Review Article

Role of intercropping in sustainable Insect-pest management: A Review

ABSTRACT

Reduced soil fertility and rising pest and disease pressures are contributing to the already serious problem of global food insecurity. Monoculture is the most labour and resource-intensive form of crop production around the globe. Unfortunately, monocultures are more vulnerable to pests, diseases, and weeds, so the expansion of this system is accompanied by a host of biological issues. Negative effects on the environment, human health, and ecosystem stability are all associated with monocropping because it relies so heavily on the use of chemical plant protection products of all generations of pesticides. Although crop production strategies are important for overall enhancement in production, the intercropping can help farmers in attaining raised economic returns by taking multiple crops in a single season. Intercropping is an alternative strategy for improved resource use efficiency, environmental safety, and sustainable pest management without the use of chemical pesticides that can help mitigate these risks. Intercropping (two or more crop species coexisting) is a cultural practice in pest management that reduces insect pests by increasing ecosystem diversity. Intercropping and planting crops that kill or repel pests, attract natural enemies, or have antibacterial effects can reduce disease and pest damage and pesticide use. Intercropping, where crops grow between main crops, reduces the likelihood of pest infestation. Intercropping is a potential pest management practice because it diversifies crops in an agro-ecosystem to reduce insect populations and attacks. Intercropping relies on a deep understanding of insect ecology and crop traits. Intercropping can be used alone or in combination with host-plant resistance and biological control. Intercropping ensures crop yield stability, protects against crop failure, improves soil fertility, increases soil conservation, and reduces pesticide use, minimizing agriculture's environmental impact. The aim is to define the role and importance of intercropping as a strategy in crop pest management and as a boost for crop production vis-à-vis soil fertility.

Keywords: Environmental impacts, Intercropping, Pesticide, Sustainable pest management, Insect ecology, Environmental safety, Pest infestation.

1. INTRODUCTION

A doubling (100-110%) of crop production relative to its 2005 level is required to feed the 9.6-12.3% increase in the global population by 2100 [1, 2]. Losses of 10-16% of crop production due to pests [3, 4] pose a real threat to entire world regions and significantly reduce agricultural yield [5, 6, 7, 8]. Furthermore, there is growing

concern that climate change will cause an increase in plant damage from pests in the coming decades [9, 10, 11]. Global yield losses of rice, maize, and wheat grains are projected to increase between 10 and 25% per degree of global mean surface warming. The average increases in yield losses due solely to pest pressure amount to 59, 92, and 62 metric megatons per year for wheat, rice, and maize, respectively, in a projected scenario of a 2 °C warmer climate [12].

Alternative control methods within the framework of integrated pest management (IPM) have gained popularity as a result of the negative effects of synthetic pesticides [13] on the environment and human health [14], as well as reduced efficacy due to resistance within pest populations [15]. The "push-pull" strategy and the introduction of biological control agents are two common IPM systems that are widely used to achieve long-term control [16, 17]. One important aspect of push-pull strategies is the use of volatile plant compounds to influence insect behavior [18, 19, 20]. Volatile compounds produced by plants are used by insects to identify and locate potential food and breeding plants [21, 22]. So, non-host plants (e.g., aromatic plants) can be used to create insect repellents, anti-feedants, or insecticides because they release volatiles with repellent or deterrent properties in response to an attack [23, 24]. However, the 'appropriate/inappropriate landings theory' suggests that the presence of non-host plants may interfere with host-plant finding and host-plant acceptance behavior by giving insects a choice of green surfaces on which to land (host and non-host plant leaves) [25, 26]. Attracting natural enemies to the area through intercropping, particularly with aromatic plants [27, 28], providing food resources [29, 30, 31], or providing shelter and oviposition sites can all increase the efficacy of biological control. It is important to evaluate the effects of intercropped plants on both pests and natural enemies in order to optimize pest control in intercropping systems [32]. In this regard, an attempt was made to scrutinize the available literature and collect the information on the research carried out on intercropping worldwide over a period of time and look for the possible insights for future research in this domain.

Improving crop yield and income through intercropping is a time-honored agronomic practice [33, 34, 35, 36, 37, 38]. To reduce the prevalence of pests and diseases and to encourage the growth of natural predators, it is an extremely useful strategy [39]. Reducing the damage caused by diseases and pests and lowering the need for pesticides can be accomplished through the strategic use of intercropping and the planting of crops that can kill or repel pests [40, 41], attract natural enemies [42, 43, 44], or possess antibacterial effects in between the rows of economic crops [45, 46, 47, 48]. Intercropping, which promotes plant diversity, can boost crop productivity and ensure greater and more consistent yields, bringing additional economic benefits [49]. As a result, it provides more financial security than monoculture and is thus well-suited to small farms that require a lot of human labor. As an added bonus, intercropping reduces the need for fertilizer and pesticides [50], lessening the negative effects that agriculture has on the environment and allowing for more effective biological insect pest management.

2. OBJECTIVES OF INTERCROPPING: The major objectives of intercropping include:

1. Intercropping is aimed at production maximization under limited land availability
2. It can serve as an alternate for generation of additional increome through crop diversification.
3. It can serve as a soil fertility booster by improving the soil microflora and ecological diversification in soil.
4. It can help in minimizing the dependency on chemical fertilizers especially under legume intercropping system through improvement in soil fertility status and nutrient utilization capacity.

5. It can serve as a potential alternative for enhancing land use efficiency by occupation of limited arable land under diverse crops.

3. PROBLEMS ASSOCIATED WITH MONOCROPPING:

Monocropping is the utilization of same land for single crop year after year. The concept is ideal for crop production but needs favorable conditions and may require higher production costs. However, the bottlenecks still remain as it does not provide any insurance under a complete crop failure owing to weather adversities or incidence of pests and diseases. The problems associated with monocropping include:

3.1. Higher pest infestation: Due to the lack of genetic diversity of plants, pests thrive on farms where only one type of crop is grown year after year [51]

3.2. Higher pesticide use: Reduced biodiversity makes monoculture crops more vulnerable to pests and diseases, prompting a higher reliance on pesticides to protect the crop, which in turn increases the likelihood of pest resistance [52, 53].

3.3. Soil degradation and fertility loss: The delicate equilibrium of soils is disrupted by monoculture farming. Growing the same crop year after year depletes soil nutrients and leads to a decline in the diversity of bacteria and microorganisms [54].

3.4. Higher use of fertilizers: Growing only one type of crop on a given plot of land eventually depletes and exhausts the soil because it has no living organisms to replenish its natural diversity. Farmers often use chemical fertilizers, which disrupt the delicate balance of the ecosystem by altering the soil's natural composition, to artificially increase the fertility of their degraded fields [55].

3.5. Higher water use: If only one type of crop is grown on a piece of farmland, the soil will deteriorate and water will be wasted because the root systems aren't strong enough to hold the soil together. This is why such farmlands have an uneven distribution of water after rainfall. It is necessary for farmers to increase their water consumption to compensate for this loss.

3.6. Decrease in biodiversity: As a result of the overuse of chemical pesticides in monoculture, biodiversity declines, and the ecosystem as a whole suffers.

3.7. Negative impact on pollinators: As pesticide use increases in monoculture, pollinating insects become sicker and eventually die off, and their absence from the ecosystem is a direct result. The use of chemicals has a serious impact on pollinizers and therefore it is often recommended to avoid chemical sprays during bloom.

3.8. Economic risks: In the event of a catastrophic failure in crop development, such as an unusually long drought, unusually heavy rainfall, or an infestation of a particularly virulent strain of a pest, for example, a monoculture farm could lose its entire harvest all at once [56].

3.9. Environmental degradation: Chemicals are overused in monoculture, leading to environmental degradation. These chemicals not only deteriorate the soil health but also lead to deterioration of soil micro biota especially the beneficial microbes [57].

4. PESTICIDE CONSUMPTION IN WORLD AND INDIA:

Pesticides are the chemical or mixture of chemical substances aimed to prevent or destroy the losses due to biotic species likewise weeds, diseases, insects, etc., by mitigating the target pest. A pesticide is typically a chemical or biological agent, such as a virus, bacterium, antibiotic, or disinfectant, that discourages, renders ineffective, or kills pests. It is frequently applied to get rid of or manage a wide range of agricultural pests that can harm livestock and crops and lower farm output. Global production and use of pesticides are on the rise (Fig. 1) production of BHC began in India in 1952 at a plant in Calcutta, and today India is the largest producer of pesticides in Asia after China and the twelfth in the world, according to the Food and Agriculture Organization. Technical grade pesticide production in India has increased steadily from 5,000 metric tonnes in 1958 to 102,240 metric tonnes in 1998. In 1996–97, it was estimated that worldwide demand for pesticides would reach Rs. 22 billion (USD 0.5 billion), representing roughly 2% of the total market [58]. The graph shows that in the last seven decades, pesticide use in India has increased hundreds of times, from 154 MT in 1953-54 to 57,000 MT in 2016-17. India used 80,000 MT of pesticides in just one year between 1994 and 1995 [59].

The use of pesticides was highest in Maharashtra in 2016–17, followed by Uttar Pradesh, Punjab, and Haryana. Pesticide use was highest in Punjab (0.74 kg per acre), then Haryana (0.62 kg), and finally Maharashtra (0.40 kg) (0.57 kg). Figure 2 shows that the two states of Maharashtra and Uttar Pradesh are responsible for 41% of India's total consumption of pesticides. Collectively, the six most populous states in India use more than 70 percent of the country's crop protection chemicals. Due to rising health and environmental awareness, many people today opt for non-chemical, all-natural alternatives to traditional, synthetic ones. Biopesticide is becoming increasingly popular as a result of its many advantageous properties, such as low toxicity to non-target organisms, high efficiency, rapid biodegradation, and suitability for use in integrated pest management (IPM) initiatives. It's no secret that biopesticides could be used without negatively impacting the ecosystem [60].

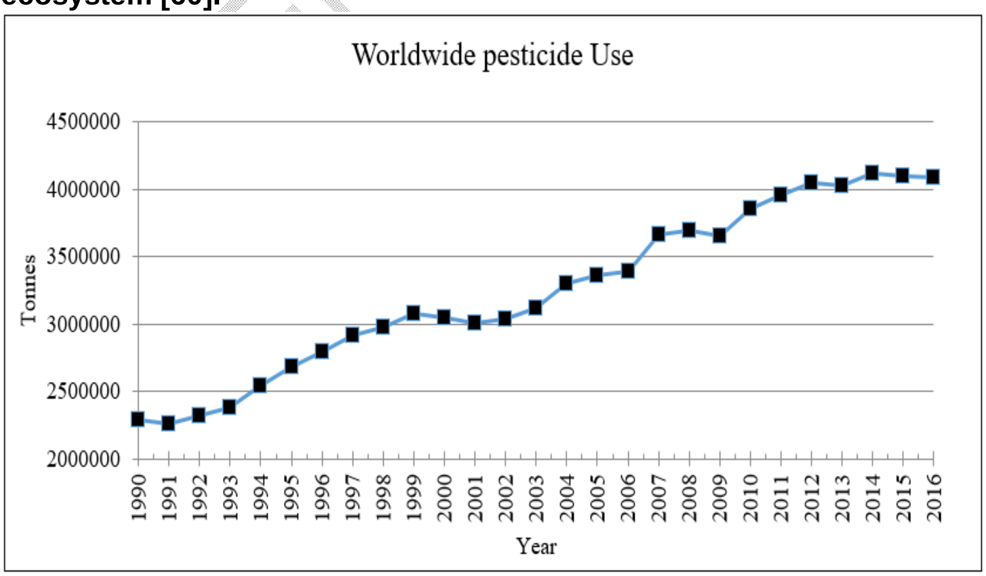

Fig. 1: Pesticide usage and consumption in World.
Source: [56]

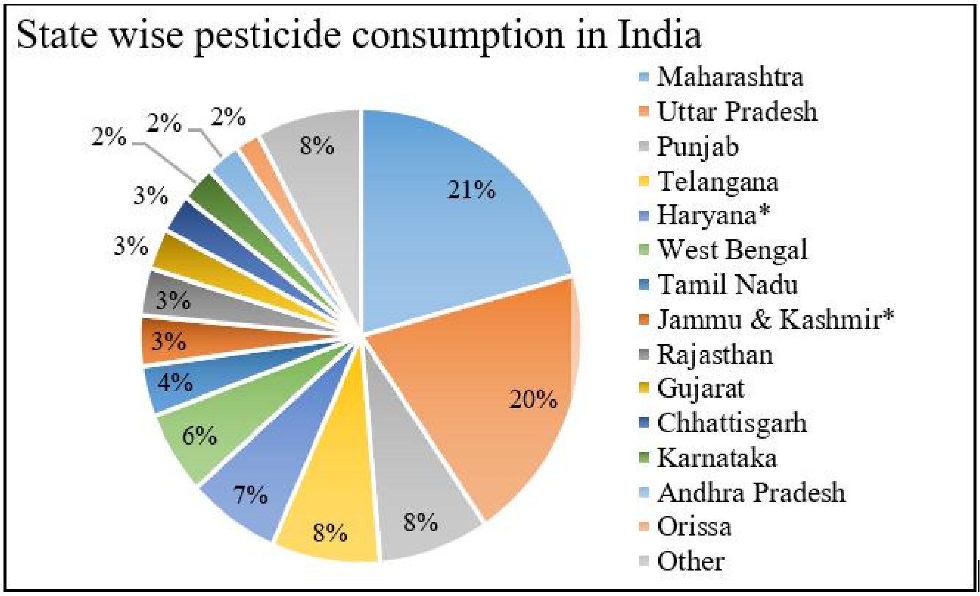

Fig. 2: State wise pesticide consumption in India.
Source: [56]

4.1. Adverse Effects of Pesticides:

- **Pesticides can have a major impact on the production workers, formulators, sprayers, mixers, loaders, and agricultural farm workers and all those who are directly or indirectly exposed. This can cause serious health hazards in humans and may damage the ecological diversity as well. Besides being possible human carcinogens, mutagens, and acetylcholinesterase inhibitors, most of these pesticides cause chronic toxicities like reproductive toxicity, genotoxicity, endocrine disruption, kidney damage, metabolic alterations, liver and bladder toxicity, gastrointestinal problems, etc.[61,62,63]**
- **The effects of pesticides on food commodities as a result of poisoning and increased residue retention on crops is a serious problem especially to the final consumers and the presence of residues in the food products makes the produce unacceptable in the global markets following the strict guidelines from international food standard committees like CODEX Alimentarius Commission, FSSAI, etc., [64,65].**
- **Pollution of water sources and other forms of plant life are just two examples of the environmental effects. Pesticides aren't just bad for the insects and weeds they're meant to kill; they can also be harmful to birds, fish, beneficial insects, and non-target plants.**
- **Surface and subsurface water contamination from untreated plant and soil runoff in addition to detrimental effects on soil health, such as those caused by persistent pesticides.**

- Reducing the population of pollinators and beneficial soil microorganisms can result in a loss of biodiversity, which has an effect on soil fertility.
- Sprays of pesticides can contaminate nearby air, soil, and non-target plants in several ways: by landing directly on the plants, by drifting from the treated area, or by evaporating into the air.

5. Intercropping as an alternative to chemical pesticides for sustainable insect pest management

- ❖ One of the key cultural practices in pest management, intercropping (where two or more crop species are grown together and coexist for a time) is predicated on the idea that increasing biodiversity in a given area will lead to a decrease in the prevalence of insect pests [66]. Therefore, reducing the harm inflicted by pests and diseases and lowering the need for pesticides can be accomplished through the use of appropriate crop pairing for intercropping and the planting of crops that can kill or repel infestations, attract natural enemies or acquire antimicrobial action in between the rows of economic crops. Pests are less likely to infest intercropped crops than main crops. By increasing crop diversity within a given agro-ecosystem, intercropping has a potential to serve as a cultural practice based strategy for pest management by lowering the insect population and the frequency with which it attacks individual plants (Fig. 3).

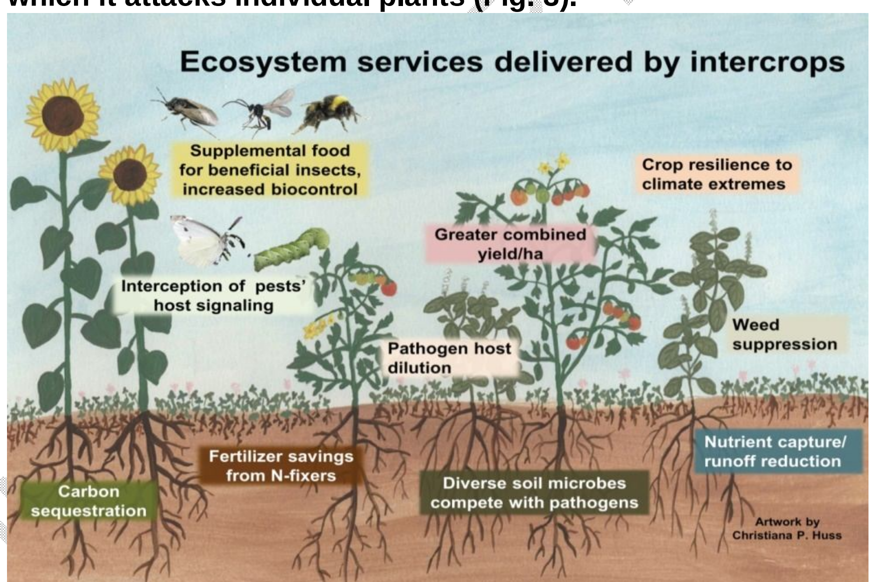

Fig 3: Illustration of benefits of intercropping

6. TYPES OF INTERCROPPING:

6.1. Row-intercropping: Planting two or more crops at once, with one or more crops planted in straight rows and the other(s) planted either next to or at random among them.

6.2. Mixed- intercropping: Concurrently cultivating two or more crops in a field without using a definite row arrangement. This variety has the potential to thrive in pastures where grass and legumes are grown in symbiosis. When you plant a variety of crops together, you fortify your main crop against storms, freezes, and droughts.

6.3. Strip-intercropping: To practice multi-cropping, two or more crop varieties are grown on the same plot of land in narrow strips that are wide enough to accommodate individual plantings but narrow enough to prevent physical interactions between the plants.

6.4. Relay- intercropping: Multiple crop cultivation during a single growing season. Planting a second crop occurs when the first has completed its reproductive cycle but is still a few months away from being harvested.

6.5. Alley cropping: Planting rows of food between hedges, trees, or bushes. The strong root systems of taller plants protect the soil from erosion and provide shade for the roots of shorter plants.

6.6. Trap cropping: The intercropping method is useful for preventing damage to the primary crop by trapping pests. The basic idea is to lure pests or disease-causing organisms to the secondary crops instead of the primary cash crop.

6.7. Repellent intercropping: The use of plants that naturally deter pests is a sustainable method of pest control that can be implemented in this cropping. Certain species are used for their natural repellent properties, which keep predators away from the cash crop.

7. **Mechanisms of reduction in pest incidence by intercropping:**

Reducing the population growth rate of the attacking organism is one of three ways in which associated plants in an intercropping system can mitigate pest or disease attacks.

- ❖ When an associate crop is present, plants of the attacked component suffer (e.g. the host component is less vigorous and smaller in the intercrop than when sole-cropped).
- ❖ By diluting the host plant, the associate crop makes it more difficult for the attacking organism to do its damage-inducing work.
- ❖ The host's environment is altered by the associate crop in a way that benefits the organism's natural predators.

8. **Push-pull agricultural pest management:**

- Intercropping with repellent "push" plants and trap "pull" plants is known as "push-pull technology," and it is used to reduce the number of agricultural pests. Stem borers, for instance, are a common pest of cereal crops like maize and sorghum (Fig. 4). Planting grasses around the crop's perimeter attracts and traps the pests, while planting plants like *Desmodium* in the spaces between the maize rows deters pests and helps keep *Striga* under control. The ICIPE in Kenya and Rothamsted Research in the United Kingdom created the push-pull system.

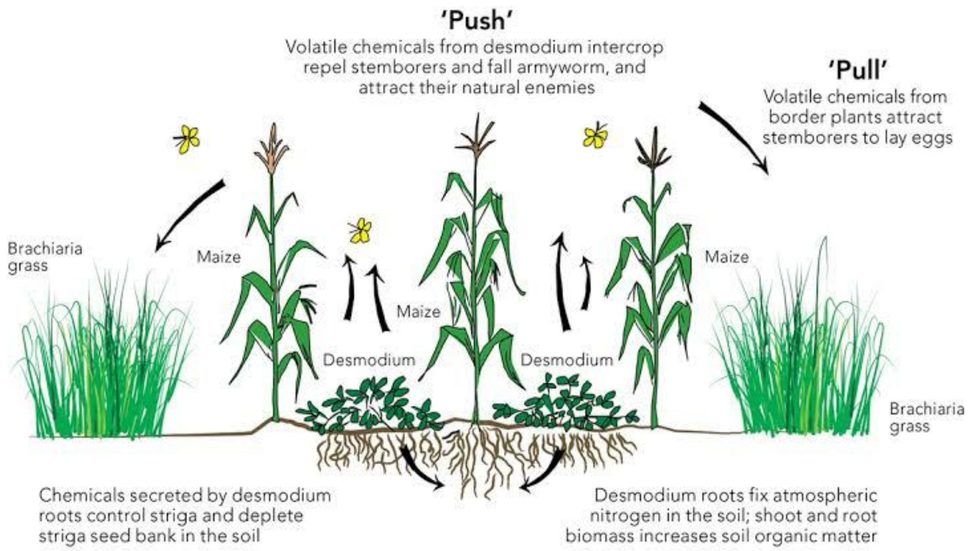

Fig. 4: Figure showing Push-pull pest management in Maize crop

8.1. Principles of Push-pull strategy of insect pest management:

The push-pull strategy seeks to maximize control efficacy, efficiency, sustainability, and output while minimizing unintended consequences to the environment. Each part of the strategy is unlikely to reduce pest populations as effectively as a single application of a broad-spectrum insecticide. Yet, when both push and pull elements are used together, performance improves [67]. Pests can be contained more effectively and their population reduced more rapidly by moving them to one central location. The use of broad-spectrum, synthetic insecticides is discouraged in favor of biological control methods or highly selective botanicals for population reduction. It is recommended that semiochemicals be made from renewable sources like plants, and this is increasingly possible [68]. If you want to get the most out of your farm without spending too much money, you should use harvestable intercrops or trap crops instead of sacrificial crops [69]. Understanding the biology of the pest and the behavioral/chemical ecology of its interactions with its hosts, conspecifics, and natural enemies is crucial to the development of reliable, robust, and sustainable push-pull strategies. Each tactic uses a unique set of components that is tailored to the pest at hand (based on factors like its specificity, sensory abilities, and mobility) and the resource that is being guarded.

9. Advantages and disadvantages of intercropping systems:

Table 1 outlines the positives and negatives of intercropping systems in agriculture. Table 2 lists crops that are recommended for their ability to reduce pest occurrence when grown in between other crops. In Table 3, several examples of crop pests whose population dynamics have been observed to shift as a result of intercropping are given. In Table 4, some examples of intercrops used as trap crops in farming practices are presented, and in Table 5, the results of scientific trials are given, that have used intercropping as a tool for reducing pest populations.

Table 1: Benefits and uncertainties of intercropping systems

Benefits	Uncertainties
Efficient use of available land	Inadequate possibilities for production mechanization
Possibility of multiple harvests per year	Harvesting produce more challenging
Increasing crop diversity to ensure market supply	Demand for management has increased
Potential crop failure risks may be mitigated	There is no major harvest of stable or cash crops
Farmers may be able to handle price fluctuations	Disparately matched intercrops reduce yields of primary crops
Greater productivity and less wasteful use of materials	It's possible that increasing the soil's nitrogen levels through intercropping won't have much of an effect
Increase the amount of nitrogen in the soil gradually over time, especially if legumes are planted	The use of herbicides might be limited
Different plant species have different root systems, and this may lead to better soil structure	Possibility of allelopathy
Improving rotational control of soil erosion	Decline in crop specific pesticide use
Reduction in pests, diseases and weeds	May increase drudgery
Reducing eutrophication and emissions by decreasing the use of energy-intensive farming inputs	Potentially challenging intercultural operations

Table 2: Recommended crops that impact the occurrence of pests under intercropping conditions

S. No.	Intercrop	Major Taxa	Main pest	Reference
1.	Alfalfa, carrot, maize, mungbean, wheat, sunflower, sorghum	Aphids	*Aphis gossypii*	[70]
2.	Cowpea, safflower, sunflower	Plant bugs	*Lygus Hesperus*	[71]

3.	**Apricot**	**Thrips**	***Thrips tabaci***	**[72]**
4.	**Wheat**	**Predatory bugs**	***Nabis sinoferus***	**[73]**
5.	**Maize**	**Green Lacewings**	***Chrysopa sinica***	**[74]**
6.	**Soybean**	**Spider mite**	***Tetranychus cinnabarinus***	**[75]**

Table 3: Examples of crop pests for which changes in the behavior or development of the population have been observed due to intercropping

Name of pest	**Host Plant**	**Type of intercropping**	**Changes in the Pest Behavior and Pest Population**	**Reference**
Acalymma vittata	**Cucumber**	**Inter-row cultivation, cucumber and corn or broccoli in separate rows**	❖ **Three times fewer beetles than in pure cucumber crop.** ❖ **Reduction in the reproductive rate and decrease in the period of foraging**	**[76]**
Phyllotreta Cruciferae	**Broccoli**	**Inter-row cultivation, broccoli in rows and vetch and bean between rows**	❖ **Decrease in the foraging period** ❖ **Decreasing of the population**	**[77]**
Aphis craccivora	**Groundnut**	**Row-crop mixture, groundnut and common beans in separate rows**	❖ **Common bean's sticky tendrils kept aphids away** ❖ **A reduction in aphids by decreasing foraging time**	**[78]**

Oulema spp	Oat, barley	Row-crop mixture of both cereals	❖ Mixed cultivation of each species reduces the degree of damage to oat leaves by 48% and barley by 51% compared with pure stands	[79]
Sitobion avenae	Barley	Row-crop mixture of barley with yellow lupine and pea	❖ The number of aphids on barley heads was 3–6 times lower in crops with legumes	[80]

Table 4: Examples of some intercrop used as trap crop in farming practices

S. No.	Main Crop	Trap Crop	Pest Controlled
1.	Bengal gram	Marigold	*Heliothis sp.*
2.	Cowpea	Cotton	*Heliothis sp.*
3.	Soybean	Corn	*Heliothis sp.*
4.	Beans	Soybean	Mexican bean beetle
5.	Sunflower	Cotton and Marigold	*Heliothis sp.*
6.	Groundnut	Cowpea	Leaf folder
7.	Mustard	Cabbage	Cabbage head borer
8.	Cotton	Marigold	*Heliothis sp.*
9.	Tomato	Cabbage	Diamond back moth
10.	Brinjal	Coriander	Shoot and Fruit borer
11.	Cabbage	Radish	Flea beetle
13.	Radish	Cabbage	Flea beetle
14.	Potato	Marigold	Nematodes

Source: [81]

Table 5: Intercropping for Pest Reduction – Reported Successful Scientific Trials

S. No.	Crop	Intercrop	Pest reduced/controlled	Mechanisms

1.	**Apple**	***Phacelia* sp.**	**San Jose scale, aphid**	**Parasitic wasps**
2.	**Barley**	**Alfalfa, red clover**	**Aphid**	**Predators**
3.	**Bean**	**Goosegrass**	**Leafhopper**	**Chemical repellent**
4.	**Cabbage**	**Tomato**	**Diamondback moth**	**Uncertain**
5.	**Carrots**	**Onion**	**Carrot fly**	**Chemical repellent**
6.	**Cauliflower**	**White or red clover**	**Cabbage aphid**	**Predators**
7.	**Collards**	**Tomato**	**Flea beetle**	**Chemical repellent**
8.	**Corn**	**Beans**	**Leafhoppers, leaf beetle, fall armyworm**	**Physical interference, Predators**
9.	**Cow pea**	**Sorghum**	**Leaf beetle**	**Chemical repellent**
10.	**Crucifers**	**Wild mustard**	**Cabbageworm**	**Parasitic wasps**
11.	**Fruit trees**	**Wheat, sorghum**	**European red mite**	**Predators**
12.	**Walnut**	**Weedy ground cover**	**Walnut aphid**	**Parasitic wasps**

Source: [82]

5. CONCLUSION

Intercropping is an additional workable strategy for warding off insect pests in crops. Diversifying crops in a given agro-ecosystem can help lower the insect population and, in turn, the risk of attack, making it a promising cultural practice for pest management. There are a few different ways in which intercropping protects the primary crop. The choice of companion crops and their additional valuation after harvest, as well as the farmers' knowledge and the mechanization practiced, play a role in the success of intercropping for pest management. Planting multiple crop types in a single field is known as intercropping, a cultural practice used in the IPM system to reduce the need for pesticides. Concerns about potential negative impacts of pesticide on human health and the environment, pesticide resistance, the resurgence of insect pests, and general considerations of agricultural production led to the development of intercropping as an IPM tool. Since not all possible crop combinations have the desired effect, figuring out which ones will reduce pest abundance is a major challenge when trying to select the best intercrop combination for pest suppression. Therefore, intercropping can either stand

on its own as a pest management strategy or be used in tandem with others, such as host-plant resistance, supplementary biological control, and chemical control. To effectively use intercropping for insect pest management in today's modern agriculture, one must have an in-depth understanding of how different crop characteristics and combinations will affect the behaviour of pests.

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