/reduced tillage system reduces the fallow between crops, a change in sowing period of the following crop may result in altered incidence of certain insects.

These IPM concerns are discussed in detail here.

Crop residues as survival habitat for insects

An important aspect of pest life history is the strategy for survival in the period in which either host plant is not available or the climatic conditions are unfavourable for their proliferation. Insects generally pass through unsuitable conditions by way of using different mechanisms. While the oligophagous and the polyphagous species have a range of hosts to survive on, the monophagous ones mainly use the mechanisms of dormancy. The ability of many coleopterans and hemipterans to survive for long helps them to overcome the adverse conditions. The adults of several generalist species are active fliers and thus have little difficulty in locating the alternate hosts. Most rice stem borers pass through unfavourable periods in a restive stage called diapause (aestivation or hibernation). The survival habitat for such tissue borers are mostly the post-harvest crop residues. The cropping system also greatly influences the survival of these insects in crop residues. Reduced tillage systems particularly under staggered planting system of crops like rice in monoculture may contain comparatively high levels of pest inocula than the conventional system. The stem borers of rice overwinter in the stubble of rice crop. After the harvest of crop, the larvae of pink stem borer *S. inferens*, yellow stem borer *S. incertulas*, striped stem borer *C. suppresallis* and white stem borer *S. innotata* seek refuse in the stubble. While, the last three species undergo hibernation and stay there unnoticed, the larvae of *S. inferens* may damage the wheat crop even upto maturity in subtropical semi-arid region. Hence, in rice-wheat cropping sequence this is the only borer species, which damages both the rice and wheat crops. In Orissa, medium and upland rice crops stubble contain both *S. incertulas* and *C. suppressalis* in equal proportion, while in deep water rice stubble the former is the only hibernating species. Interestingly in *C. polychrysus* no dormancy or diapause has been reported, and the overlapping generations may occur throughout the year.

The stem borer larvae generally hibernate during October-March in subtropics. This follows a pupa stage lasting April. The moth emergence normally takes place during April-May most of which perish while searching for the host. Ploughing of wheat fields immediately after harvest exposes the larvae/pupae to hot sun resulting in high mortality. On the other hand, planting of summer rice and availability of volunteer rice in wheat fields during spring season may ensure survival of first generation.

In Pakistan, the fallow unploughed fields and those of oilseeds, lathyrus, chickpea and berseem when planted with minimal tillage represent the major overwintering sites of rice stem borers. Our studies have revealed that the larvae of *Scirpophaga* spp. usually overwinter in the basal part of rice stubble. Migration of larvae to underground stems seems to be an adaptation to their specialized feeding. Ploughing/harrowing of fields immediately after harvest of crops kills most of these hibernating/aestivating individuals as also prevents unwanted crop re-growth which helps perpetuate several insect species. Stubble plough down kills the ratoon to stop pest cycles. Turning the soil over crushes insects, buries them, destroys their nests and exposes them to desiccation and predators. Tillage can be performed most frequently in irrigated and dryland agriculture. Many soil dwelling pests and those hiding in underground stubble become reduced in number with each tillage operation. Land preparation by ploughing and planking controls dormant tissue borer larvae before they emerge as adults. Hence, tillage practices and the crop following rice greatly influence the survival of these larvae. In Pakistan, Majid (1983) reported on the survival of hibernating rice stem borer larvae under different cultural practices. While cent per cent larvae were not killed in any of the tillage system, maximum survival was noticed in rice stubble remaining intact in following Berseem crop.

Table 2. Effect of cultural practices on survival of overwintering larvae of rice stem borers

Tillage practices	Live larvae	Dead larvae	Mortality (%)
Fallow – unplowed	29.7	2.0	6.3
Fallow – bullock plowed	13.0	3.3	20.4
Wheat – tractor plowed	21.7	4.0	15.6
Wheat – bullock plowed	10.7	2.3	17.9
Berseem – unplowed	35.0	2.0	5.4
Berseem – tractor plowed	17.3	2.7	13.3
Berseem – bullock plowed	20.7	3.7	15.0
Mean	21.1	2.9	13.4

Source : Majid (1983).

In rice fields under RWCS, we recorded a maximum of 61 species of insects and spiders in north-west Haryana. Of the noxious insect species found, seven were of major economic significance while an additional 12 species were of minor importance to the crop. The population density of all these herbivores was almost similar in the tillage treatments. The rice fields also had wide range of natural enemies. Among the potentially beneficial organisms, 12 were ground and webbing spiders, six parasitic and predatory wasps, seven damsel and dragonflies, four bugs, five beetles, two crickets and one each of earwigs, ants, flies, and grasshoppers. The soil fauna mainly consisted of millipedes, carabids and root weevil. The remaining species were 'neutral' simply taking shelter in the crop and a few of them serving as food for some spiders and bugs. Here, the survival of rice stem borer larvae especially those of yellow stem borer (YSB) was noticed to increase with crop intensification. The fields double cropped with susceptible cultivars like ProAgro hybrid 611 and Traori Basmati in sequence recorded higher YSB population surviving in stubble than those planted with single crop of less susceptible cultivar HKR 126 (Fig. 1). The rapid adoption of double cropping without proper fallow and staggered planting of rice in some districts of Haryana during 1997-2003 infact, may have caused increased incidence of YSB even in non-Basmati rice. The observation gets credence from the reports of Loevinsohn (1984) that in irrigated rice systems around IRRI farms at Los Banos a rise in double cropped area from 39 per cent in 1969 to 99 per cent two years later resulted in significant increases in yellow stem borer incidence. In Bangladesh also, the YSB has been reported to become increasingly prevalent in main season rice due to the expansion of area under irrigated dry season crop which favours build up of this species.

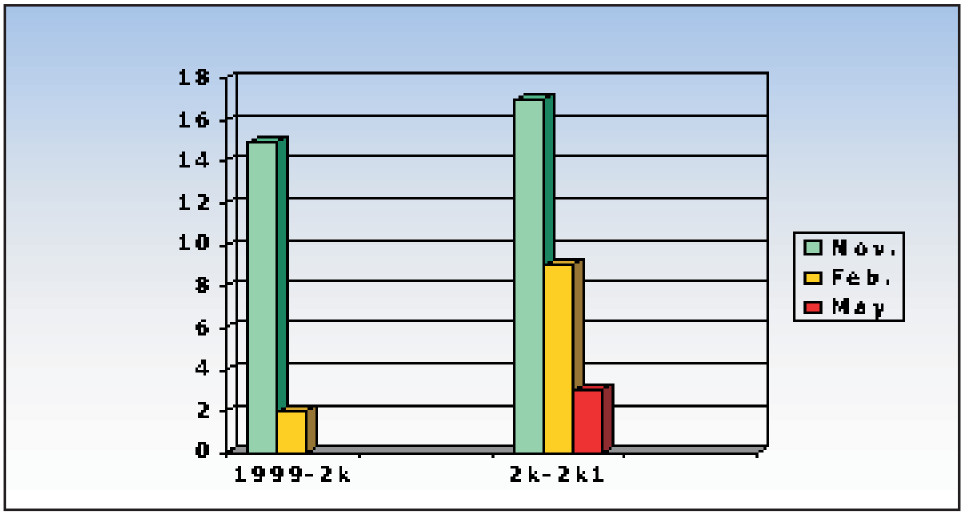


Fig. 2. Maximum no. of yellow stem borer larvae/pupae (15 m^2) in rice stubbles in a zero till wheat field at Kulvaheri in Karnal.

Similarly, a higher survival of pink stem borer (PSB) is also currently being noticed with planting of cultivar HKR 47 (Personal communication) in rice-wheat sequence in Haryana. Our observations have revealed that the retention of straw of this variety in following wheat crop especially in form of a surface cover or when rice panicles are removed superficially with a combine harvester leaving long stubble has resulted in increased incidence of PSB in wheat crop during 2004 at Uchana, while the incidence of YSB at this site varied according to cultivar susceptibility. Therefore, within the framework of our research, any increase in stem borer survival in rice-wheat cropping sequence was seen to be more related to crop intensification, cultivar susceptibility, climate and increased use of N fertilizer than the tillage treatment. 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. In zero-till wheat fields, the YSB larvae as usual occupy the underground stalks of rice, but their number has been seldom abundant to become significant in the next crop. The natural decay and decomposition of stubbles brings out mortality of the hibernating larvae of these stem borers as these cannot survive long apart from the host residues. A critical examination of population fluctuations over a period of past five years in the hibernating YSB larvae in rice stubble located in zero till wheat fields at Uchana has made this evidently clear (Fig. 2). The fall in winter temperature further results in declining 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 larvae also move to the soil under situation of *in situ* burning of rice stubble and straw. Destruction of crop residues is, although, considered a subtle way of reducing the survival and carry over of YSB population from one crop to another, our results indicated that no-tillage method of wheat sowing in rice-wheat sequence may not increase the problem of this borer anticipated to arise by a number of field functionaries and farmers. The discrepancies of reports on the carry over of specialist species in large number to next crop may be due to some specific factors or conditions and hence should not be generalized. In semi-arid environments of Central Queensland, Robertson *et al*. (1994) and Wilson-Rummerie *et al*. (1999) also did not find any increase in pest density under conservation tillage (CT) system.

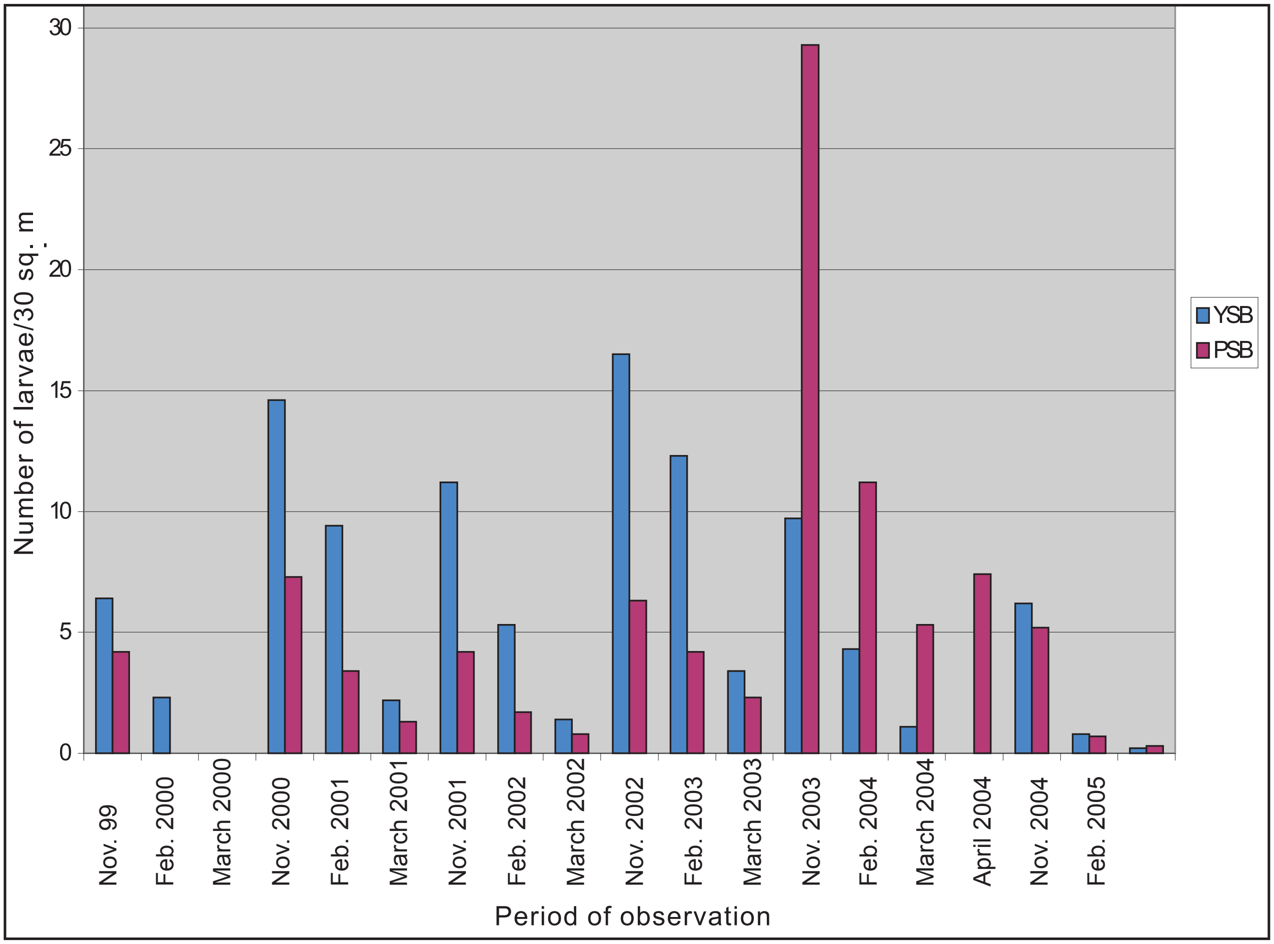


Fig. 3. Population densities of YSB larvae in rice stubbles and PSB larvae in rice stubbles/wheat crop at Uchana during 1999-2005.

Soil dwelling pests under irrigated and dryland agriculture, however, may increase in number under zero tillage. In our studies, sporadic incidences of termites, armyworm (PSB), cutworm (Spodoptera sp.) and rats occurred in a few zero-till wheat fields. With CT, stubble retained in the soil/on the surface ensures food and refuges to these pests. Since termites are major decomposers in forests and agricultural systems, their association with crop residues seems to be quite obvious. The minimum soil disturbances under CT may also be held responsible for their increased incidence. Rats have also shown constant association with crops and crop commodities. Being highly migratory communities under multi-cropping agro-systems, rats keep shifting between crops according to the harvesting schedules of the crops. Armyworm, cutworm and grasshoppers generally seek refuge in the crop residue especially when it forms a surface cover over the soil. In our studies, their problem has been witnessed in those zero-till sown wheat fields where the loose rice straw formed a sort of carpet providing shelter mainly to pink worm larvae which then acted as armyworm, cutting and destroying the young wheat plants. Burning straw and stubble in fields is a common practice with the farmers and is claimed to contain these problems (Alam and Narullah, 1977).

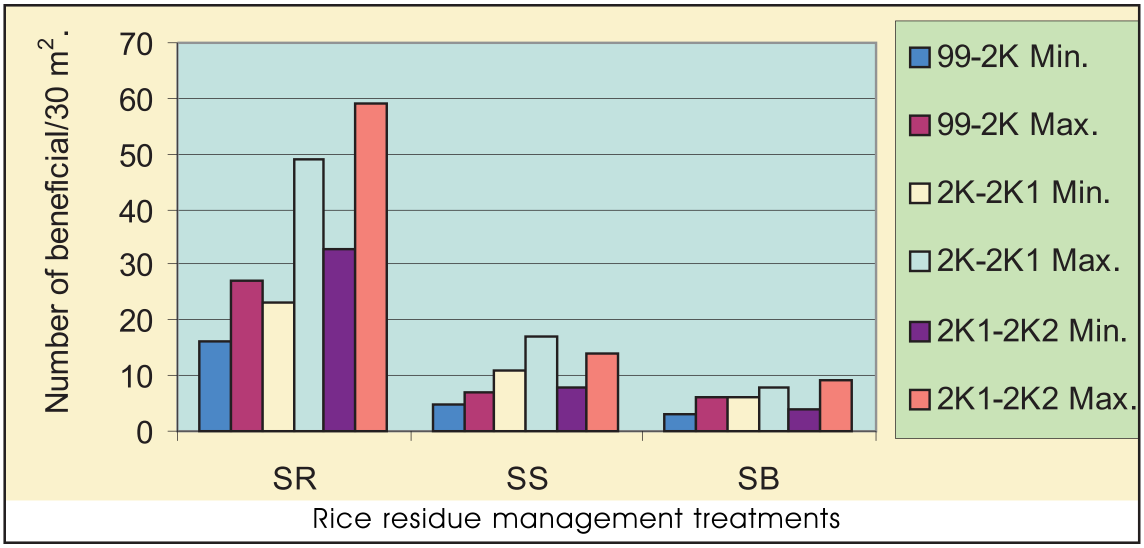
Exposing the straw to sun in hot summer or cool nights in winter is targeted to kill stem borer larvae and may prove as effective as burning. This allows natural enemies to seek shelter to survive (Lim, 1970) as well as conserves nutrients which otherwise would be lost in smoke during burning.

By virtue of rice stubble retention in wheat fields if, zero tillage seems to create environments for the survival of some destructive pests it also has appeared to result in a very conducive environment for the survival of several useful insects because, besides providing shelter to destructive insects, the crop residues, here, have shown to serve as refugia to a number of beneficials. Recently, our studies conducted in collaboration with the Rice -Wheat Consortium (RWC) on species diversity and population density of macro fauna of rice-wheat cropping habitats in relation to modified tillage practices of wheat sowing have indicated that retention of rice stubble in no-till wheat fields immensely enhances the diversity and population density of natural enemies of rice pests, particularly the predatory crickets, beetles, bugs, ants and spiders. The predators occupy in abundance the rice stubble as also the nearby grasses and weeds in the early stages of the wheat crop which subsequently shift to the bases of wheat hills, their number declining gradually during the cold winter months. This fauna, however, remains almost absent in wheat fields sown with conventional tillage or on raised beds.

Our results during 1999-2000 indicated that the zero-till fields at all the five sites in Haryana were substantially rich in beneficial fauna as compared to conventional planting. These differences in the two crop establishments have appeared mainly due to difference in tillage operation and stubble retention. In conventional sowing, the preparation of land through a series of ploughing and planking results in killing of beneficials as also their shifting to vegetation around. Non-availability of suitable conditions or host or both causes mortality of most of this useful fauna. Therefore, in conventionally sown fields the colonization of natural enemies is always quite low and occurs late in the season when most of the pests have already inflicted the damage to the crop. On the other hand, the zero-tillage with stubble intact ensures survival of these organisms and facilitates early colonization of predators in the next crop. Early colonization of natural enemies leading to a higher and timely parasitism of pests, therefore, is of great significance in keeping pest population densities below the economic thresholds. The increase in predator density in zero-till fields may lead to greater predation of pest larvae (Brust *et al*., 1986).

The stubble and open furrows in zero-till fields in which straw was not burnt contained the largest number of predators (Table 3). However, their number declined gradually from December through February under low temperature conditions. The fields in which rice straw was burnt had very little number of beneficials than those with stubble intact. During 2000-01, the population of predators seeking refuse in the stubble varied greatly among the sites (7667 to 16333/ha) and at two sites was higher than the previous year (5333-9000/ha). These include a wide range of predatory spiders (*Oxypes, Clubiona, Tetragnatha, Lycosa),* beetles *(Casnoidea, Paederus, Lemnia, Harmonia),* ants *(Monomorium, Camponotus)*, and some unidentified predatory crickets and bugs. A further substantial increase in natural enemies density (11000 to 19670/ha) particularly of ground beetles was evident in the next year crop. During the early crop season these inhabited the rice stubbles but in the later season with the decomposition of crop residues and fall in temperature shifted to the bases of wheat hills.

Differences in population of predators between no-till and conventionally sown wheat fields were also shown at two sites in Pakistan in the recent past (Rehman *et al*., 2002) Here, the population of predators was comparatively high throughout the study period from 1999-2000 to 2001-02 in wheat fields sown after rice with a no-till drill (without seedbed preparation) compared to wheat fields sown conventionally after proper seedbed preparation. At both the sites the magnitude of difference in the population of predators between no-tillage and conventional method of sowing wheat increased with the passage of time (Table 3). Such differences were comparatively less during the first year (2000), increased in the second year (2001) and further increased in the third year (2002). The difference in the population of predators between the two crop establishments may widen further in subsequent years.



SR–Stubble retained, SS–Stubble shaved, SB–Stubble burnt

Fig. 4. Population density of beneficial in zero-till wheat fields in relation to rice residue management.

Table 3. Most commonly seen predators in rice stubbles during 1999-2003

A. Beetles

(a) Lady-bird beetle

Lemnia sp.

Harmonia sp.

Micraspis sp.

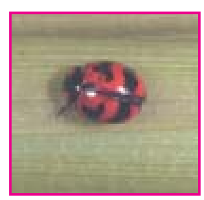
(b) Ground-beetle

Casnoidea indica

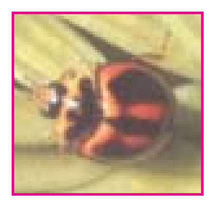
Ophionea sp.

(c) Rove-beetle

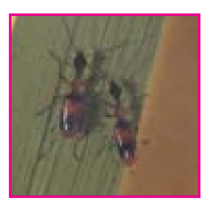
Paederus fuscipes



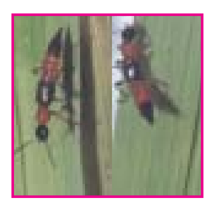
Harmonia sp.



Micraspis sp.



Casnoidea indica



Paederus fuscipes

B. Spiders

Oxypes spp.

Lycosa pseudoannulata

Araneus inustus

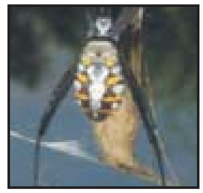
Tetragnatha spp.

Clubiona sp.

Unidentified (*Argiope* sp.?)

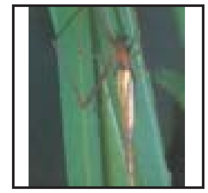
Oxypes sp.

Lycosa pseudoannulata



Argiope sp.

Araneus inustus



Tetragnatha spp.

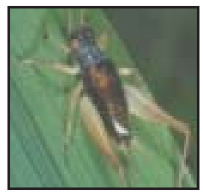
C. Long-horned grasshopper

Conocephalus longipennis

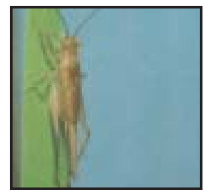
D. Sword-bearing cricket

Metioche vittaticollis

Anaxipha sp.



Metioche vittaticollis



Anaxipha sp.

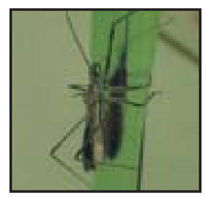
E. Bugs

Microvellia sp.

Cyrtorhinus lividipennis

Assassin bug

Polytoxux sp.



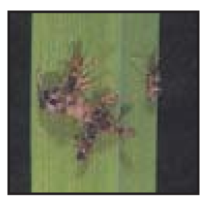
Assassin bug

Microvellia sp.

F. Ants

Monomorium sp.

Camponotus sp.



Monomorium sp.

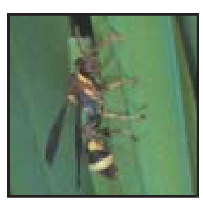
Camponotus sp.

G. Wasps

Ropalidia spp.

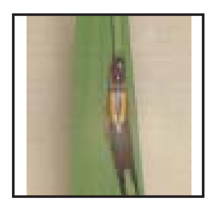
H. Earwigs

Prareus sp.



Ropalidia marginata

Ropalidia fasciata



Prareus sp.

Table 4. Population of predators in wheat crop sown with zero (ZT) and conventonal tillage (CT) after the harvest of rice crop

Month	Number/m^2							
	Spiders		Paederus		Coccinellids		Total	
	ZT	CT	ZT	CT	ZT	CT	ZT	CT
2000								
January	2.6	1.4	2.7	1.2	0.5	0.2	5.8	2.7
February	3.8	1.7	3.5	1.4	0.6	0.3	7.8	3.3
March	3.0	1.1	3.2	1.5	1.3	0.8	7.5	3.4
April	2.6	1.4	2.1	1.3	1.2	0.7	5.9	3.3
2001								
January	3.1	1.5	2.8	1.1	0.5	0.3	6.2	2.7
February	3.3	1.3	3.6	1.7	0.7	0.2	7.6	3.2
March	3.5	1.3	3.2	1.6	1.1	0.7	7.8	3.6
April	3.2	1.9	2.8	1.7	1.8	0.9	7.8	4.5
2002								
January	4.7	1.4	4.1	1.3	0.9	0.1	9.7	2.8
February	4.9	1.3	4.5	1.6	1.3	0.5	10.0	3.3
March	4.8	1.7	4.3	1.5	1.7	1.0	10.8	5.3
April	4.3	2.1	4.0	2.0	2.3	1.4	10.6	5.5

Source : Salim *et al*. (2004).

The population of predators in the rice crop planted after wheat sown with zero tillage was also comparatively higher than when the rice crop was planted after a conventionally sown wheat crop. The availability of natural enemies in the vicinity of rice fields due to their conservation through zero tillage and their timely immigration provides an explanation to this. Early arrival of predators in newly planted rice fields depends on immigration from local sources (Cook and Perfect, 1985, 1989; Heong *et al.*, 1991). Early arriving predators can quickly overtake and keep population of rice insect-pests low (Way and Heong, 1994). It is, therefore, crucially important that key natural enemies should arrive as early as the crop colonizes pests. In conventional system of crop planting, there is minimal chance of the presence of any predators in the fields or in the agricultural matrix as a whole.

The increase in the population of predators in rice fields due to zero-tillage sowing of wheat is of great importance to enhance the activity of predators in suppressing the population/infestation of insect-pests of rice. Emergence of *Glyptomorpha deesae, Chelonus* sp., *Isotima* sp. and *Bracon chinensis* from the overwintering larvae generally coincides with the emergence of the pest. This synchronization could be quite advantageous for the management of the stem borer population as the parasitism of stem borer larvae has been generally higher (Beg and Khan, 1982) under such conditions. Almost all the larval and pupal parasitoids of stem borers and other insect-pests remain in the stubbles after the harvest of rice (Table 5). On the other hand, in conventional method of sowing wheat, due to tillage operations for the preparation of seedbed, rice stubbles are destroyed which result in high mortality of natural enemies.

Table 5. Insect-pests and their natural enemies commonly seen in rice crop sown after zero till wheat crop during 1999-2004

Insect-pests	Predators	Parasitoids	Pathogen
Stem borers	**Long-horned grasshopper**, (*Conocephalus longipennis*) (*Trichogramma japonicum*) **Cricket** (*Metioche vittaticollis*) (*Anaxipha longipennis*)	**Wasp** (*Telenomus rowani*) (*Tetrastichus* sp.) (*Cotesia flavipes*) (*Sturmiopsis inferens*) (*Stenobracon nicevillei*)	White muscardine (*Beauveria bassiana*)
Leaf hoppers and plant hoppers	**Cricket** (*Metioche vittaticollis*) (*Anaxipha longipennis*) **Damselflies and Dragon flies** **Bug** (*Cyrtorhinus lividipennis*) (*Microvellia* sp.) **Long-horned grasshopper** (*Conocephalus longipennis*) **Lady-bird beetle** (*Harmonia octomaculata*) (*Micraspis* sp.) **Wolf spider** (*Lycosa pseudoannulata*)	**Wasp** (*Gonatocerus* sp.) **Big -headed fly** (*Tomosvaryella* sp.)	
Leaf folders and whorl maggot	**Ground beetle** **Damselflies and** **Cricket** (*Metioche vittaticollis*) (*Anaxipha longipennis*)	**Wasp** *(Ophionea* sp.*)* *(Cotesia flavipes)*	
Hispa beetle	**Orbweb spider** (*Argiope* sp.)	**Wasp** *(Trichogramma* sp.*)* **(***Bracon* sp.*)*	
Rice bug	**Assassin bug** (*Rhinocoris* sp.) **Long-horned grasshopper** (*Conocephalus longipennis*)	**Wasp** (*Gryon* sp.*)*	

Effect of cutting heights of straw/stubble on insect survival

The population size of surviving insects in crop residues is also greatly influenced by the cutting height of crops at harvest. Panicle cutting traditionally practised by the farmers ensures maximum survival and carry over of stem borers (FAO, 1979). Stem borer larvae descend to the base of the plants to pass an unfavourable season in a restive stage. How far they descend depends on the pest species. Lowering the cutting height generally results in proportionally more larvae in the removed straw. The highest number is removed when the stubble is cut at the ground level. Therefore, adjusting cutting heights for rice crop grown preceding zero tillage wheat would be an important step in curtailing pest survival and carry over. However, cutting of crops with combine harvesters leaves long stubbles and hence may leave a large population of insects in straw/stubble to carry over to the next crop. Our observations on farmer fields have evidently made it clear that pink stem borer population in rice stubble of those fields where the crop cutting at harvest was done at about 15-25 cm height from the ground level was significantly less as compared to fields in which the stubble height was more than half a meter from the ground level. However, the fields from which straw was removed superficially with the combine harvester had a higher population of predators as well. The data recorded from one of our experiments on stubble management at Uchani (Karnal) showed that stubble height of 30-45 cm supported about four times more natural enemies and twice the pink borer larvae than the plots where the cutting height was 10-15 cm.

After harvesting, the larvae in stubble move towards the base, some of these occupying the underground stalks during cool winter months, while others may attack the wheat crop. The survival of stem borer larvae in rice straw generally ranges from 10-30% depending on the size of stubble cutting (Mahar and Hakro, 1984). The survival is seen to increase with an increase in stubble height. The recent increase in pink borer incidence in rice and wheat may, therefore, also be attributed to wide spread introduction of custom hire mechanical harvesting in rice and wheat. A spill-over of its population from other graminaceous crops available in the agroecosystems further accentuates the PSB problem in the cropping system.

Effects of weeding on insect survival

Many insects, both harmful and beneficial can develop on weeds on bunds, in fallows or that occur in association with crops. Several weeds serve as alternate hosts to a number of insects and diseases. For example rice fields infested densely with wild vegetation may contain higher populations of leaf folders (Kalshoven, 1981), planthoppers (Oka, 1979), root weevils (Ishly, 1975) and Rice hispa (Prakasa Rao and Israel, 1970). Armyworms and grasshoppers (Grigarick, 1984) dwell on grasses on or around the bunds and in fallow fields and shift to crops after border areas are cleaned of grasses. Wild vegetation around crop fields and on bunds also shelter many beneficial species. Biocontrol agents and species diversity are most abundant in weedy fields and not all weeds harbour all pests. Vegetation in areas adjunct to crop fields provide food and shelter to natural enemies the same way as it does to harmful insects. Abundance and diversity of parasites and predators within a field are closely related to the nature of surrounding vegetation (Altieri, 1994). Paddies with weeds on the bunds have the most abundant natural enemies and they are least abundant in paddies without weeds on bunds. Marcos *et al.* (2001) observed natural enemies in close association with broadleaf weeds. Of the 36 weed species recorded on bunds, only seven had insect-pests, while all weed species except *Alysicarpus vaginalis* harbored natural enemies among them. Of the grass species, two contained pest insects. Sedges did not contain any pest insects. The most common predators inhabiting weeds were ants, spiders and beetles. Ants inhabited all the 30 species of weeds, spiders 14 and coccinellids three species.

The levees with grass weeds tend to be an important source of natural enemies of rice pests (Lan *et al.*, 2001). Several factors determine the importance of bunds as key sources of natural enemies (Way and Javier Jr., 2001. The bunds around tropical irrigated rice fields usually support an abundant and diverse ant community with nesting populations limited to the dry land bunds when fields are flooded. Many ants prey on insects in rice fields, both on the canopy and during fallows (Way *et al.*, 1998). Narrow vegetation-covered bunds surrounding each field are important for early arriving species such as spiders and are also an immense source of some predators like *Cyrtorhinus lividipennis* and gryllids that seasonally gather in rice (Way and Heong, 1994). Therefore, certain weeds are important components of agro-ecosystems as they positively affect the biology and dynamics of beneficial insects by way of meeting out their important requisites in form of alternative prey/hosts, pollen, or nectar as well as microhabitats that are not available in weed-free monocultures (Marcos *et al.*, 2001). Herbivore-natural enemy interactions occurring in a cropping system can be influenced by the presence of herbivores on associated weed plants (Altieri and Letourneau, 1982). In our studies, it was observed that soon upon the harvesting of rice crop, several predators migrated to the wild vegetation on the bunds and nearby wasteland apart from their occupying the rice stubbles from where these were seen shifting to the bases of wheat hills during winter months. On these grounds a clean weeding may not be wise.

Planting time shifts and insect survival

The basis for planting time shifts is in the cyclical occurrence of insect stages, as not all stages injure the crop plant. Shifting the planting date will disadvantage the pest when prevalent insect stage is vulnerable to air or water temperature extremes, heavy rainfall, a non-preferred crop growth stage or the abundance of natural enemies (Teetes, 1981). Although there are exceptions, often early plantings escape pest colonization (Pimentel and Goodman, 1978) while late plantings of a crop are benefited by high level of natural enemies and delayed planting by suicidal flights of stem borers in rice. Planting time interactions are greatest if carried out over large areas and against monophagous pests like YSB and WSB that attack one crop stage or are highly seasonal in appearance. Shifting planting time also means growing the crop under unfavourable weather conditions for the pest to proliferate. An early planted crop may also take the advantage of flush of mineralized nitrogen which could either mean greater tolerance to pest damage due to active crop growth or increased susceptibility to pests and diseases. Shifting planting time in an asynchronous area has, however, little effect. Delayed planting until the moths emerged and died termed as 'suicidal stubble flight'- suppresses the stem borers for the entire crop season. Late planting likewise also minimizes incidence of many pests like gall midge, leaf beetles, root weevils, leafhoppers, planthoppers, etc. in rice crop. Pests for which early wheat planting due to zero tillage resulted in low populations are shootfly, *Atherigona oryzae*, aphid, *Macrosiphum miscanthi*, and *Rhopalosiphum maidis.*

Effect of decomposition of residues on insect survival

Plant residues in one form or another and in all stages of decomposition are always present in/on field soils. During the decomposition process of these residues, various organic compounds are produced which exhibit a wide range of properties and may directly or indirectly involve in insect development. The decomposition of plant residues may produce phytotoxic substances particularly during early stages of decomposition (Patrick *et al.*, 1963). The effects might be severe in reduced tillage systems which incorporates huge amount of residues into the soil and extra application of nitrogen is specially made to balance the increased carbon in the soil consequent to quick decomposition of residues. In our studies, the latter situation at some of the farmer fields forced pink stem borer larvae to immediately leave the stubble and shift to wheat during early crop stage where these acted as armyworm, cutting and destroying sporadically the young wheat plants. On the other hand, the incorporation of residues improves soil health by maintaining organic matter. Consequently, this will lead to healthier crop e.g. with the decomposition of residues, certain nutritional substances like silica known to impart resistance to plants against insects and diseases are also released into the soil in favour of plant health. Therefore, under zero tillage of wheat with stubbles of rice incorporated naturally in the soil, this precious element will increase in the soils leading to more resistant crop plants against pests and diseases.

Management of pest-insects under zero tillage in RWCS

There is every indication that innovative cultural practices involving conservation tillage systems will continue to be developed because of a host of benefits these are expected to result in. These practices will be refined and may possibly replace conventional tillage practices of crop production in large areas in the near future. The rapid changeover to reduced tillage systems is exemplified by wheat crop. The significance of the relationship between some insects and abundant plant residues resulting from the reduced tillage operations in rice wheat signals both benefits and risk which are listed as under :

Benefits	Risks
Rice crop	
• Conserves natural enemies. • Reduces the pest risks by enhancing natural control. • Makes the ecosystem more stable. • Creates species diversity. • Reduces the cost of pest control. • Environmentally friendly and ecologically sustainable.	• Rice stubbles inhabit pest stages the incipient populations of which survive and may shift to wheat crop (pink borer, *Chilo* sp.) or to early sown rice nurseries, ratoon sprout, etc. (monophagous species).
Wheat crop	
• Timely sowing reduces the risks of shootfly and aphid damage.	• Sporadic damage occurrences by pink borer, termites, cutworm or armyworm may be encountered depending on the agricultural matrix, cultivar suscepti-bility, climate, cultural practices, carry over.

Our recent observations in wheat crop established in rice residues have indicated that the cutworms, armyworms, grasshoppers and termites especially under conditions where straw is cut to form a surface cover may sporadically damage wheat crop. The point is that the surface residues here provide shelter to these extremely polyphagous species. Thus, the role of residues in the damage occurrences by such insects must be considered and studies made in formulating control measures against pests associated with conservation tillage. Based on the understanding of the effects, a preventive pest management programme that provides conditions to avoid or prevent pest outbreaks or helps maintain pest below economic threshold level or an ecologically sound biointensive management programme focussing mainly on ecological and biological principles be developed and used. Recently, Landis *et al.* (2000) suggested a more holistic conservation biological control which should fit in the requirements of pest control under this conservation tillage.

Integrated biodiversity management (Kiritani, 2000) is another similar option which also looks into the needs for conservation and aims to make the agricultural systems sustainable with a strong ecological base. Following tactics may form an important component of such a pest control programme :

- **Host plant resistance**
- **Cultural, mechanical and physical control**
- **Biological control**
- **Behavioural control**
- **Use of biopesticides**
- **Need based use of safer insecticides in low doses, at early pest stage and preferably through spot applications and seed treatment**

For management of destructive insects in zero tillage system of rice-wheat, a combination of varied control tactics instead of relying on just one tactic should be the approach to plant protection.

Resistant cultivars

The use of resistant cultivars, wherever possible, is to be encouraged. Biotechnology has offered new vistas in developing resistant crop plants. Transgenic plants carrying alpha-endotoxin protein gene from Bt have been successfully attempted in Thailand, China and Japan. The transgenic lines showed high tolerance to both striped stem borer and yellow stem borer. Apart from resistant varieties control of insects in conservation tillage systems may be achieved through changes in plant architecture and developing varieties better suited to zero/reduced-tillage cultural practices. The dwarf varieties with thicker and upright canopy may increase the amount of light intercepted by the plants and reduce egg laying sites or hatching as well. However, the absence of cultivars due to polygenic nature of inheritance and the poor plant type of donors or plant architecture has made pest control presently slightly tedious. The current integrated management strategy in rice, therefore, should currently rely mainly on cultural, biological, behavioural and chemical means, the judicious blending of which has shown promise in keeping the population density of pests below economic threshold levels.

Cultural, mechanical and physical control

A wide range of mechanical, physical and cultural methods are potential practices and their use in reduced tillage will depend on existing alternatives and local conditions. The cultural practices advocated for use on campaign basis include timely and synchronous planting of short stature, early to medium maturing varieties with profuse tillering and grain yield ability, straw/stubble management, balanced fertilization and application of optimal rates of nitrogen fertilizer in split doses. Short crop rotation particularly in areas where contiguous cropping is in practice may be an effective means of controlling insects in rice-wheat system. Ecofallow is an example of controlling some of the pest and disease problems resulting from a monoculture system. Machine or animal drawn rollers can be used to mechanically kill the overwintering population of stem borers in stubbles or to crush the cutworms, armyworms, grasshoppers, crickets hiding under the surface residues. However, this may also kill the predators seeking refuse in the stubble. Some of the meaningful cultural practices that have relevance in management of insects under zero tillage are discussed here.

Avoiding early rice crop

Summer rice in North West India is reported to increase pest problems especially of specialist borer species whenever the planting has coincided with the moth emergence for first brood. The adults of YSB and WSB generally emerge in April-May and most of these head for a suicidal flight in the dry hot summer in the absence of the host. On the other hand, the rice nurseries for summer crop if, available in the vicinity of wheat crop ensure both food and environment for the survival of first generation. Moths generally begin to appear early in the areas which switch to early planting. The moths of these stem borers are active fliers. These are reported to cover a distance of about 5 km in a single flight and thus face little difficulty in locating rice nurseries of summer crop on windy days. Further, in a double or triple cropping system the larvae of stem borer have tended to discard diapause thereby damaging crop for a longer duration than in a single cropping system. On the other hand, reversing to one rice crop in rice wheat sequence would break the life cycles through appropriate diapause stage, resulting into reduced YSB and WSB numbers (Loevisohn, 1994).

Timely planting and maturity period

Timely and synchronous planting of rice lowers the damage occurrences by stem borers, gall midge, brown plant hopper, white backed plant hopper, green leaf hopper while in wheat this reduces chances of infestation by shoot fly and aphids. Early planted wheat crop is also able to tolerate pink borer damage by way of compensatory tillering. Increased damages by this borer have been reported with an expansion in period of wheat sowing. In our experiments at Uchana in 2004, it was observed that wheat planted in end of November 2003 recorded maximum PSB damage (measuring a mean incidence of 12.3 per cent) during mid December 2003 to February 2004 . The infestation gradually declined as the crop attained maturity, the white heads remaining less than one per cent at harvest.

Long duration rice cultivars have shown to encourage stem borers and brown plant hopper and hence should be avoided in reduced tillage systems else management of the stubbles in the following wheat crop becomes important.

Nutrient management

Maintaining desired levels of soil organic matter, enrichment through fully decomposed farm yard manure and compost and balanced use of inorganic sources of macro and micro nutrients aid plants in resisting insect attacks. Judicious and optimum N applications in split doses reduce the risks of stem borers, gall midge, leaf hopper , brown plant hopper, white backed plant hopper, etc. This is targeted to achieve both high yields and low pest incidence. Contrarily, high N use results in increased incidence of pests, reduced yields poor grain quality and high costs of pest control which collectively lower the farmers earning. Farmers also suffer from fertilizer and pesticide related health problems arising out of excessive input use. Therefore, crop-need-based, nutrient especially N application is of utmost importance in enhancing the sustainability of zero tillage system. The inexpensive, simple and easy to use leaf colour chart is the right tool for real time N management in rice crop. Foliar application of micro- and macro-nutrients has vast potential in meeting out deficiencies at low costs and therefore need promotion under IPM.

Zero tillage system in a way is self replenishing as the *in situ* incorporation of rice straw enriches the soil in organic matter and nutrients like silica which have a great role in imparting resistance to plants against insects and diseases. A due care should be taken while further enriching the soil with farm yard manure as an incompletely decomposed FYM could be a source of termite infestation.

Timely harvesting and low cutting heights

Timely harvesting of rice crop at heights of not more than 30 cm from the ground level ensures removal of larvae in the straw adequately before their descending to the bases of plants. Both the practices help reduce the number of diapausing /resting larvae in the anchored stubbles in wheat fields and their carry over to the next crop. Farmers use different stubble management practices such as burning, removal or incorporation under zero tillage. Burning evidently reduces carry over of hibernating larvae but has several deleterious effects and hence should be avoided. Stubble cutting to lower height also reduces the pest inoculum to a significantly low level but shelters lower number of natural enemies than long stubbles.

Tillage operations destroy rice stubbles and the proportion of destruction of stubbles depends on the type of tillage equipment and the number of tillage operations. One operation of a rototiller plus two passes with a cultivator and one of planking cause 99% destruction of rice stubbles (Zafar and Razzaq, 1988). The rototiller destroys rice stubbles completely and kills hibernating stem borer larvae (Table 4). With the conventional cultivator tillage, rice stubbles are not completely destroyed even after several plowings (Inayatullah *et al.*, 1989). However, the effects of tillage vary among the organisms depending on their bio-ecology and hence will not be the same for all insects of rice crop.

Table 6. Effect of different tillage practices on the destruction of stubbles and hibernation of rice stem borer larvae (figures are mean of two years)

Treatment	Stubbles/m^2	Tillers/ stubble	Infested stubble		Larvae/ stubble	Stubble destroyed
			No.	%		(%)
No tillage	138	14	119	86.2	4	-
Cultivator (2)+Plank (1)	41	13	18	43.9	2	70.3
Cultivator (3)+Plank (2)	21	11	2	9.5	1	84.8
Rotavator (1)+Cultivator (2)+Plank (1)	1	3	0	0	0	99.3

Source : Razzaq *et al.* (1997).

Biological control

Use of biocontrol agents is the core component of IPM system. This entails liberation of natural enemies and their conservation. In general, rice fields have rich communities of beneficial that help keep stem borer population densities at economically insignificant levels. Without these beneficials the insect-pests would multiply so quickly, they would completely consume the rice crops. In rice, for each group of insect-pests there are hundreds of natural enemies in the form of parasitoids, predators and pathogens. However, the principal enemies include several parasitoids and predators apart from a few pathogens. Of the promising parasitoids, the most frequently noticed are egg parasitoids belonging to genera *Telonomus, Tetrastichus* and *Trichogramma* and larval and pupal parasitoids from *Braconidae, Elasmidae , Ichneumonidae* and *Tachinidae. Telonomus dignoides* Gohan, *Trichogramma japonicum* Ashmead and *Tetrastichus schoenobii* Ferr. are widely distributed in various rice ecosystems. In Orissa, the natural parasitism by *T. dignoides* is the highest, averaging about 22 per cent with an annual variation from 7-35 per cent followed by *T. schoenobii* and *T. japonicum*. The extent of yellow stem borer, *S. incertulas* in the country varies from 4-97 per cent. Examples of larval and pupal parasites include *Cotesia, Anagrus, Gonatocerus, Gryon, Platygaster, Eulophus, Opius, Temelucha* and *Trichoma*. Innundative releases of egg parasite, *T. japonicum* and *T. chilonis* for YSB and leaf folder control is an effective approach and should form part of the IPM package. Simple, inexpensive and farmers friendly cottage or home production system for the mass production of these egg parasitoids already exists (Jaipal, 2002, 2005) which needs to be commercialized or directly adopted by the farmers. Apart from stem borers, *Trichogramma* spp. are also the common natural enemies for leaf folder. Recently in Panjab, inundative liberations of *T. japonicum* @1,00,000/ha when made eight times during the season resulted into 60 per cent reduced leaf folder incidence than the control plots and proved as effective as the chemical application (Brar, 2000). The most frequently observed parasite of gall midge is *Platygaster oryzae* recording parasitic levels of even upto 90 per cent in the larvae of leaf folder.

Predators are often the most important group of biocontrol agents in rice fields. In fact, these occur in almost every part of the rice crop environment. The long-horned grasshopper, *Conocephalus longipennis* (de Hann) is recorded to feed voraciously on the eggs of *S. incertulas*. The predatory crickets *Metioche vittaticollis* Stal. and *Anaxipha longipennis* Sew and the mirid bug, *Cyrtorhinus lividipenis* prefer to feed on the eggs of *Chilo* species. The coccinellid beetles, *Micraspis* and *Harmonia* spp. and the carabid *Ophinea* devour young larvae of the borers. While water bug, *Microvellia* sp. and ants, are considered good predators of stem borer larvae, the spiders, birds, dragonflies are also seen to prey on adult moths. Leaf hoppers and leaf folders are better controlled by predators like *Cyrtorhinus lividipenis, Coccinella arcuata, Paederus* sp., *Microvellia, Lycosa pseudoannulata* and *Casnoidea indica.*

Natural enemies also have enemies of their own. For example, predators tend to be generalist feeders and several of them are cannibalistic in the absence of host insects. Hence, to maintain populations of beneficials it is essential that populations of pest insects at levels below which they cause no economic damage are also maintained in the fields. The augmentation of most natural enemies particularly the predators is quite uneconomical because it is extremely costly to mass rear predators. Since there are already many natural enemies in the rice fields, they should be conserved firstly by avoiding indiscriminate use of pesticides. Although insecticides may be needed in some cases, these must be used judiciously and selectively in order to maximize the effect of the natural control agents. Provision of refugia and natural (pollen, nectar, host insects) and artificial (sprays of mixtures containing protein and sugar source) foods in agroecosystems help colonise and conserve natural enemies. Habitat diversification through introduction of plant diversity, crop rotation, cover crops, etc. also improves biological control because diverse agroecosystems tend to enhance abundance of natural enemies due to availability of alternate prey, food and suitable microclimate. Organic soil management and low soil disturbance tillage practices enhance the activity of decomposers and hence are also supportive in improving biological control.

Table 7. Some common parasitoids of stem borers

Borer species	Stage attacked		
	Egg	Larva	Pupa
S. incertulas & *S. innotata*	*Tetrastichus schoenobii* *Telonomus rowani* *T. minutum* *Trichogramma japonicum*	*Temelucha philippinensis* *Stenobracon nicevillei* *Isotima* sp. *Bracon* spp. *Goniozus* sp. *Glyptomorpha dessae* *Chelonus* sp. *Rhaconotus oryzae*	*Tetrastichus ayyari*
S. inferens		*Bracon* spp. *Apanteles flavipes*	*Xanthopimpla stemmator*
C. Polychrysus	*T. japonicum*	*Cotesia flavipes* *Propobracon schoenobii*	
C. suppressalis	*Telonomus dignus*	*A. flavipes* *B. chinensis*	*X. stemmator*

Table 8. Some common parasitoids of leaffolders

Leaffolder species	Stage attacked		
	Egg	Larva	Pupa
Cnaphalocrosis medinalis &	*Copidosomopsis*	*Goniozus nr. triangulifer* *nacoleiae*	*X. flavolineata*
Marasmia patnalis	*T. japonicum*	*C. angustibasis* *Cardiochiles philippinensis* *Macrocentrus philippinensis* *Trichomma cnaphalocrosis* *T. philippinensis*	*T. ayyari*

Table 9. Some common predators and parasitoids of brown planthopper and green leafhopper

Hopper species	Predator/parasitoid species	stage attacked
Nilaparvata lugens	*Cyrtorhinus lividipennis*	Egg/nymph
	Lycosa pseudoannulata	Nymph/adult
	Microvelia douglasi atrolineata	Nymph/adult
	Synharmonia octomaculata	Nymph/adult
	Paederus fuscipes	Nymph/adult
	Anagrus spp.	Eggs
Nephotettix spp.	*L. pseudoannulata*	Nymph/adult
	C. lividipennis	Egg/nymph
	Tetragnatha spp.	Adults
	Oxypes spp.	Nymph/adult
	Gonatocerus spp.	Egg
	Tomosvaryella spp.	Nymph/adult

Other important interventions and manipulations required to conserve beneficials are :

- **Burning of crop residues *in situ* in the field should be abandoned.**
- **Growing alternate crops at appropriate sites :** The population of predators is higher in rice nurseries located near Egyptian clover, alfalfa and sorghum fields. By growing such crops in the vicinity of zero till sown wheat fields, it seems possible to increase the population of predators in following rice crop.
- **Strip cutting of crops :** The wheat crop cutting should begin at the farthest end and proceed towards fields of rice nurseries or fodder crops, such as Egyptian clover, alfalfa and sorghum. In this way, the bio-control agents move from the harvested portion of the field to the above cited crops from where these finally shift to rice crops and the cycle continues, thus ensuring their survival in the cropping system.
- **Creating shelter for natural enemies during unfavourable season :** In China keeping rice bundles in the vicinity of harvested rice fields is an age old tradition targeted to shelter the natural enemies during adverse weather conditions. These heaps are important for the carry-over of certain species of predators during the winter months, and their usefulness can be harnessed in conservation of beneficials by making small modifications. In RWCS, the rice stubbles remaining intact in zero till sown wheat fields in itself create natural shelter for beneficials to survive thereby saving on artificial modifications.
- **Wild vegetation during off season be left to grow around crop fields** (on bunds and other wasteland).

Sampling, survey and surveillance are basic to maximizing the impact of predators and parasitoids. Recognition of pests and the natural enemies and maintaining their inventory is the first step. Sampling for the composition of pest and natural enemies and their seasonal and relative abundance is the next step which is very important in decision making. Field studies of both pests and natural enemies may lead to the development of practical pest surveillance and forecasting techniques. After going through the procedures of sampling, survey and surveillance the final step is demonstrating the impact to the farmers. It is our firm belief that our understanding of the natural biological control in RWCS in the past five years span will help the rice-wheat farmers in harnessing the benefits this natural biological resource.

Chemical control

Need based application of safer pesticides is the most crucial component of IPM as their non-judicious usage in crops has led to catastrophic impacts on populations of both destructive and beneficial insects. According to Way (1977) under IPM the pesticides should be used in integration with other methods to avoid predictable economic loss while keeping in view the socio-economic considerations. The economic threshold levels entailed in Table 10 should be precisely considered before making pesticide applications.

For effective use of pesticides, a detailed knowledge of their formulation, dosage, time and method of application and past history of their inducing resurgence are key factors in achieving successful control. Some important aspects of judicious chemical control in reduced tillage under RWCS are discussed underneath :

Table 10. Economic threshold levels (ETLs) of major insect-pests of rice at different locations in India

Insect-pest	ETLs	Location (State)
I. Planting to pre-tillering stage		
Stem borer	5% dead hearts	Chinsurah and Kharagpur (West Bengal), Cuttak (Orissa), Hisar (Haryana), Hyderabad (A. P.), Kapurthala (Punjab).
	One egg mass/m^2	Chinsurah (West Bengal), Hyderabad and Warangal (A. P.)
	One moth/ m^2	Chinsurah (West Bengal), Hyderabad (A. P.)
Gall midge	One gall/m^2 in endemic areas or 5% affected tillers in non-endemic areas	Hyderabad (A. P.)
	5% affected tillers	Chinsurah (West Bengal)
	2-3 galls/ m^2	Kharagpur (West Bengal)
Leaf folder	One damaged leaf/hill	Hyderabad (A. P.)
	One larva/hill	Hisar (Haryana)
	One adult/ hill	Hyderabad (A. P.)
Hispa	One adult/hill	Hyderabad (A. P.)
	One grub/hill	Hisar (Haryana)
	One damaged leaf/hill	Cuttak (Orissa), Hyderabad (A. P.) Kharagpur (West Bengal)
Whorl maggot	20% damaged hills	Hyderabad (A. P.)
	25% affected hills	Warangal (A. P.)
Green leafhopper	2 insects/hill in tungro endemic area 10 insects/hill in non-endemic areas	Hyderabad (A. P.)
	2-3 insects/hill in tungro endemic areas, 20-30 insects/hill in non-endemic areas	Chinsurah (West Bengal)
Whitebacked	10 insects/hill	Hisar (Haryana), Hyderabad (A. P.)
planthopper	5-10 insects/hill	Kapurthala (Punjab), Kharagpur (W. Bengal)
Brown	10 insects/hill	Warangal (A.P.)
planthopper	5-10 insects/hill	Kharagpur (West Bengal), Hyderabad Kapurthala (Punjab)
Rice root	3-4 insects/hill	Chinsurah (West Bengal)
weevil	1-2 grubs/plant	Hisar (Haryana)
II. Mid tillering		
Stem borer	5% deadhearts	Chinsurah (West Bengal),Cuttak (Orissa), Hisar (Haryana),Hyderabad (A. P.) Kapurthala (Punjab)
Gall midge	5% affected tillers	Cuttak (Orissa), Hyderabad (A. P.) Kharagpur (West Bengal)
	2-3% gells	Chinsurah (West Bengal)
Hispa	One adult/ hill	Hyderabad (A. P.)
	1-2 damaged leaves/hill	Hyderabad (A. P.)
	One damaged leaf/hill	Cuttak (Orissa), Kharagpur (West Bengal)
Brown planthopper	5-10 insects/hill	Hyderabad (A. P.), Kapurthala (Punjab), Kharagpur (West Bengal)
Whitebacked	10 insects/hill	Warangal (A. P.)
planthopper	5-10 insects/hill	Cuttak (Orissa), Kapurthala (Punjab)
	10 insects/hill	Cuttak (Orissa), Hisar (Haryana), Hyderabad (A. P.)

Insect-pest	ETLs	Location (State)
Green leafhopper	20 insects/hill	Hisar (Haryana), Hyderabad (A. P.)
	25 insects/hill	Warangal (A. P.)
Case worm	1-2 ceases/hill	Hyderabad (A. P.), Kharagpur (W. Bengal)
Leaf-folder	1-2 fresly damaged leaves/hill	Hyderabad (A. P.), Kharagpur (W. Bengal)
	1 damaged leaf/hill	Cuttak (Orissa)
	One larva/hill	Hisar (Haryana)
III. Panicle initiation to booting		
Stem borer	One moth/m^2	Hisar (Haryana), Kharagpur (W. Bengal), Hyderabad (A. P.)
Leaf-folder	1-2 fresly damaged leaves/hill	Hyderabad (A. P.), Kharagpur (W. Bengal)
	1 larva/hill	Hisar (Haryana)
Green leafhopper	20 insects/hill	Hisar (Haryana), Hyderabad (A. P.)
Brown planthopper	5-10 insects/hill	Hisar (Haryana), Hyderabad (A. P.) Kharagpur (W. Bengal)
	10 insects/hill : 25 insects if mirid bug/spiders are active maintaining a ratio of 1: 5 with BPH	Warangal (A. P.)
Whitebacked planthopper	5-10 insects/hill	Hisar (Haryana), Kapurthala (Punjab) Hyderabad (A. P.)
	10 insects/hill	Hisar (Haryana)
IV. Flowering and after		
Stem borer	One moth/m^2	Chinsurah (W. Bengal), Cuttak (Orissa), Hisar (Haryana), Hyderabad (A. P.), Kharagpur (W. Bengal)
	One egg mass/m^2	Chinsurah (W. Bengal), Cuttak (Orissa)
	2% white heads	Chinsurah (W. Bengal)
Brown planthopper	5-10 insects/hill	Hyderabad (A. P.), Kapurthala (Punjab) Kharagpur (W. Bengal)
	20-25 insects/hill	Chinsurah (W. Bengal)
	10 insects/hill : 25 insects if mirid bug and spiders are active maintaining a ratio of 1: 5 with PBH	Warangal (A. P.)
Whitebacked planthopper	5-10 insects/hill	Kapurthala (Punjab), Kharagpur (W. Bengal)
	10 insects/hill	Hisar (Haryana)
Armyworm	One caterpillar/hill	Chinsurah (W. Bengal)
Gundhi bug	One bug/hill	Hyderabad (A. P.), Cuttak (Orissa)
	1-2 bugs/m^2	Hisar (Haryana)

Use of selective and safe insecticides

Rice fields have rich communities of beneficials. To avoid their destruction while controlling the harmful ones, use of insecticides which are inherently more toxic to the target pest should be done. This kind of pesticides are, however, limitedly available. Alternatively, it is always better to use insecticides with a moderate toxicity than one with acute toxicity to target pest if the former ensures safety to natural enemies. *Neem* derived pesticides have been shown to offer moderate control of a number of rice insects. This botanical, in different formulations, has also been reported safe to the predominant natural enemies. In rice, therefore, Neem and other botanicals with reasonably good efficiency against the rice pests need to be promoted. Some broad insecticides like monocrotophos, malathion, diazinon are comparatively safer to a number of predators like *Lycosa, Cyrotorhinus* , *Harmonia Paederus*. Granular soil applications have been found more safe to rice beneficials than foliar application. Their applications in various formulations in standing crop have proved more effective against various rice pests especially the stem borers and leaf folders. Incorporating granules of carbofuran at last harrowing during field preparations have given effective control of whorl maggot, brown plant hopper, green leaf hopper and rice weevils (IRRI, 1979).

Seed, seedling and spot applications

Soaking sprouted rice seeds or coating wheat seeds with insecticides or dipping rice seedling roots in insecticides such as chlorpyriphos 0.02 per cent provides protection against soil pests like termites root grubs and weevils. Similarly, spot treatment may be considered for application in rice nurseries, treating hot spots for the pest breeding, trap crops and border applications around the crop fields as required in case of leaf folder and grass hoppers. This minimizes the pesticide quantity as also the pesticide induced effects in the crops and environment and safety to natural enemies.

Timing of application

Pesticides are generally more effective when used against the pest in young susceptible and nascent stage e.g. the most appropriate time for stem borer control is the first stage larvae whilst for brown plant hopper it is the third instar nymph and for hispa it should be done at adult stage. Timing pesticides application rightly saves in quantity of pesticide used and is also safe to the natural enemies (Heinrichs, 1979).

Microbial pesticides

There is need to introduce microbial biopesticides because of a number of advantages associated with their usage. A number of *Bacillus thuringiensis* based formulations are now easily available in the market. Indigenous white muscardine Beauveria bassiana strains have also been found effective against a number of rice pests. Cottage production system utilizing industrial wastes has been developed for the cheap and easy multiplication of the fungus (Siwach and Jaipal, 2003; Jaipal, 2004). In our laboratory bioassays the fungus has offered more than 90 per cent control of YSB when application was made at young larvae stage (Siwach and Jaipal, 2002).

Behavioural management

For integrated management of pest insects, behavioural tactic has also shown vast potential as pest monitoring tool or as attractant/mating disruption tactic. The behaviour modifying chemicals, identified from *S. incertulas, C. suppressalis* and *S. inferens*, are non-toxic, biologically active and specific in action and have been found effective in managing yellow stem borer through mating disruption. A mixture of yellow stem borer pheromones when used in different proportions in polyvinyl formulation, reduced its damage by disrupting communication in male moths as effectively as the insecticide treatment. Field rials conducted recently in Uttar Pradesh and Uttaranchal State in India have revealed the male annihilation technique a successful method for the management of YSB in any coarse or fine grain rice variety. The damage during tillering or maturity stage was below economic threshold level in either of the varieties which did not warrant chemical application. There are several factors like the quality of trap and its design, quantity of the lure, installation height and time of installation and climate which govern the performance of pheromone traps should be attended for achieving success of the programme.

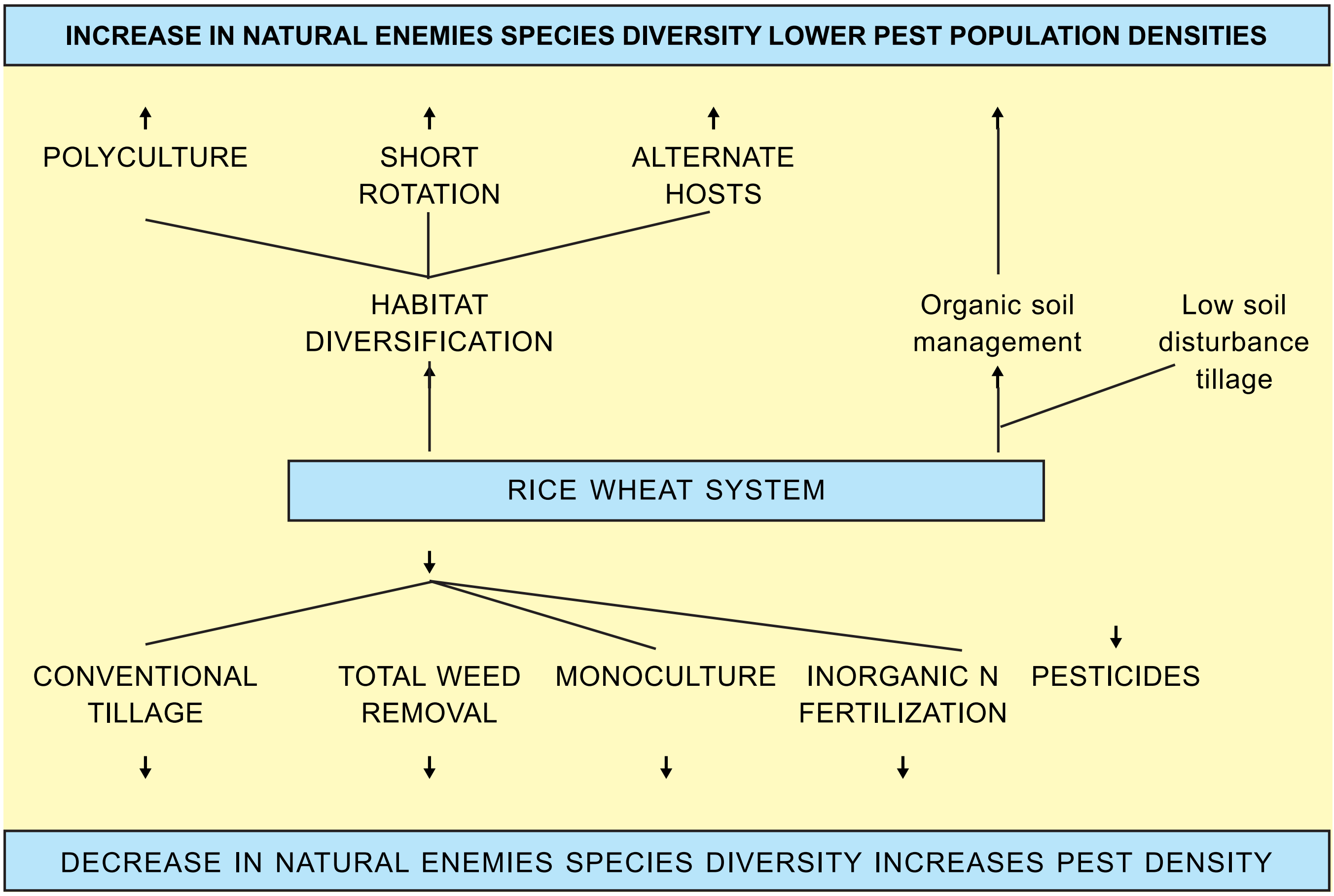


Fig. 5. Impact of cultural practices on abundance of pests and natural enemies in RWCS.

For making IPM technology workable in conservation agriculture, a holistic approach based on pest and crop ecology has to be rigorously followed by integrating appropriate and yet safer and environment-friendly alternatives to insecticides. It would also require the active co-ordination and co-operation between research organisations, Government agencies, extension linkages and NGO's to promote the preventive IPM concepts under CA, disseminate the technologies and educate the masses on campaign basis regarding the objectives of IPM. A policy environment conducive to IPM, which discourages use of pesticides, is very important under CA systems. Human resource development is also a very crucial aspect and should receive special consideration. Funding for IPM projects from national and international agencies is crucial and needs immediate attention. There are nearly always exceptions so local conditions and knowledge have to be considered. The practicality of different practices must also be considered in light of the farmers circumstances and the effect of the practice on farmer's profit and lifestyle. The future research and development issues for pest management in CA systems should involve :

- Regular monitoring of the system through survey, surveillance and sampling
- Developing GIS based systems of monitoring

- Minimizing use of hazardous pesticides and promoting need-based use of safe and selective pesticides in low doses and more as spot application and seed treatment
- Promoting use of biopesticides, bioagents, lures, botanicals, etc.
- Developing cultivars suited to CA systems
- Increasing diversification
- Emphasising conservation of natural enemies and enhancing biological control
- Development of location based IPM packages for a host of pests
- Empowerment of farmers through farmers participatory approach, travel workshops, trainings on IPM, biodiversity conservation and preventive control

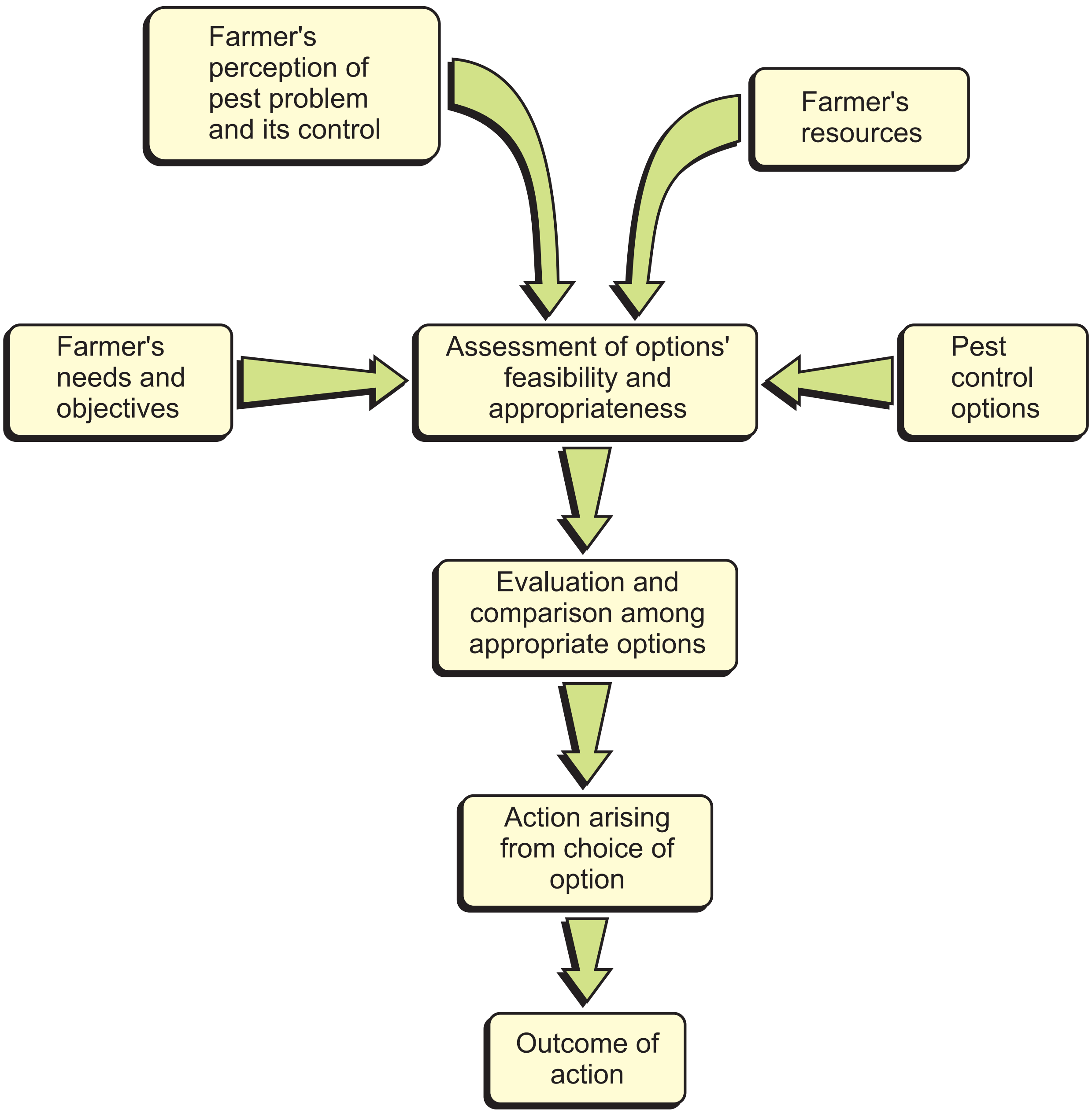


Fig. 6. The process of decision making in IPM (After Reichelberfer *et al.*, 1984).

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Zero-tillage sowing in wheat conserves natural enemies, reduce the risks of pest outbreak by enhancing natural control, creates species diversity which makes the ecosystem more stable, thereby reducing the cost of pest control. The method is environment friendly and ecologically sustainable.