PRINCIPLES AND CONCEPT OF INTEGRATED PEST MANAGEMENT

History of Pest Management

- 2500 BC First records of insecticides; Sumerians used sulfur compounds to control insects and mites.
- 200 BC Romans advocated oil sprays for pest control.
- 300 AD First records of biological controls; Chinese used. predatory ants in citrus orchards to control caterpillar and beetle pests.
- 1880 First commercial spraying machine.
- 1930 Introduction of synthetic organic compounds for plant pathogen control.
- 1940 First successful use of an entomopathogen; Milky Spore (*Bacillus popillae) used to control Japanese beetle.*

- Supervised insect control –

  Shortly after World War II, when synthetic insecticides became widely available,

  entomologists in California developed the concept of Supervised Control.

- It is an alternative to calendar-based insecticide programs.
- Supervised control was based on a sound knowledge of the ecology and analysis of projected trends in pest and natural-enemy populations.
- Integrated control-

  Supervised control formed much of the conceptual basis for "integrated control" that

  University of California entomologists articulated in the 1950s.

- Integrated control sought to identify the best mix of chemical and biological controls for a given insect pest.
- The adage of "if a little works, a lot will work better" was the major premise for applying chemical to address pest problems on the farm and around the home
- Ecological Backlash –
- As early as the 1950's, pesticide-induced problems such as pest resurgence, pest replacement, and pesticide resistance caused problems in agriculture.
- Pest resurgence = In 1959, scientists discovered that aphids could be better controlled by reducing the amount of pesticide used because the pesticides were killing aphid predators as well as the aphids themselves, causing large-scale pest resurgence (Stern, et al., 1959).

Pest Management –

- The concept of 'pest management' was proposed in 1961 (Geier and Clark, 1961)
- For the reduction of pest problems actions are selected after the life systems of the pests are understood and the ecological and economic consequences of these actions have been predicted, as accurately as possible, to be in the best interests of mankind.
- **Widespread pest resistance in 1950's to DDT and other** Pesticides
- **Environmental Awareness d**uring the 1960s – new awareness of ecology and the environmental impact of pesticide pollution resulted from a public outcry about environmental contamination found in the air and foul water found in rivers and streams.
- By 1962, when "Silent Spring" by Rachel Carson was published, serious concerns about the disadvantages of pesticide use were widely raised .
- Rachel Carson and others suggested that pest control methods other than chemical pesticides should be used in order to protect wildlife, human health and the environment.
- Public pressure led to government legislation restricting pesticide use in many countries resulting in ban of DDT and other pesticides.
- **Integrated Pest Management-** In 1967 the term IPM was introduced by R.F. Smith and R. van den Bosch.
- The term IPM was formalized by the US National Academy of Sciences in 1969.
- IPM was adopted as policy by various world governments during the 70's and 80's, including the USA (1972)
- **1970's-1980's IPM adapted for managing pests of landscape trees and shrubs in Urban Areas**
- In 1985 India declared IPM as official Ministerial Policy.
- **IPM and its evolution**-

  Over the years IPM underwent several changes in its focus and approaches.
- Some of the key approaches are
- **Damage threshold –**

The basic IPM principle relied on the damage boundary/ economic damage relationship i.e no injury level below the damage boundary merits suppression, but injury predicted to result in economic damage does.

- **Economic Injury Level-** The EIL is the most basic of the decision rules; it is a theoretical value that, if actually attained by a pest population, will result in economic damage.

ECOLOGICAL ENGINEERING FOR PEST MANAGEMENT

- Ecological Engineering explores the ecological engineering strategies based on the management of habitat to achieve pest suppression.

- It could be argued that all pest management approaches are forms of ecological engineering, irrespective of whether they act on the physical environment (e.g., via tillage), chemical environment (e.g., via pesticide use) or biotic environment (e.g., via the use of novel crop varieties).

- However, the use of cultural techniques to effect habitat manipulation and enhance biological control most readily fits the philosophy of ecological engineering for pest management.

Plant protection in India and most of the developing countries is mainly based on the use of pesticidal chemicals. Chemical control is one of the effective and quicker method in reducing pest population where farmer gets spectacular result within a short time. However, over reliance and indiscriminate use of pesticides resulted in a series of problems in the Agricultural ecosystem mainly, the development of resistance in insects to insecticides, resurgence of treated population, out break of secondary pests into primary nature, environmental contamination and residue hazards, destruction of natural enemies of insect pests, expenses on pesticides, equipment, labour etc. All these problems contributed to a new way of thinking concerning pest control practices, i.e. the integrated approach of pest control. This was first proposed by Stern and his colleagues for integration of biological and chemical control measures.

This is not altogether a new concept. It was practiced before the advent of modern chemicals. Dates of planting of a crop were carefully studied to ensure that a crop was not being planted when it would encounter severe pest problems, cultural practices such as ploughing after harvest, timely weed control, well timed irrigation and a reduced use of fertilizers all contributed to reduce pest population. Most of these methods were curtailed when modern pesticides become available, it was thought that these chemicals alone could control pests, but now we know that this is not possible, and the single method of approach to pest control is not feasible. Hence, we have to form an integrated approach in pest management. IPM. “Integrated Pest Management is an ecological approach in which utilization of all available techniques of pest control to reduce and maintain the pest population at levels below economic injury level”. Hence the new concept or approach is based on the principles of managing the pest rather than eradicating them. In other words pest management will be working 24 hours a day, every day of year. This is possible and must become a part of cultivators every day thinking and activities.

- Hence the new concept or approach is based on the principles of managing the pest rather than eradicating them.
- **AIM of Selected IPM strategies and prescriptions**
    - Promote natural controls.
    - Protect human health.
    - Minimize negative impacts to non-target organism.
    - Enhance the general environment.
    - Be most likely to produce long-term, beneficial results.
    - Be cost-effective in the short and long-term
    - Be easily and efficiently implemented

- IPM fits best way in PHM

- Integrated Crop Management
- IPM + IWM + INM = ICM
- ICM + Soil Health Management = PHM
- Plant health is impacted by several factors such as soil health, nutrient management, abiotic stresses, pest population and ecological balance between pest and beneficial insects
- These factors vary from one agro-climatic region to another.
- In order to reduce crop losses due to pests, expertise is required in plant health management, the science and practice of understanding and overcoming biotic and abiotic factors that limit plants from achieving their full genetic potential as crops.
- ***"Subeezum sukshetram Dhyayate sampadate"***
- PHM = Here we take a broad view :
  - Considering not only IPM but also
  - Soil Health
  - Nutritional deficiency
  - Overall Plant health (Holistic view)
  - Seed to seed

Tools of Pest Management

The available techniques for controlling individual insect pests are conveniently categorised in increasing order of complexity as -

1. Cultural
2. Mechanical
3. Physical
4. Biological
5. Genetic
6. Regulatory
7. Chemical

1.Cultural methods or agronomic practices:

a. Use of resistant varieties

b. Crop rotation

c. Crop refuse destruction

d. Tillage of soil

e. Variation in time of planting or harvesting

f. Pruning or thinning and proper spacing

g. Judicious and balanced use of fertilizers

h. Crop sanitation

i. Water management

j. Planting of trap crops

2.Mechanical methods :

a. Hand destruction

b. Exclusion by barriers

c. Use of traps

3.Physical methods :

a. Application of heat
- Hot water treatment
- Exposing of infested grain to sun
- Super heating of empty godowns at 50 degree C to kill hibernating stored grain pests.

b. Manipulation of moisture
- Reduction of moisture content of grains helps to prevent from the attack of stored grain pests.

c. Energy
- Light traps

4. Biological control :

a. Protection and encouragement of natural enemies

b. Introduction, artificial increase and colonization of specific parasitoids and predators.

- conservation of natural enemies
- Parasites and Parasitoids
  - Egg Parasitoids
  - Larval Parasitoids
  - Pupal Parasitoids

c. Propagation and dissemination of specific bacterial, viral, fungal and protozoan diseases.

5. Genetic methods :
- Use of sterile male technique

6. Regulatory methods :
- Plant quarantine
  a. Foreign quarantine
  b. Domestic quarantine

7. Chemical methods :
- Use of attractants
- Use of repellants
- Use of growth inhibitors
- Use of insecticides

Basic principles of Integrated Pest Management :

1.Consideration of Ecosystem :

Control of insect pest population is a function of the ecosystem itself by means of natural enemies and other factors. Knowledge of the role of the principle elements of the units is essential to an understanding of population phenomenon. The study of individuals is of prime importance, their biology behaviour response to other members of the same species and to other organisms and to biotic factors in the environment. The study of individuals offers a potent method for this analysis of population change. The most effective system for controlling pests can be derived only after understanding the principles responsible for the population fluctuation in the ecosystem.

2.Pest Surveillance :

Pest Surveillance and forecasting are having a vital part in the integrated pest management. Surveillance or monitoring means constant observation of a subject i.e., a crop or pest, and recording the factors observed, compilation of information obtained and prediction of future events about pest population. Hence pest surveillance comprises of three basic components.

a. Determination of the level of incidence of the pest species.

b. Determination of what loss the incidence will cause.

c. Determination of economic benefits or other benefits the control will provide.

The above information would be immense use in determining the need for a pest control measure. Mere presence of a few numbers of pest species should not be the criterion for pesticide application and there should be sufficient justification. Surveillance can provide the necessary information to determine the feasibility of a pest control programme. It should be a tool that assists pest management specialists in determining the actual factors that are involved in a pest build up, so that the specialists can determine practices that will manage these factors and prevent the initial build up of a pest.

3. Utilization of Economic Threshold Levels (ETL)

The level of pest population is very important consideration for taking up control measures. Pest population must be maintained at levels below those causing economic injury. The economic threshold is the pest density at which control measures should be determined to prevent an increasing pest population from reaching economic injury level. The determination of these thresholds is a pre-requisite to the development of any pest management strategy.

4. Application of minimum selective hazards :

The application of chemical measures to pest population has to be in such a manner that target pest populations are just kept below economic injury thresholds. By observation of this principle the development of resistant populations of pest is avoided or delayed, the possibility of resurgence of treated population is decreased, adverse effect on non target organism and amount of environmental contamination are reduced, and the cost of control is also lowered.

When insecticide treatments are deemed necessary special consideration should be given to (1) Effectiveness of the insecticide against most vulnerable life stage of the pest (2) Employing an insecticide that will cause least disturbance in the ecosystem. (3) Applying the insecticide in such a way that it will restrict its distribution to the area where it is needed.

Advantage of Integrated Pest Management :

1. Fits better in National Economy.

Pest control activities at present are mainly based on the application of chemical pesticides, quite a large proportion of which has to be imported. The expenditure envisaged for plant protection runs into crores of rupees even when only one or at the most two pesticide application are envisaged per crop. High yielding varieties show that many more pesticide applications are called for many crops if pest control has to depend only on the use of pesticide. Thus a time has come where Integrated Pest Management is not only advisable but also inevitable.

2. More efficient and cheaper method.

In IPM schedule efforts are made to utilize various methods of control including use of pesticides but some times and in some cases it is feasible to nip the trouble in the bud itself even by a mechanical campaign like destruction of egg masses of some pests or collecting the caterpillar stages. In such cases it envisages a lot of saving in the use of pesticides, this means saving of money and saving of foreign exchange and also the destruction of the pest before it has been able to inflict damage.

3.Avoid upsetting the balance of nature.

Chemical control has often been reported to upset the balance of nature at times leading to upsurge of new type of pest problem which did not exist before. The seriousness of mites in many parts of the world has occurred by the use of DDT. It is confidently expected that such adverse side effects will be much less as a result of integrated pest management schedule.

4. Minimises residue hazards of pesticides :

It is obvious that in an IPM schedule the use of pesticides will be considerably reduced, hence the pesticide residue hazards will also get automatically minimised.

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INTRODUCTION TO AGRO-ECOSYSTEM ANALYSIS (AESA)

The important rational planning for effective land use to promote efficient is well recognized. The ever increasing need for food to support growing population @2.1% (1860 millions) in the country demand a systematic appraisal of our soil and climatic resources to recast effective land use plan. Since the soils and climatic conditions of a region largely determine the cropping pattern and crop yields. Reliable information on agro ecological regions homogeneity in soil site conditions is the basic to maximize agricultural production on sustainable basis. This kind of systematic approach may help the country in planning and optimizing land use and preserving soils, environment.

India exhibits a variety of land scopes and climatic conditions those are reflected in the evolution of different soils and vegetation. These also exists a significant relationship among the soils, land form climate and vegetation. The object of present study is to delianate such regions as uniform as possible introspect of physiographic, climate, length of growing period (LPG) and soils for macro level and land use planning and effective transfer of agro - technology.

Agro Climatic Zones: - Agro climatic zone is a land unit in Irens of mator climate and growing period which is climatmenally suitable for a certain image of crops and cultivars (FAO 1983). An ecological region is characterized by district ecological responses to macro - climatic as expressed in vegetation and reflected fauna and equatic systems. Therefore an agro-ecological region is the land unit on the earth surface covered out of agro - climatic region, which it is super imposed on land form and the kinds of soils and soil conditions those act as modifiers of climate and LGP (Length of growing period).

With in a broad agro climatic region local conditions may result in several agro - ecosystems, each with it's own environmental conditions. However, similar agro ecosystems may develop on comparable soil, and landscape positions. Thus a small variation in climate may not result in different ecosystems, but a pronounced difference is seen when expressed in vegetation and reflected in soils. India has been divided into 24 agro - climatic zone by Krishnan and Mukhtar Sing, in 1972 by using "Thornthwait indices".

The planning commission, as a result of mid. term appairasal of planning targets of VII plan (1985 - 90) divided the country into 15 broad agro - climatic zones based on physiographic and climate. The emphasis was given on the development of resources and their optimum utilization in a suitable manner with in the frame work of resource constraints and potentials of each region.

(Khanna 1989).

Agro climatic zones of India :- (Planning commission 1989)

1	Western Himalayan Region	Ladakh, Kashmir, Punjab, Jammu etc.brown soils & silty loam, steep slopes.
2	Eastern Himalayan Region	Arunachal Pradesh, Sikkim and Darjeeling. Manipur etc. High rainfall and high forest covers heavy soil erosion, Floods.
3	Lower Gangatic plants Regions	West Bengal Soils mostly alluvial & are prone to floods.
4	Middle Gangatic plans Region	Bihar, Uttar Pradesh, High rainfall 39%

		irrigation, cropping intensity 142%
5	Upper Gangatic Plains Region	North region of U.P. (32 dists) irrigated by canal & tube wells good ground water
6	Trans Gangatic plains Region	Punjab Haryana Union territory of Delhi, Highest sown area irrigated high
7	Eastern Plateaus & Hills Region	Chota Nagpur, Garhjat hills, M.P, W. Banghelkhand plateau, Orissa, soils Shallow to medium sloppy, undulating Irrigation tank & tube wells.
8	Central Plateau & hills Region	M. Pradesh
9	Western Plateau & hills Region	Sahyadry, M.S. M.P. Rainfall 904 mm Sown area 65% forest 11% irrigation 12.4%
10	Southern Plateau & Hills Region	T. Nadu, Andhra Pradesh, Karnataka, Typically semi and zone, Dry land Farming 81% Cropping Intensity 11%
11	East coast plains & hills Region	Tamil Nadu, Andhra Pradesh Orissa, Soils, alluvial, coastal sand, Irrigation
12	West coast plains & Hills Region	Sourashtra, Maharashtra, Goa, Karnataka, T. Nadu, Variety of cropping Pattern, rainfall & soil types.
13	Gujarat plains & Hills Region	Gujarat (19 dists) Low rainfall arid zone. Irrigation 32% well and tube wells.
14	Western Dry Region	Rajasthan (9 dists) Hot. Sandy desert rainfall erratic, high evaporation. Scanty vegetation, femine draughts.
15	The Island Region	Eastern Andaman, Nikobar, Western Laksh dweep. Typical equatorial, rainfall 3000 mm (9 months) forest zone undulating.

All crops cannot be grown in all types of agro climatic zones. Some crops can be possible to grow in all zones and some crops will be grown in some zones.

Every plant has its own agro-ecosystem.

Decision making in IPM requires an analysis of the ecosystem. Sampling and thresholds are important parts of that analysis. Some parts of the ecosystems interact. Now we will begin to use a method of Eco-system Analysis to facilitate discussion and decision making.

- First of all we have to take soil testing.
- Send it for analysis at local State Soil Testing Laboratory.
- According to the result we have to recommend the dose of organic and inorganic fertilizer.
- Selection of suitable seed variety
- Testing the seed viability
- Suggesting suitable seed treatment
- Raised nursery bed

- Preparation of compost
- Vermicompost preparation
- Preparation of rhizobium culture
- Blue green algae preparation
- Preparation of neem coated urea preparation

Agro Ecosystem Analysis (AESA)

AESA is an approach which can be gainfully employed by extension functionaries and farmers to analyse field situations with regard to pests, defenders, soil conditions, plant health, the influence of climatic factors and their interrelationship for growing healthy crop. Such a critical analysis of the field situations will help in situations will help in taking appropriate decision on management practices.

A. The basic components of AESA are :

i. Plants health at different stages. Monitor symptoms of diseases and nematodes.
ii. Built-in-compensation abilities of the plants.
iii. Pest and defender population dynamics.
iv. Soil conditions.
v. Climatic factors.
vi. Farmers past experience.

B. The methodology of AESA is as under :

- . **Field Observations :**

i. Enter the field at least 5 ft. away from the bund. Select a site with a dimension of 1 sq mt. randomly.
ii. Record the visual obervation in following sequence:
    a. Flying insects (both pests & defenders)
    b. Close observation on pests and defenders which remain on the plants.
    c. Observe pests like borer, BPH etc. and defenders like cooccinellid, chrysopa, ground beetle/rove beetle and earwigs etc, by scrapping the soil surface around the plants.
    d. Record disease and its intensity.
    e. Record insects damage and disease incidence in percentage.
iii. Record parameters like number of leaves, plant height and reproductive parts of the selected plants for makingobservation in the following weeks. Observe nematode damage symptoms.
iv. Record the types of weeds, their size and population density in relation to crop plant.
v. Record soil conditions viz flooded, wet or dry.
vi. Observe rodent live burrows.
vii. Record the climatic factors viz sunny, partially sunny, cloudy, rainy etc. for the preceding week.

C. Drawing :

First draw the plant at the centre on a chart. Then draw pests on left side and defender on the right side. Indicate the soil condition, weed population, rodent damage etc. Give natural colours to all the drawing, for instance, draw healthy plant with green colour, diseased plant/leaves with yellow colour. While drawing the pests and the defenders on the chart care should be taken to draw them at appropriate part of the plant, where they are seen at the time of observation. The common name of pest and alongwith diagram. The weather factor should bereflected in the chart by drawing the diagram of sun just above the plant if the attribute is sunny. If cloudy, the clouds may be drawn in place of sun. In case of partially sunny, the diagram of sun may be half masked with clouds.

D. Group Discussion and Decision making :

The observations recorded in the previous and current charts should be discussed among the farmers by raising questions relating to change in pest and defender population in relation to crop stages, soil condition, weather factors such as rainy, cloudy or sunny etc. The group may evolve a strategy based upon weekly AESA, ETL and corresponding change in P.D. ratio and take judicious decision for specific post management practices.

E. Strategy for decision making :

Some of the defenders like lady beetles, groundnut beetles, rove beetles, wasps play useful role in arriving at P.D. ratio.

F. AESA by Extension Functionaries :

The extension functionaries during their regular visit to the village mobilize the farmers, conduct AESA and critically analyse the various factors such as the pest population vis-a-vis defender population andtheir role in natural suppression of the pest, the influence of per prevailing weather condition/soil conditions on the likely build-up of defender/pest population. They may also take the decision based on the AESA which IPM components like release of defenders, application of need formulations/ safe pesticides are to be used for specific pest situation. Such an exercise may be repeated by the extension functionaries during every visit to the village and motivate the farmers to adopt AESA in their fields.

G. AESA by Farmers :

After a brief exposure during IPM demonstrations/ field trainings, farmers can practice AESA in their own field. Whenever trained farmers are available their experiences could be utilized in training their fellow farmers in their own villages. Thus a large group of farmers could be made proficiently competent in undertaking weekly AESA thereby empowering themselves in decision making on any specific pest situations. Farmers-to-farmers training approach will go a long way in practicing IPM on a large area on sustainable basis.

H. Pest Monitoring Through Pheromones/ Light Traps etc.

Certain pests required positioning of various kinds of traps like pheromones, light trap to monitor the initial pest build up. Therefore, the State Department of Agriculture is to initiate action for positioning of different kinds of traps at strategic locations at village level as per the following details.

1. **Pheromone trap** – 8 traps per ha. may be used to monitor stem borer moth population in Summer rice initiate in February to April (Boro & Early Ahu) trapping should be done from February to April and in Winter rice –(Sali rice), it should be done from July to September lures should be replaced at 10 days intervals.

2. **Light trap -** Chinsurah light trap or any other light trap with 200 watts mercury lamps can be operated for two hours in the evening to observe photo tropic insect pests. Traps should be placed away from other light sources.

3. **Sweep-nets-water pans** – Besides visual observations sweep-nets and water pans may also be used to assess the population of insect pests and bio-control agents.(In paddy crop) and mechanical collection and identification in vegetable crops.

I. Economic Threshold Level (ETL)

The Economic threshold level (ETL) is an attempt to improve decision making practices by using partial economic analysis on the impact of the control practice such as spraying a pesticide. At the ETL,the benefit of spraying a pesticide. At the ETL, the benefit of spraying is equal to the losses caused by the insects in the field. The farmers are advised to take appropriate control measures when the incidence crosses ETL. The ETL for some of the major pests are listed below:

Pest	**Economic Threshold Level**
Tomato fruit borer	One egg/one larve/one damaged fruit per plant
Whitefly (as a sucking pest)	4 adults/leaf
Root-knot reniform Nematode	1-2 larvae/g soil

Objective:

The goal of the activity is to analyze the field situation by observation drawing and discussion. At the end of the activity, the group should have made a decision about any actions required in the field.

Time required = 120 minutes

Materials (per group)

One piece of note-book, paper one large size, drawing crayons or sketch pens.

Procedure:

1. Go to the field. Walk diagonally across the field and randomly choose 20 plants on the diagonal from. For each plant follow this examination process and record your observation. This should be done for each plot.

Insects : Then examine each plant from bottom to the top for hoppers, other insects. If many of the leaves are damaged by feeding look for caterpillars, *Epilachna* beetles and Shoot and fruit borer on leaves, fruits and tender shoots. Estimate the percent defoliation on the plant. Are larvae still present ? Collect the eggs and egg masses). Count the number of shoot damage and fruit damage. Record the number of all observation for the plant.

Disease : Notice the leaves and stems. Are there any discoloration due to disease (Ask the trainer if uncertain). Estimate the percent of leaf/stem area infected.

Record all observations.

Rats : Count the number of live burrows and observe for pieces of damaged fruit near the burrow.

Natural enemies : Count the each type of predator, and the number of larvae with parasites per plant.

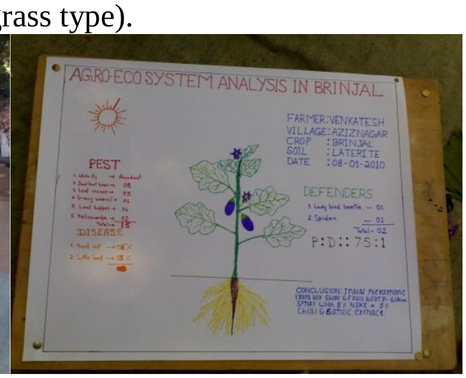
Plant: Find the shady place to sit as a group. Each group should sit together in a circle, with pencils, crayons data from each of the field activities (IPM), local package and other studies), and the drawing of the field ecosystem from the previous weeks.

2. Now make a drawing on the large piece of paper. Everyone should be involved in The drawing. Make a drawing for the each plot observed (IPM plot and local package). There are several rules for drawing which are as follows:

Draw plant with correct average number branches. Write the number branches on the plant somewhere. If the plant is healthy, color the plant as green. If the plant is diseased and lacking nutrients (or low in fertilizer) then color the plant or plant parts as brown or yellow.

Draw dead and dried leaves as yellow in color.

For weeds, draw approximate density and size of weeds in relation to the size of the plant. Draw the kind of weeds in the field (Broad leaf or grass type).



For pest population intensity, draw the insect pests as found in the field on the left side of the plant. Write the average number next to the insect. Also write the local name next to the insect. The data can also be summarized in a table on the right side.

For natural enemy population intensity, draw the predatory insects, other larval parasitoids and spiders as found in the field on the right side of the plant. Write the average number of the natural enemies and their local names next to the drawing.

For rats show the average number fruits/ plant or fruits cut by drawing the fruiting bodies laying near the burrow.

If the week was mostly sunny, add a sun. If the week was mostly sunny and cloudy together, draw a sun but half covered with dark clouds. If the week was cloudy all the day, for most of the week, put just dark clouds.

If the field was fertilized, then place a picture of a hand throwing N's, P's or K's into the field depending on the type of fertilizer used.

If insecticides were used in the field, show sprays with a nozzle and write the type of chemical coming out of the nozzle. If granules were broadcast, show a hand with the name of the pesticide being broadcast.

3. Keep your drawings for comparison for weeks later in the season.

4. Now discuss the questions listed for each stage of the plant depending on the crops observed. One person in the group is designated as the questioner (Change the person each week). This person will ask questions about the field. Write your answers on the paper and add a summary.

Each group should make a presentation of their field observation, drawing, discussion and summary. Different person should make the presentation each week.

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AGRO-ECOSYSTEM ANALYSIS METHODOLOGY IN VEGETABLE

Ecosystem analysis is the basic training method that helps farmers to understand their crop and to make decisions about their crop. Ideally, every weekly field school session should start with an Ecosystem Analysis by sub-groups, with group discussions afterwards. In this way, weekly development of the ecosystem can be followed, and weekly decision making can be practiced by the farmer.

AESA in vegetables will be taken in all three stages of the crop every weeks

Nursery Stage	- Observe all the nursery beds for insect pests and diseases
Vegetative Stage	- Observe 20 plants and scan entire plant for pests and bioagents -for sucking pests top two, middle two and bottom one leaves to be observe.
Flower and Fruiting Stage:	- Observe 20 plants and scan entire plant for live insect pests attack on flower buds, flower and fruit damage and healthy pests and available bioagents (all live ones) -for sucking pests top two, middle two and bottom one leaves to be observe.

Materials for each group of farmers:

- Note paper, pen
- Colour crayons
- Large piece of paper (about 60x80 cm.)

Activities:

1. Farmers form groups of four to five persons each. Some groups take the Farmers Practice field, and the other groups take the IPM field.

2. Each group sample 20 plants across the diagonal of the field. To select a plant, walk across the diagonal of the field and choose a plant at every 5 m. In large fields increase the distance between plants selected.

1. Then, select <u>three leaves</u> from the plant, one taken from the <u>top</u>, one from the <u>middle</u> and one from the <u>bottom</u> of the plant. Pick or turn the leaf and count the number of jassids, whitefly adults and nymphs, and aphids (ignore other sucking pests if not common).

4. Then, check <u>all leaves and the stem</u> systematically for any <u>predators</u> (starting from the top leaf downwards).

5. Then, <u>count the total number of fruiting parts</u>.

6. Then, <u>open the bracts of each individual fruiting part</u> and record:

   - Number of fruiting parts with <u>fruit damage</u>.
   - Number of <u>fruit borer larvae</u>.
   - Any <u>predators</u>.

7. Then, check on the <u>ground surface</u> under the plant and record any predators found.

8. <u>Collect predators</u> encountered in plastic vials to show to the other groups.

9. <u>Uproot</u> one brinjal or tomato or bhindi plant for drawing.

10. After 20 plants are sampled, find a place to sit as a group and make colour <u>drawings</u> on the large piece of paper. Draw the plant with the correct number branches. Draw the sun and indicates clouds if it is a cloudy day. Draw shedding buds in yellow. On the right hand side of the cotton plant, draw the pests found:

    Sucking pests:

    - Indicate the total number found (Top two leaves, Middle two leaves and bottom one leaves.

- And the total number of leaves checked (50 leaves).

  (- calculate the average per leaf)

Fruit borer larvae :

- Indicate the total number of fruiting parts checked.

- Indicate the total number of fruiting parts with fruit borer damage.

  (- calculate the percentage damaged fruiting parts).

On the left hand side of the cotton plant, draw the predators found. Again indicate the total numbers found (and calculate the average per plant). If weeds are common draw some weeds next to the vegetable plant. Indicate the intensity of disease incidence, rodent damage etc.

11. After drawing, discuss the following questions, for presentation.

    Questions:
    a) Describe the general condition of the plant.
    b) What do farmers think are the most important factors affecting their crops at this stage ?
    c) What, if any, measure should be taken ?

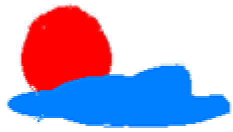
12. Then, when all groups have finalized their drawings and answered the questions, the groups should present their work in front of the other groups. They explain the sampling, explain the drawings and discuss the answers to the three questions.

13. One group for each treatment presents its results.

14. Each week, a different person of each group should do the presentation. In Farmers Field Schools, the Ecosystem analysis drawings of the previous weeks should be available for comparison and to discuss development of the crop and insects populations. It is easy to forget what the field looked like earlier in the season, what insect populations were found, and when control measures were taken.




AGRO ECO-SYSTEM ANALYSIS IN BRINJAL



General Observation
Village :
Farmer :
Variety :
Stage :

PEST

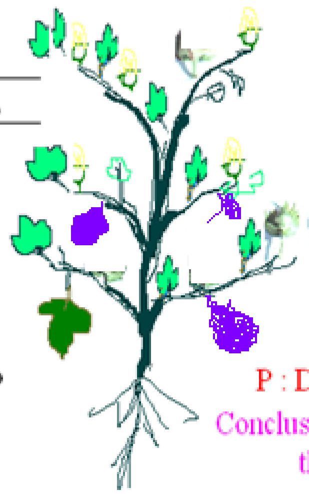
Aphids - 10 %
Thrips - 12
Jassids - 10
White fly - 20
Fruit borer - 12
54

DISEASES

Anthracnose 10%

WEEDS

RODENTS



DEFENDERS

Spiders : 15
Dragonfles : 10
Anthocorid : 10
Geocorid : 11
L.B.B.s : 10
Chrysoperla sp. : 20
Campolitis : 5
80

P : D Ratio 0.67 : 1

Conclusion : Since pest population is low there is no need for pesticidal spray

ECOLOGY & AGROECOSYSTEM CONCEPTS

Ecology is the scientific study of relationships in the natural world. It includes relationships between organisms and their physical environments (physiological ecology); between organisms of the same species (population ecology); between organisms of different species (community ecology); and between organisms and the fluxes of matter and energy through biological systems (ecosystem ecology).

"THE STUDY OF THE RELATIONSHIP BETWEEN AN ORGANISM AND ITS' ENVIRONMENT IS CALLED ECOLOGY"

Definitions of Ecology

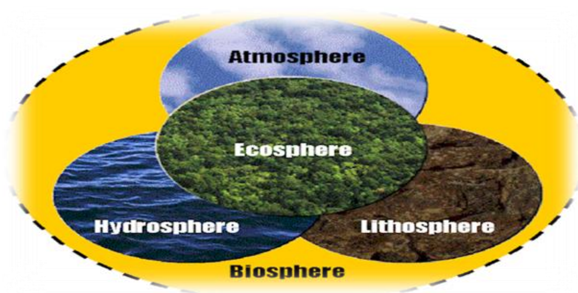
- ☐ 1866 Ernst Haeckel: the comprehensive science of the relationship of the organism to the environment
- ☐ 1927 Charles Elton: Scientific natural history
- ☐ 1963 E. P. Odum: The study of the structure and function of nature
- ☐ 1972 C. J. Krebs: The scientific study of the interactions that determine the distribution and abundance of organisms

Ecological spectrum

Biosphere, Landscape, Ecosystem, Community, Population, Organism, Organ system, Organ, Tissue, Cell, Sub cellular organelles, Molecules

Biosphere

- While the earth is huge, life is found in a very narrow layer, called the biosphere. If the earth could be shrunk to the size of an apple, the biosphere would be no thicker than the apple's skin.
- The biosphere, like the human body, is made up of systems that interact and are dependent on each other.



Ecosystem

- " ***Ecosystem is a Functionally independent unit in which there is an intricate & interdependent among the components*** *" Ex: Pond, River, Forest, tree, desert.*
- All ecosystems must have a constant source of energy *(usually the sun)* and cycles. Examples are the water, nitrogen and carbon cycles.
- An ecosystem is made up of

1. Biotic or living
2. Abiotic or non-living components in a given area.

A biotic Factors

The *nonliving* things in an environment are called A BIOTIC factors. Examples of a biotic factors are

Sunlight , Temperature, Rainfall, Climate and Soil conditions.

Biotic Factors

Biotic factors are all the living things or their materials that directly or indirectly affect an organism in its environment. This would include organisms, their presence, parts, interaction, and wastes. In this type of classification, there are:

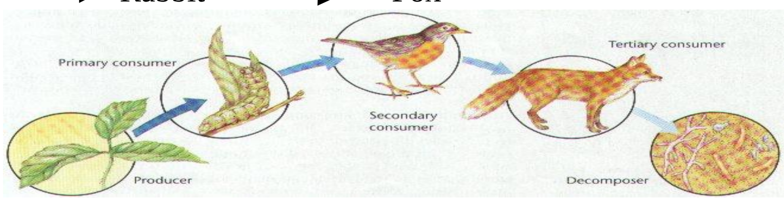
1. Autotrophs
2. Heterotrophs

Organisms that produce their own food from an energy source, such as the sun, and inorganic compounds. Organisms that consume other organisms as a food source.

Food Chain

Food chains show which organisms eat other organisms

Grass ⟶ Rabbit ⟶ Fox



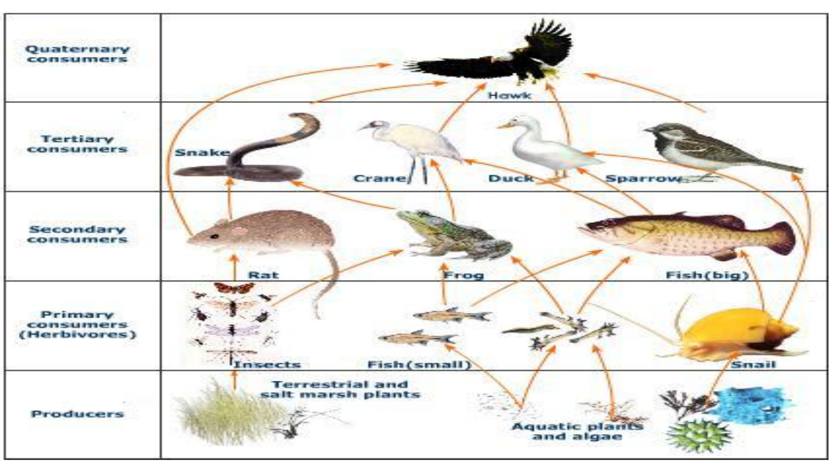
- ✓ Producers - organisms which can make their own energy from carbon dioxide and water using sunlight for energy (plants)
- ✓ *Primary consumer* - organisms which eat producers (herbivores)
- ✓ *Secondary consumers* - organisms which eat primary consumers (carnivores)
- ✓ *Tertiary consumers* - organisms which eat secondary consumers (carnivores)

Each level of a food chain is known as a trophic level Food chains always start with a producer. Producers are always on the first trophic level.

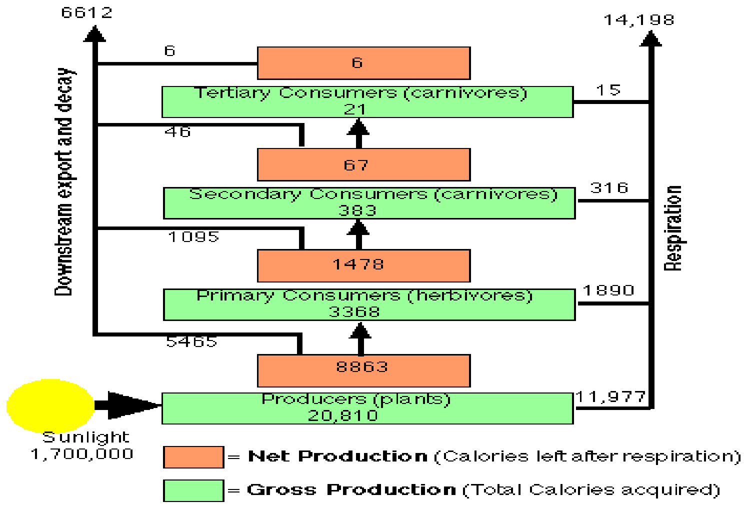
Tertiary consumer	Barn owl	Fourth trophic level
Secondary consumer	Wood mouse	Third trophic level
Primary consumer	Bark beetle	Second trophic level
Producer	Oak Tree	First trophic level

Food Webs

All the food chains in an area make up the food web of the area



Energy Flow Through Food Chains



Ecological pyramid

An ecological pyramid is a graphical representation designed to show the biomass or biomass productivity at each trophic level in a given ecosystem.

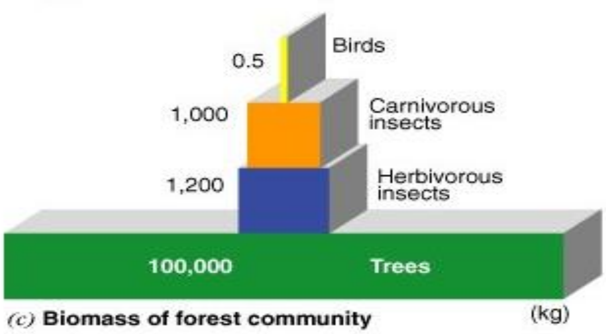
1 .Pyramid of biomass

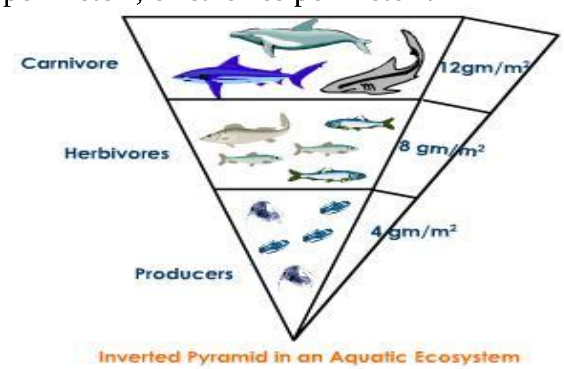
2 .Pyramid of Energy

3 .Pyramid of numbers

1 .Pyramid of biomass

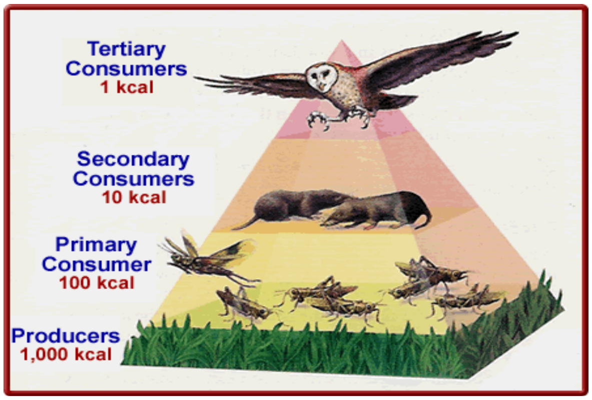
Typical units for a biomass pyramid could be grams per meter^2, or calories per meter^2.



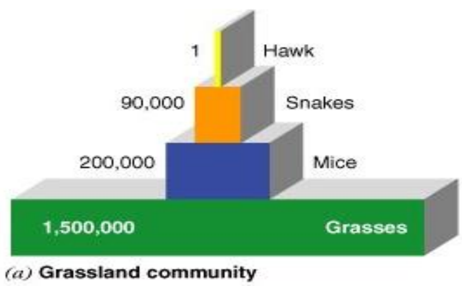


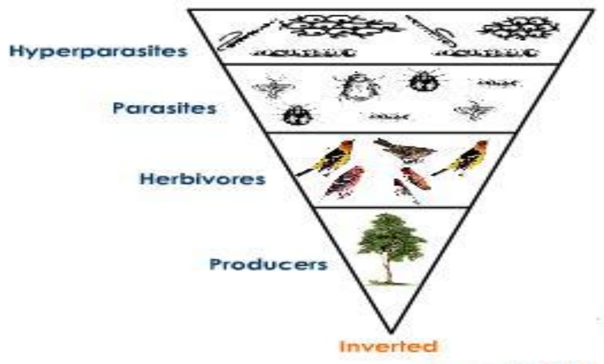
2 . Pyramid of Energy

Typical units would be grams per meter^2 per year or calories per meter^2 per year.



3. Pyramid of numbers





Population

All the organisms in an ecosystem that belong to the same species

Example - All the turtles in Town Lake

Community

A community is a group of interacting populations that occupy the same area at the same time

Habitat

The place in which an organism lives .Provides the kinds of food and shelter, the temperature, and the amount of moisture the organism needs to survive.

Ecological Niche

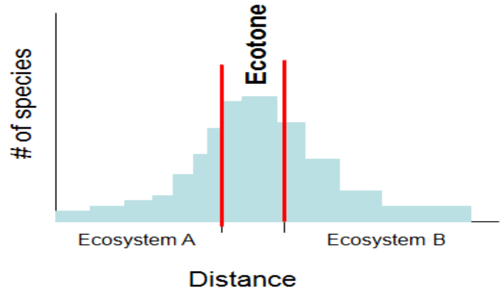
A plant's or animal's ecological niche is a way of life that is unique to that species.

Niche and habitat are not the same. While many species may share a habitat, this is not true of a niche. Each plant and animal species is a member of a community. The niche describes the species' role or function within this community.

- **Ecotone** = transition zone between two ecosystems , Ecotones are often overlooked roads, fences, old fences, wind breaks.
- Ecotone (boundary) more diverse than either ecosystem

  numbers of species often greater in ecotone than in neighboring habitats.
- Edge effect

  In agroecosystem, edges of fields (near ecotone) often most diverse, highest number of species (natural enemies).



Biogeochemical Cycles

Nutrient circuits involving both biotic and abiotic components of ecosystems

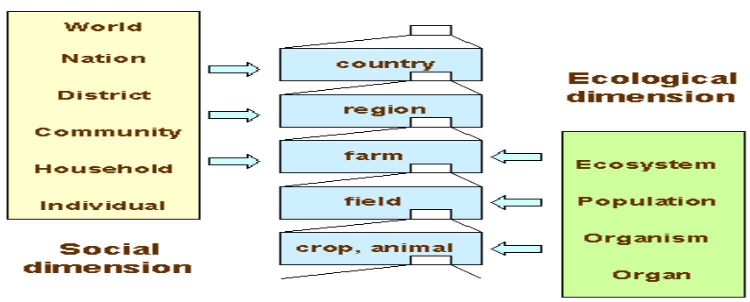
Two categories:

1.Gaseous cycles– Co2, N2,

2.Sedmentary -- Phosphorous, Sulpher

Agro-ecosystem

agro-ecosystems" to result from the manipulation of natural and biological resources by social groups. Agro-ecosystems represent an integration of social and ecological systems, and can be considered from different disciplinary standpoints (social, economic, ecological) as well at several different levels of organization (crop, farm, community, watershed,etc).



System components

- ✓ different components of a system at any level is Agro-ecological "niches" (e.g. soil types, vegetation types, crops, woods, water sources, etc);
- ✓ Infrastructure (roads, wells, etc);
- ✓ Social units (different stakeholders, social groups, types of farmer, markets,etc).

- ✓ The instability of agroecosystems, which is manifested as the worsening of most insect pest problems, is increasingly linked to the expansion of crop onocultures at the expense of the natural vegetation, thereby decreasing local habitat diversity.
- ✓ Plant communities that are modified to meet the special needs of humans become subject to heavy pest damage and generally the more intensely such communities are modified, the more abundant and serious the pests.
- ✓ The inherent self-regulation characteristics of natural communities are lost when humans modify such communities through the shattering of the fragile thread of community interactions.
- ✓ Agroecologists maintain that this breakdown can be repaired by restoring
- ✓ the shattered elements of community homeostasis through the addition or enhancement of biodiversity.

Based on current ecological and agronomic theory, low pest potentials may be expected in agroecosystems that exhibit the following characteristics

1. High crop diversity through mixing crops in time and space.
2. Discontinuity of monocultures in time through rotations, use of short maturing varieties, use of crop-free or preferred host-free periods, etc.
3. Small, scattered fields creating a structural mosaic of adjoining crops and uncultivated land which potentially provide shelter and alternative food for natural enemies. Pests also may proliferate in these environments depending on plant species composition. However, the presence of low levels of pest populations and/or alternate hosts may be necessary to maintain natural enemies in the area
4. Farms with a dominant perennial crop component. Orchards are considered to be semi-permanent ecosystems, and more stable than annual cropping systems. Since orchards suffer less disturbance and are characterized by greater structural diversity, possibilities for the establishment of biological control agents are generally higher, especially if floral undergrowth diversity is encouraged.
5. High crop densities or the presence of tolerable levels of specific weed species.
6. High genetic diversity resulting from the use of variety mixtures or crop multilines

A key feature of annual cropping systems is the nature and frequency of soil disturbance regimes Periodic tillage and planting continually reverts the tilled area to an earlier stage of ecological succession. Physical disturbance of the soil caused by tillage and residue management is a crucial factor in determining soil biotic activity and species diversity in agroecosystems .

Tillage usually disturbs at least 15–25 cm of the soil surface and replaces stratified surface soil horizons with a tilled zone more homogeneous with respect to physical characteristics and residue distribution.

The loss of a stratified soil microhabitat causes a decrease in the density of species that inhabit agroecosystems.

One gram of soil may contain over a thousand fungal hyphae and up to a million or more individual bacterial colonies. Energy, carbon, nitrogen and other nutrient fluxes through the soil decomposing subsystem are dominated by fungi and bacteria, although invertebrates play a certain role in N flux.

	Nutrient Cycling	Soil Structure
Microflora (fungi, bacteria, actino-mycetes)	Catabolize organic matter; mineralize and immobilize nutrients	Produce organic compounds that bind aggregates; hyphae entangle particles onto aggregates
Microfauna (Acarina, Collembola)	Regulate bacterial and fungal populations; alter nutrient turnover	May affect aggregate structure through interactions with microflora
Mesofauna (Acarina, Collembola, enchytraeids)	Regulate fungal and microfaunal populations; alter nutrient turnover; fragment plant residues	Produce fecal pellets; create biopores; promote humification
Macrofauna (isopods, centipedes, millipedes, earthworms, etc.)	Fragment plant residues; stimulate microbial activity	Mix organic and mineral particles; redistribute organic matter and micro-organisms; create biopores; promote humification; produce fecal pellets

biodiversity in agroecosystems

Modern agriculture implies the simplification of the structure of the environment over vast areas, replacing nature’s diversity with a small number of cultivated plants and domesticated animals

In fact, the world’s agricultural landscapes are planted mostly with some 12 species of grain crops, 23 vegetable crop species, and about 35 fruit and nut crop species.

more than 70 plant species spread over approximately 1440 million ha of presently cultivated land in the world.

Genetically, modern agriculture is shockingly dependent on a handful of varieties for its major crops. For example, in the US, 60–70% of the total bean area is planted with 2–3 bean varieties, 72% of the potato area with four varieties and 53% of the cotton area with three varieties

In contrast, biodiversity is not foreign to traditional farmers in the Third World. In fact, a salient feature of traditional farming systems is their degree of plant diversity in the form of polycultures and/or agroforestry patterns.

In fact the species richness of all biotic components of traditional agroecosystems is comparable with that of many natural ecosystems.

Traditional, multiple cropping systems are estimated to still provide as much as 15–20% of the world's food supply.

In general, the degree of biodiversity in agroecosystems depends on four main characteristics of the agroecosystem

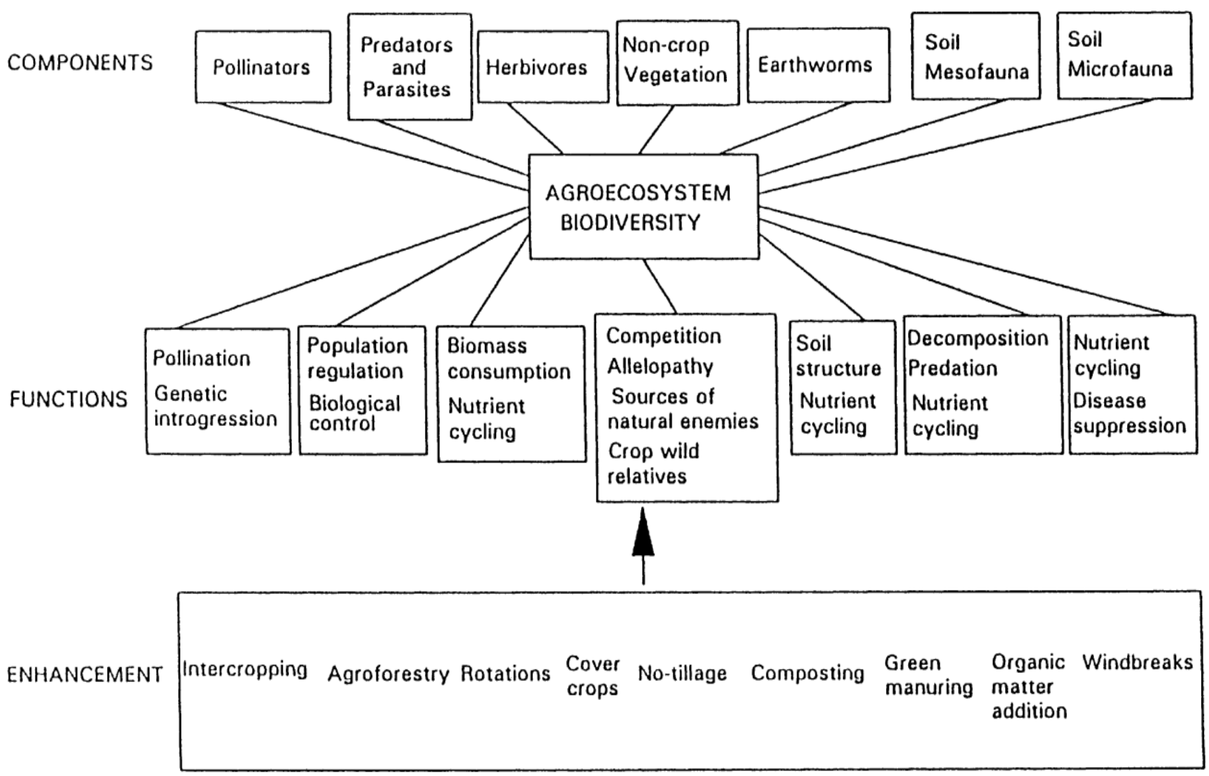
1. The diversity of vegetation within and around the agroecosystem.
2. The permanence of the various crops within the agroecosystem.
3. The intensity of management.
4. The extent of the isolation of the agroecosystem from natural vegetation.

The biodiversity components of agroecosystems can be classified in relation to the role they play in the functioning of cropping systems According to this, agricultural biodiversity can be grouped as follows.

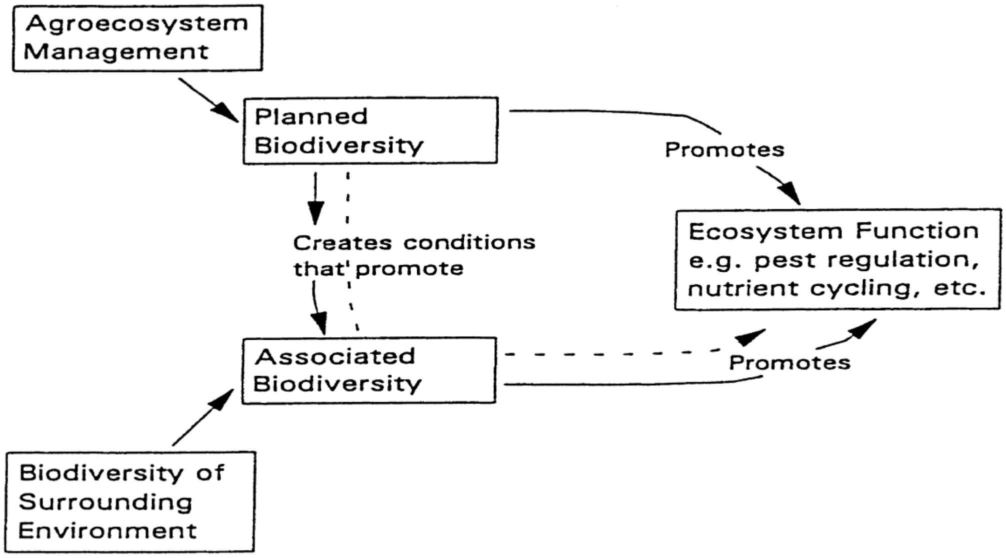
Productive biota: crops, trees and animals chosen by farmers which play a determining role in the diversity and complexity of the agroecosystem.

Resource biota: organisms that contribute to productivity through pollination, biological control, decomposition, etc.

Destructive biota: weeds, insect pests, microbial pathogens, etc. which farmers aim at reducing through cultural management



The components, functions, and enhancement strategies of biodiversity in agroecosystems

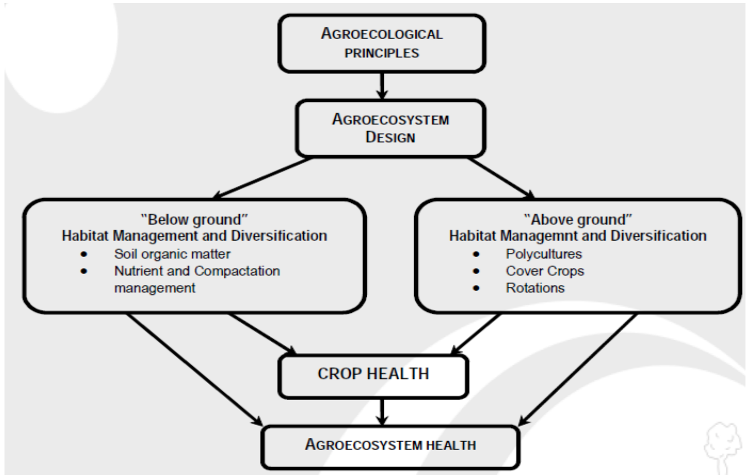


The relationship between planned biodiversity and associated and how the two promote ecosystem function

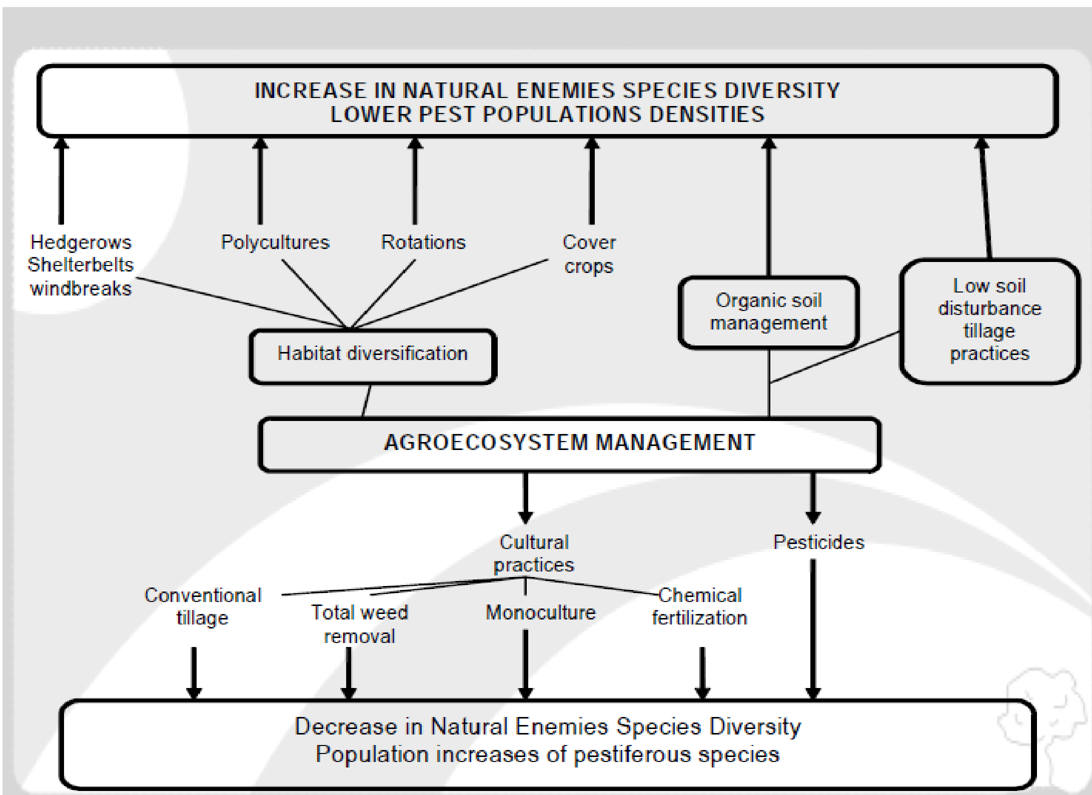
Agroecology provides basic ecological principles on how to study, design and manage agroecosystems that are productive, enduring and natural resource conserving. Agroecosystems can be manipulated to improve production andproduce more sustainably, with fewer negative environmental and social impacts and fewer external inputs. The design of such systems is based on the application of the following ecological principles

1. Enhance recycling of biomass and optimizing nutrient availability and balancing nutrient flow.
2. Securing favorable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biotic activity.
3. Minimizing losses due to flows of solar radiation, air and water by way of microclimate management, water harvesting and soil management through increased soil cover.
4. Species and genetic diversification of the agroecosystem in time and space.
5. Enhance beneficial biological interactions and synergisms among agrobiodiversity components thus resulting in the promotion of key ecological processes and services.

These principles can be applied by way of various techniques and strategies



Summary of how agro ecosystem design may affect the health of crops and the agro ecosystem.



The effects of agroecosystem management and associated cultural practices on the diversity of natural enemies and the abundance of insect pests.

In india there are several classifications of agro-climatic regions and soils proposed by several agencies. The reader is advised to study the earlier booklets on the related topics "Land Capability Classification" Booklet No.518 and " Agro-climatic Divisions of India" Booklet No.521. This booklet is on the agro-ecological regions of India; but there may be several things similar to the Booklet on Agro-climatic Divisions of India.

Planning Commission as part of the mid-term appraisal of the planning targets of VII Plan (1985-1990) divided the country into 15 broad agro-climatic zones based on physiography and climate. They are the following

1. Western Himalayan Region, 2. Eastern Himalayan I Region, 3. Lower Gangetic Plains Region, 4. Middle Gangetic Plains Region, 5. Upper Gangetic Plains Region, 6. Trans-Gangetic Plains Region, 7. Eastern Plateau & Hills Region, I 8. Central Plateau and Hills Region, 9. Western Plateau and Hills Region,10. Southern Plateau and Hills Region, 11. East Coast Plains and Hills Region, 12. West Coast plains & Hills Region, 13. Gujarat Plains & Hills Region, 14. Western Dry Region and 15. The Island Region.

ECOSYSTEM SERVICES AND THEIR SIGNIFICANCE

Rivers, streams and wetlands provide people with a wide range of benefits often referred to as "Ecosystem Services"

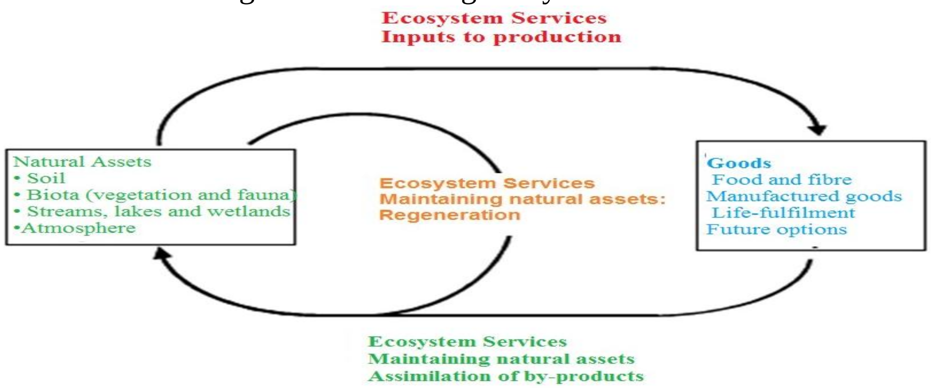
Ecosystem Services Approach

Provides a frame work by which ecosystem services are integrated into public and private decision making.

Its implementation typically incorporates a variety of methods includes

1. Ecosystem service dependency and impact assessment
2. Valuation
3. Scenarios

policies and other interventions targeted at sustaining ecosystem services



1)Transformations of natural assets into products valued economically

(2) Transformations of the by-products - ecosystem services back into natural assets

(3) internal transformations among natural assets to maintain those assets

Ecosystem services into four broad categories:

1. Provisioning services - the goods or products obtained from ecosystems
2. Regulating services - the benefits obtained from an ecosystem's control of natural processes
3. Cultural services - the nonmaterial benefits people obtain from ecosystem services
4. Supporting services - the underlying processes that are necessary for the production of all other ecosystem services

1. *Provisioning services - the goods or products obtained from ecosystems*			
Service	**Sub-category**	**Definition**	**Examples**
Food	Crops	Cultivated plants or agricultural produce which are harvested by people for human or animal consumption	Grains Vegetables Fruits
	Livestock	Animals raised for domestic or commercial consumption or use	Chicken Pigs Cattle
	Capture fisheries	Wild fish captured through trawling and other non-farming methods	Cod Shrimp Tuna
	Aquaculture	Fish, shellfish, and/or plants that are bred and reared in ponds	Clams Oysters Salmon
	Wild foods	Edible plant and animal species gathered or captured in the wild	Fruits and nuts Fungi Bush meat
Fiber	Timber and wood fibers	Products made from trees harvested from natural forest ecosystems, plantations, or	Industrial round wood Wood pulp

		non-forested lands	Paper
	Other fibers (e.g., cotton, hemp, silk)	Non-wood and non-fuel based fibers extracted from the natural environment for a variety of uses	Textiles Cordage (twine, rope)
Biomass fuel		Biological material derived from living or recently living organisms –both plant and animal – that serves as a source of energy	Fuel wood, Grain for thanol production, Dung
Freshwater		Inland bodies of water, groundwater, rainwater, and surface waters for household, industrial, and agricultural uses	Freshwater for drinking, cleaning,
Genetic resources		Genes and genetic information used for animal breeding, plant improvement, and biotechnology	Genes used to increase crop Resistance
Biochemicals, natural medicines, and pharmaceuticals		Medicines, biocides, food additives, and other biological materials derived from ecosystems for commercial or domestic use	cancer drugs, Tree extracts used for pest control
2. Regulating services - the benefits obtained from an ecosystem's control of natural processes			
Air quality regulation		Influence ecosystems have on air quality by emitting chemicals to the atmosphere or extracting chemicals from the atmosphere	Lakes serve as a sink for industrial emissions of sulfur Compounds
Climate regulation	Global	Influence ecosystems have on the global climate by emitting greenhouse gases or aerosols to the atmosphere	Forests capture and store carbon dioxide , Cattle and rice paddies emit methane
	Regional and local	Influence ecosystems have on local or regional temperature, precipitation and other climatic factors	Forests can impact regional rainfall levels
Water regulation		Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge	Permeable soil facilitates,
Erosion regulation		Role vegetative cover plays in soil retention	Vegetation such as grass and trees prevents soil loss
Water purification and waste treatment		Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water	Soil microbes degrade organic waste rendering it less harmful
Water purification and waste treatment		Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water	Soil microbes degrade organic waste rendering it less harmful

Disease regulation		Influence that ecosystems have on the incidence and abundance of human pathogens	standing water, a breeding area for mosquitoes
Pest regulation		Influence ecosystems have on the prevalence of crop and livestock pests and diseases	Predators from nearby forest, such as bats, toads, snakes
Pollination		Animal-assisted pollen transfer between plants, without which many plants cannot reproduce	Bees from nearby forests pollinate crops

3. Cultural services - the nonmaterial benefits people obtain from ecosystem services

Service	Definition	Examples
Ethical values	Spiritual, religious, aesthetic, intrinsic or other values people attach to ecosystems, landscapes, or species	Spiritual fulfillment derived from sacred lands and rivers
Existence values	The value that individuals place on knowing that a resource exists, even if they never use that resource.	Belief that all species are worth protecting regardless of their utility to human beings
Recreation and ecotourism	Recreational pleasure people derive from natural or cultivated ecosystems	Hiking, camping and bird Watching Going on safari

4. Supporting services - the underlying processes that are necessary for the production of all other ecosystem services

Service	Definition
Nutrient cycling	Process by which nutrients – such as phosphorus, sulfur and nitrogen – are extracted from their mineral, aquatic, or atmospheric sources or recycle from their organic forms and ultimately return to the atmosphere, water, or soil
Soil formation	Soil formation Process by which organic material is decomposed to form soil
Primary production	Formation of biological material through assimilation or accumulation of energy and nutrients by organisms
Photosynthesis	Process by which carbon dioxide, water, and sunlight combine to form sugar and oxygen
Water cycling	Flow of water through ecosystems in its solid, liquid, or gaseous forms

what are the ecosystem services that are essential for agriculture?

(a) Pollination

- Pollination is another important ecosystem service to agriculture that is provided by natural habitats in agricultural landscapes.
- Approximately 65 per cent of plant species require pollination by animals, & an analysis of data from 200 countries indicated that 75 % of crop species of global significance for food production rely on animal pollination, primarily by insects.

- Only 35–40% of the total volume of food crop production comes from animal-pollinated crops, however, since cereal crops typically do not depend on animal pollination.

(b)Ecosystem services flowing to agriculture

- The production of agricultural goods is highly dependent on the services provided by neighbouring natural ecosystems,

Biological pest control

- Biological control of pest insects in agro ecosystems is an important ecosystem service that is often supported by natural ecosystems.
- Non-crop habitats provide the habitat and diverse food resources required for arthropod predators and parasitoids, insectivorous birds and bats, and microbial pathogens that act as natural enemies to agricultural pests and provide biological control services in agroecosystems.

These biological control services can reduce populations of pests, thereby reducing the need for pesticides

(c) Water quantity and quality

- The provision of sufficient quantities of clean water is an essential ecological service provided to agroecosystems, and agriculture accounts for about 70 per cent of global water use (FAO 2003).
- Perennial vegetation in natural ecosystems such as forests can regulate the capture, infiltration, retention and flow of water across the landscape.
- The plant community plays a central role in regulating water flow by retaining soil, modifying soil structure and producing litter.

(d) Soil structure and fertility

- Soil structure and fertility provide essential ecosystem services to agroecosystems (Zhang et al. 2007).
- Well-aerated soils with abundant organic matter are fundamental to nutrient by crops, as well as water retention.
- Soil pore structure, soil aggregation and decomposition of organic matter are influenced by the activities of bacteria, fungi and macro fauna, such as earthworms, termites and other invertebrates.

  Micro-organisms mediate nutrient availability through decomposition of detritus and plant residues and through nitrogen fixation

(e) Landscape influences on the delivery of ecosystem services to agriculture

- The delivery of ecosystem services to agriculture is highly dependent on the structure of the landscape in which the agroecosystem is embedded.
- Agricultural landscapes span a succession from structurally simple landscapes dominated by one or two cropping systems to complex mosaics of diverse cropping systems embedded in a natural habitat matrix .
- In complex landscapes, natural enemies and pollinators move among natural and semi-natural habitats that provide them with resources that may be scarce in crop fields.

Ecosystem disservices from agriculture

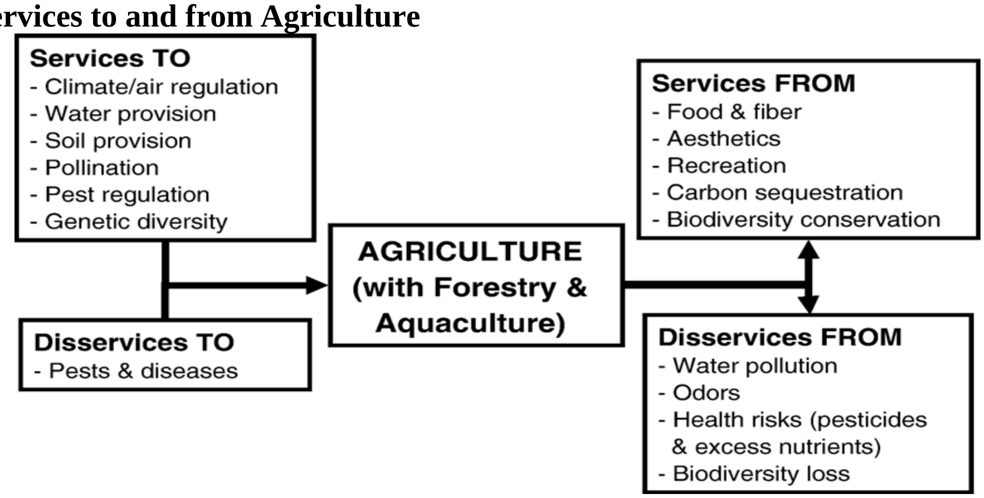
- (a) Agriculture can also be a source of disservices, including loss of biodiversity, agrochemical contamination and sedimentation of waterways, pesticide poisoning of non - target organisms, and emissions of greenhouse gases and pollutants.
- Nutrient cycling and pollution- From the local scale to the global scale, agriculture has profound effects on biogeochemical cycles and nutrient availability in ecosystems.
- The two nutrients that most limit biological production in natural and agricultural ecosystems are nitrogen and phosphorus, and they are also heavily applied in agroecosystems.
- Nitrogen and phosphorus fertilizers have greatly increased the amount of new nitrogen and phosphorus in the biosphere and have had complex, often harmful, effects on natural ecosystems

- The anthropogenically mobilized nutrients have entered both groundwater and surface waters, resulting in many negative consequences for human health and the environment.
- Approximately 20 per cent of N fertilizer applied in agricultural systems moves intoaquatic ecosystems (Galloway et al. 2004).
- Impacts of nutrient loss from agroecosystems include groundwater pollution and increased nitrate levels in drinking water, eutrophication, increased frequencyand severity of algal blooms,.
- Agricultural intensification in the landscape can diminish other ecosystem services as well. Protection of groundwater and surface water quality can be threatened by intensification because of increased nutrients, agrochemicals and dissolved salts.
- Other ecosystem disservices from agriculture include applications of pesticides that result in loss of biodiversity.
- pesticide residues in surface and groundwater, which degrades the water provisioning services provided by agroecosystems.
- Emissions of greenhouse gases Agricultural activities are estimated to be responsible for 12–14% of global anthropogenic emissions of greenhouse gases.
- Conversion of natural ecosystems to agriculture reduces the soil carbon pool by 30–50% over 50–100 years in temperate regions and 50–75% over 20–50 years in the tropics

Ecosystem services from agriculture

- On-farm management practices can significantly enhance the ecosystem services provided by agriculture.
- Habitat management within the agroecosystem can provide the resources necessary for pollinators or natural enemies.
- Many studies have identified the important role of perennial vegetation in supporting biodiversity in general and beneficial organisms in particular.
- Agriculture (including planted forests) conventionally supplies food, fiber, and fuel—“provisioning services” in Ecosystem Services

Ecosystem services to and from Agriculture



Pest Resistance to Pesticides

Controlling Pests with Pesticides

Humans have been controlling or attempting to control insect and other arthropod pests, plant pathogens, weeds, rodents, and other vertebrate pests for thousands of years. However, it has been only within the last 50 years that significant progress has been made in controlling pests of humans and our food, fiber, animals, and the structures in which we live and work. This significant advance has occurred because of synthetic (man-made) pesticides, including insecticides, herbicides, fungicides, rodenticides, and algicides. Early successes with the first pesticides, such as DDT, came swiftly. Was the war against pests won so easily? Very soon after the rapid and astounding victories over mosquitoes and other biting flies, house flies, lice, and agricultural pests such as scale insects, a decline in the effectiveness of these new chemical weapons was observed. Application rates (ie., amounts used) were increased to regain the initial levels of control. However, the levels of control seemed to decline even more rapidly. The reduced levels of control, and eventual control failure in many instances, was found to be due to resistance of the pests to these chemicals.

What Is Pesticide Resistance?

Pesticide resistance is a genetically based phenomenon. Resistance occurs when a pest population— insects, for instance— is exposed to a pesticide. When this happens, not all insects are killed. Those individuals that survive frequently have done so because they are genetically predisposed to be resistant to the pesticide. Repeated applications and higher rates of the insecticide will kill increasing numbers of individuals, but some resistant insects will survive. The offspring of these survivors will carry the genetic makeup of their parents. These offspring, many of which will inherit the ability to survive the exposure to the insecticide, will become a greater proportion with each succeeding generation of the population.

Because of the rapid reproductive rate of many pests — a generation of many insects can take place in a few weeks — many generations can be produced in a single season or year. It's easy to see that repeated applications of an insecticide will quickly eliminate all susceptible insects in the population, essentially selecting out those individuals that are resistant. In a short period the entire population of insects will be resistant. The more times a population is exposed to a pesticide, especially a broad-spectrum pesticide, the more quickly resistance will develop. Resistance develops in a similar manner in other pests, such as plant disease agents, weeds, and rodents. Ironically, to produce a resistant population one must start with a pesticide that initially gives very good control.

The Pesticide Resistance Problem

Today, pests that were once major threats to human health and agriculture but that were brought under control by pesticides are on the rebound. Mosquitoes that are capable of transmitting malaria are now resistant to virtually all pesticides used against them. This problem is compounded because the organisms that cause malaria have also become resistant to drugs used to treat the disease in humans. Many populationsof the corn earworm, which attacks many agricultural crops worldwide including corn, cotton, tomatoes, tobacco, and peanuts, are resistant to multiple pesticides.

Because many generations of some pests can develop in a single year, it is easy to see how resistance can develop so quickly in so many pest species. Recent studies indicate there are now over 500 species of insects and mites resistant to pesticides. Over 270 weed species, over 150 plant pathogens, and about a half dozen species of rats are resistant to pesticides that once controlled them.

Multiple resistance—resistance to more than one pesticide and to pesticides in more than one chemical class—is increasing rapidly. There are over 1,000 insect/insecticide resistance combinations, and at least 17 species of insects that are resistant to all major classes of insecticides.

Pesticides should not be considered the sole or even the primary solution to a pest problem. However, pesticides are frequently an integral part of a pest management program. Pesticide resistance dramatically lessens our ability to bring pest numbers below damaging levels in such a program.

Combatting Resistance

After a pest species develops resistance to a particular pesticide, how do you control it? One method is to use a different pesticide, especially one in a different chemical class or family of pesticides that has a different mode of action against the pest. Of course, the ability to use other pesticides in order to avoid or delay the development of resistance in pest populations hinges on the availability of an adequate supply of pesticides with differing modes of action. This method is perhaps not the best solution, but it allows a pest to be controlled until other management strategies can be developed and brought to bear against the pest. These strategies often include the use of pesticides, but used less often and sometimes at reduced application rates.

The Decreasing Availability of Pesticides

More and more pest species are becoming resistant to pesticides at an increasing rate. For many reasons, the availability of pesticidal products that can be used in rotation against pests is decreasing. The costs of developing a pesticide(i.e., the cost of research and testing, product development, etc.) are significant. Millions of dollars are spent on chemicals that may never become marketable products. Regulatory actions have affected pesticide availability. The U.S. Environmental Protection Agency has banned and restricted many pesticides in the past two decades.

Another factor in the decreasing availability of pesticides, especially from the supply of existing pesticides, is the EPA’s reregistration of pesticides. This reregistration program often requires additional testing of pesticides to determine if their use would possibly endanger the health of humans and our environment. It is difficult to argue with the basic rationale of those requirements. However, the cost of complying with EPA’s reregistration requirements for testing, plus the subsequent reregistration fees, is having a heavy impact on the current and future availability of pesticides. Many pesticide manufacturers are simply declining to reregister their products because the reregistration costs will severely reduce or eliminate potential profits from future product sales. More important, many individual active ingredients are already lost. Between pesticide cancellations and the reregistration process, whole classes of active ingredients are at risk of being lost from future use.

BIOLOGICAL CONTROL FOR PEST MANAGEMENT

Biological control is the use by man of natural enemies to control or reduce the number of pest animal or weed. It involves the action of parasites predators and pathogens in maintaining another organisms density at a lower level than would occur in their absence. In simple terms biocontrol can be defined as the use of living organisms for pest control.

The first spectacular success was noticed in 1888 when the cotton cusion scale, *Icerya purchasi* was controlled in California by introducing a lady bird beetle, *Rodolida cardinalis*. Biological control of weeds started in 1902 by using *Teleonemia scrupulosa* for the control *Lantana.* Mass-multiplication and release of egg parasite, *Trichogramma* started in USSR during 1913. After the Second World War, biocontrol was eclipsed by chemicals but now it is seriously considered as a main component in the Integrated Pest Management.

The organisms used for biocontrol are termed as bioagents, natural enemies, crop protectors, crop defenders or simply as farmers' friends. They can be categorized as :-

1. **Parasites :** A parasite is an organism living at the expense of another organism deriving its nourishment from the host. Parasites are not necessarily lethal since the death of host means the death of parasite also. Therefore, a well adapted parasite should not kill the host but minimize the damage. eg. Nematodes.
2. **Parasitoids :** Parasitic insects are called parasitoids. The free living adult feeds entirely in a different way than the parasitic larva. eg. Wasps.
3. **Predators :** Predators are free living and consume a number of individual prey during their lives. eg. Ladybirds, spiders etc,.
4. **Pathogens :** These are parasitic micro-organisms causing outbreaks of disease in the host. eg. Bacteria, fungi and viruses.
5. **Phytophagous :** These are a special category of highly specific organisms used for weed control.

Types of biological control

There are three major types of biological control

1. Classical biological control
2. Augmentation
3. Conservation

1. Classical biological control

Classical biological control is the introduction of natural enemies to a new locality where they did not originate or do not occur naturally. This is usually done by government authorities. In many instances the complex of natural enemies associated with an insect pest may be inadequate. This is especially evident when an insect pest is accidentally introduced into a new geographic area without its associated natural enemies. These introduced pests are referred to as exotic pests.

This is the practice of importing, and releasing for establishment, natural enemies to control an introduced (exotic) pest, although it is also practiced against native insect pests. The first step in the process is to determine the origin of the introduced pest and then collect appropriate natural enemies associated with the pest or closely related species. The natural enemy is then passed through a rigorous quarantine process, to ensure that no unwanted organisms (such as hyperparasitoids) are introduced, then they are mass produced, and released. Follow-up studies are conducted to determine if the natural enemy becomes successfully established at the site of release, and to assess the long-term benefit of its presence.

Examples: One of the earliest successes in the west was in controlling *Icerya purchasi*, the cottony cushion scale, a pest that was devastating the California citrus industry in the late 19th century. A predatory insect *Rodolia cardinalis* (the Vedalia Beetle), and a parasitoid fly were introduced from Australia by Charles Valentine Riley. Within a few years the cottony cushion scale was completely controlled by these introduced natural enemies.

- Control of Prickly pear, *Opuntia Spp* in Australia with the Pyralid, *Cactoblastis coctorum* imported from Argentina in 1920,s
- The control of coconut moth *Levuana iridescens* in the Fiji Islands with the tachinid fly *Bessa romata* imported from Malay in 1925.
- The control of papaya mealybug, *Paracoccus marginatus* (a native of Mexico) in India with *Acerophagus papaya*
- Control of Eucalyptus gall wasp/Blue gum gall wasp: *Leptocybe invasa* (from Southeast Asia 2006) by *Quadrastichus mendeli* and *Selitrichodes kryceri*
- Control of Erythrina gall wasp *Quadrastichus erythrinae* (from East Africa) by *Eurytoma erythrinae* and *Aprostocetus exertus* (from South Africa and Tanzania)
- Control of Coffee berry borer, *Hypothenemus hampei* by *Cephalonomia stephanoderis*

Neoclassical biological control : A form of inoculative biological control in which natural enemies are imported from elsewhere and released in small numbers in attempt to establish a permanent population to control a native pest with which they have not co-evolved.

Examples:

- Control glassy-winged sharpshooter (GWSS; *Homalodisca vitripennis*; formerly *H. coagulata*) egg masses in California by *Gonatocerus tuberculifemur* - sharpshooter parasitoid from Argentina
- Control of *Levuana iridescens* (the coconut moth of Fiji) by the tachinid fly, *Bessa remota*, introduced from Malaya

2. Augmentative Biological control

It is defined as the efforts to increase populations of natural enemies either by propagation and release or by environmental manipulation.

It involves the supplemental release of natural enemies. Relatively few natural enemies may be released at a critical time of the season (inoculative release) or literally millions may be released (inundative release). Additionally, the cropping system may be modified to favor or augment the natural enemies. This latter practice is frequently referred to as habitat manipulation.

There are two types of augmentative biological control

1**. Inoculative releases:** An inoculative release involves releasing small numbers of a natural enemy into a crop cycle with the expectation that they will reproduce in the crop and their offspring will continue to provide pest control for an extended period of time.In this case control is expected from the progeny and subsequent generations and not from the release itself.

Eg: Periodic releases of the parasitoid, *Encarsia formosa*, are used to control greenhouse whitefly, Predaceous mite, *Phytoseiulus persimilis*, is used for control of the two-spotted spider mite.

2. Inundative releases: Inundative or mass-release, is used when insufficient reproduction of released natural enemies is likely to occur, and pest control will be achieved exclusively by the released individuals themselves.

It involves mass culture and release of natural enemies to suppress the pest population directly as in the case of conventional insecticides. These are most economical and against pests that have only one or the most a few discrete generations every year.
Eg: Mass release of *Trichogramma* egg parasitoids, predators like green lace wings, *Chrysoperla cornea* and lady bird beetles, *Coccinellid spp.*

3. Conservation

This is the most important and readily available biological control method. It is define as the actions to preserve and increase natural enemies by environmental manipulation.

In other words conservation means the avoidance of measures that destroy natural enemies and the use of measure that increase their longevity and reproduction of the attractiveness of an area to natural enemies. If the natural enemies are properly conserved the need for other control measures is greatly reduced.

i) Preservation of Inactive Stages:

This is most critical when there is small reservoir of natural enemies outside the cropped area e.g. Pupae of Epipyrops are found in large numbers on the trashes of sugarcane leaves at the time of harvesting. These are left around harvested fields to augment the supply of natural enemies in the pre-monsoon season against pyrilla.

ii) Avoidance of Harmful Cultural Practices:

Cultural practices like burning can be harmful to natural enemies e.g. burning of sugarcane trash destroy the resting stages of Epipyrops. Such practices can be modified to avoid harmful effects.

iii) Maintenance of Diversity:

The concept more the diversity more is the stability holds true because diverse system may provide alternate hosts as source of food, ever wintering sites, refuges etc. e.g. mixed cropping, intercropping etc.

iv) Natural Food, Artificial Food Supplements and Shelters:

Many parasitoids and predators require food frequently not available in monoculture. The availability of predatory mites was related to the availability of pollen. Artificial honey dew and pollen in the form of food sprays induced early ovipositor of Chrysopera spp.

V) Protection from Pesticides:

All pesticides have adverse effects on natural enemies. The solution lies in the use of relatively resistant strains of natural enemies and selective use of pesticides.

Approach to Biological Control

1. Gather information regarding identity, origin and biology of the pest and natural enemy complex.
2. Conduct survey to know the natural enemies available and their abundance. Analyse and select suitable ones.
3. Screen the selected candidates for safety so that they do not pose threat to useful animals and plants, particularly in weed control.
4. Develop suitable mass-rearing technique.
5. Release adequate numbers. A void releasing during hot, windy, wet weather conditions. Avoid long journey and exposure to heat or cold during transit. Ensure that adults are well fed, mated and are ready for oviposition. Avoid releasing old or very young material. Also avoid sprayed crops or those which are ready for harvest.
6. Evaluate whether the natural enemy released has been effective or not. Inform others who may have a similar problem.

Advantages

Biological control, if properly applied, is non-polluting, specific to the target pest or a narrow group of pests, unlikely to lead to resistance and in some cases works out to be cheap as recurrent input is not required once control is established.

Disadvantages

Biocontrol is not possible with all pests and is difficult to implement when there is a complex of pest. Generally, there is initial high cost without guarantee. It is difficult to get trained people and cooperation from farmers.

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Concepts of Biosecurity

INTRODUCTION:

Since the dawn of civilization, man utilized his best possible efforts to domesticate the bounty of nature as per his needs. It is not just in recent years that the countries are being invaded by alien species, since time immemorial, man started to move the plants and animals wherever he fancied. In a way it paved way for species richness in newer area and domestication has become part of human settlement. It is not true that all alien species are harmful or dangerous, even the invasive species are not so dangerous in their place of origin, as the invasiveness is curtailed due to influence of many factors of the particular ecosystem. The alien species become invasive in newer area due to absence of natural enemies and congenial environmental parameters. Some alien species became beneficial and some became nuisance. In the past scores of plants and animals have been exchanged, moved or introduced to newer horizons due to human aided activities. The introduction of localized species to cross the physical boundaries is made possible only by means of human interference. For example, the first record of **coffee** growing in India is traced back to 1670 in the hills of Chikmagalur, Karnataka and supposed to be introduced from Yemen (Widipedia). **Potato** was introduced to Europe from Andes (South America) by the Spanish in second half of 16th century and Potato was introduced into India in the early 17th century, most likely aboard Portugal ships, and presently a third of world production of potato is harvested in India and China (FAOSTAT). Similarly **Chilli** was introduced into India from Mexico during 15th century and it has become the integral part of Indian culinary. India is the leading producer of Chilli in the world. In India, commercial cultivation of natural **Rubber** was introduced by the British planters, although the experimental efforts to grow rubber on a commercial scale in India were initiated as early as 1873 at the Botanical Gardens, Calcutta, the first commercial *Hevea* plantations in India were established at Thattekadu in Kerala in 1902. In the 19th and early 20th century, it was often called "India rubber." Vice-a-verse, there are lots of such economically valuable plant species which originated in India is now spread to all over the world. To site a few examples: Black pepper, Tea, Cardamom, Coconut, Neem, Mango etc.

Effect of Invasive species:

Though the countries have benefitted from exchange or intentional / unintentional introduction of new species, it has not always ended up with beneficial results. History is rich with tales of the disastrous outcomes of some intentional introductions. Further careless behavior by man leads to unintentional introductions, the so-called ‘accidents’ now account for the majority of disastrous invasions. The following are few of such catastrophes of introduced invasive alien species around the globe:

- **Great Famine of Irish**: Potato was introduced into Ireland as a garden crop and during late 17th century it was consumed as supplementary food. By early 18th century, it assumed the status of staple food for the poor during winter season and as well considered as agrarian economy as it fetched more money and hence grown in more acreage (<60%). In 1843-44, a new disease started to destroy the crops and was identified as late blight of potato, *Phytophthora infestans.* Late blight of potato infection completely destroyed potato crop in 1845, which lead to the starvation and death of 1 million people and migration of another 1 million from Ireland between 1845 to 1852. The unfortunate event of late blight devastation occurred due to incursion of *Phytophthora infestans* from USA, which caused loss of around £3,500,000 potatoes.
- **Toppling of Grapevine industry in Europe**: Classical example of transboundary movement of plant pests is the introduction of Powdery mildew (*Oidium tuckeri*) into Europe with American

grape-vines. Its pathogenecity on European grape vine was unknown at that time and the disease spread like wild fire on European grape vines (1850). To control powdery mildew, root-stocks of resistant varieties were imported from America (1854). However, these grape vines carried *Phylloxera vastatrix*, a root inhabiting aphid of grape vines. To combat this pest, more American vines resistant to Phylloxera were introduced, but these additional introductions brought with them the downy mildew (*Plasmopara viticola*), and black rot (*Guignardia bidwellii*). In France, where the vine industry was thriving, had to face the burnt of these pest incursions and many business men abandoned vine production and emigrated to Algeria and other countries. Further, these incidences lead to the formulation of Bordeaux mixture pesticide.

- **Colossal toad menace**: The cane toad, *Bufo marinus*, (Giant neotropical toad), native of central and south America, was introduced into Australia by the sugarcane industry to control two pests, the grey backed cane beetle (*Dermolepida albohirtum*) and frenchie beetle (*Lepidiota frenchi*). 101 toads were imported in June1935 and within 6 months the population exploded to 60000 and was released in the cane fields. Initially, the bio-control agent was so successful, whereas it became a environmental menace in a short period of time, causing ecological imbalance replacing the native frogs due to its over population, further, it became the reason for extinction of snake and fox species due to consumption of this poisonous toad. Even the tadpoles are poisonous.
- **Green Cancer of Tahiti**: The prolific tree *Miconia calvescens* has overrun Tahiti's native forests. Miconia is one of the most destructive invaders in tropical rain forest habitats. It is a serious threat to ecosystems in the Pacific because of its ability to invade intact native forests. Miconia has earned itself the descriptions such as the 'green cancer of Tahiti' and the 'purple plague of Hawaii'. Once miconia is established at a certain place it drastically changes the ecosystem and biodiversity of that environment.
- **Food turned foe**: Philippine rice farmers have lost nearly US$1 billion in crops to the invasive golden apple snail, *Pomacea canalicualata* which was originally introduced from South America to south-east Asia around 1980, as a local food resource and as a potential gourmet export item. The markets never developed; the snails escaped or were released, and became a serious pest of rice.
- **Water weeds**: African nations spend an estimated US$60 million annually on the control of alien water weeds, like water hyacinth *Eichhornia crassipes* and water lettuce *Pistia stratiotes*.
- **Fang's of greed:** Brown snake (*Boiga irregularis*) was accidentally introduced into Guam. The brown snake decimated Guam's local bird species and herpatofauna, causing extinction of half of native birds and lizard species and 2/3rd of bat species. By eliminating the pollinators, the brown snake invasion has caused a cascading effect on Guam's ecosystems, reducing pollination by lizards and birds and reducing plant regeneration and coverage as a consequence.
- **Malaria menace**: Avian malaria, through its mosquito vector has contributed to the extinction of at least 10 native bird species in Hawaii and threatens many more.

The potential dangers imposed by invasive species on plant, animal and human health and the ecological and environmental impacts exerted all over the globe, has created awareness on preserving the natural flora and fauna of a nation, and at the same time to promote safe trade, the need for global level coordination in harmonizing the sanitary and phytosanitary measures (SPS) was initiated through WTO-SPS agreements. The SPS measures are operated through standard setting bodies such as IPPC (International Plant Protection Convention), Rome for plant health, OIE (Office international des epizooties) for animal health and CAC (Codex Alimentarius Committee) for human health related issues at international level. FAO (Food and Agriculture Organization) has realized the potent threat of bioinvasion and bioterrorism and introduced the new concept of ‘Biosecurity’ within the ambience of safeguarding the biodiversity of a nation.

The exponential expansion of trade in agricultural material and the speed at which the agricultural products are moving around the globe, coupled with the removal of trade restrictions in post-WTO era, the chance of pests, diseases and harmful organisms to move to hitherto unrecorded areas are high. It is very natural for the associated pests to trod around the globe along with plant products to newer areas, but the unnatural events of record of invasive alien species in the recent times owing to the human interference is happening at an higher scale than the pest can move around from its place of origin on its own. In the fast phased developments in international trade and tourism, there is an increased risk of introduction of exotic pests into the country. On the other hand, the threats posed by introduction of Living Modified Organisms (LMO) and the effects of GMO on human, animal and plant health are unknown. Bio-terrorism and biological warfares are the major emerging threats at international level, which can dismantle the entire nation’s economy, growth and loss of lives. Apart from all these visible dangers, transboundary diseases of virulent strains of pathogens of human, animal and plant health poses greater threat to health, food and economy. It is because of these vulnerable factors that agricultural biosecurity has emerged as an urgent issue, which requires implementation of regulations, policies, enhancement of technological capabilities and human capacity building to meet such threats.

National regulatory and export certification systems are being challenged by large increases in the volume of food and agricultural products being traded internationally, by the expanding variety of imported products and by the growing number of countries from which these imports are originating. Increased travel is also creating more pathways to spread pests, diseases and other hazards that are moving faster and further than ever before. Improved coordination is being sought among national bodies responsible for enforcing sanitary, phytosanitary and zoosanitary measures to better protect human, animal and plant life and health without creating unnecessary technical barriers to trade. There is an urgent need to protect the biosecurity of a nation from the bio-invaders to sustain food security and preserve biodiversity. ‘Biosecurity’ is a relatively a new concept and a term that is evolving as usage varies from country to country with different specialist groups using in different ways.

NEED FOR AGRICULTURAL BIOSECURITY AT GLOBAL AND NATIONAL LEVEL:

The world has truly become a global village with reference to communication and transport. The globalization of trade and disappearance of tariff barriers in trade has opened flood-gates of alien species to move around the world at a faster rate and speed. This really poses greater implications in the context of agricultural biosecurity of a nation. The later part of WTO regime is witnessing mass invasion of pests into newer areas, causing devastations and unbalancing the economy of many nations. Developing and underdeveloped countries are the most affected in the absence of preparedness to combat the invasion. The latest report of **Cotton mealy bug** (*Phenococcus solenopsis*), native of USA into Pakistan and India are major concern to the sub-continent. India, being a lead producer of cotton with more than 60 million people dependent on cotton farming is worst affected since its report in 2005. The cotton mealy bug is reported in all the states of cotton belt. Similarly introduction of **Papaya mealy bug** (*Paracoccus marginatus*) into India (2008) is a growing concern, which is likely to cripple the export potential of papaya. The transboundary movements of pathogens are posing major threats to plant, animal and human health. The incursions of Avian influenza virus, Swine flu, SARS etc., also reinstates the urgent need to strengthen biosecurity of our nation. The ISSG (Invasive Species Specialist Group) of IUCN (International Union for Conservation of Nature) has identified **100 of the World’s Worst**

Invasive Alien Species, which includes plants, animals and pests. From the identified list, unfortunately **12 invasive species** of plants and plant pests have invaded into India. Such as:

- Banana bunchy top virus
- Phytophthora root rot (*Phytophthora cinnamomi*)
- Water hyacinth (*Eichhornia crassipes*)
- Black wattle (*Acacia mearnsii*)
- Gorse (*Ulex europaeus*)
- Lantana (*Lantana camara*)
- Mile-a-minute weed (*Mikania micrantha*)
- Mimosa (*Mimosa pigra*)
- Siam weed (*Chromolaena odorata*)
- Crazy ant (*Anoplolepis gracilipes*)
- Sweet potato whitefly (*Bemisia tabaci*)
- Giant African snail (*Achatina fulica*)

DEFINITIONS:

'***Biosecurity***' broadly describes the process and objective of managing biological risks associated with food and agriculture in a holistic manner (FAO).

'***Biosecurity***' is a strategic and integrated approach consisting of policy and regulatory frameworks to analyze and manage risks to human, animal and plant life and health, and associated risks to the environment.

'***Biosecurity***' is a balancing act between a nation and people and encouraging tourism and international trade that are vital to a nation's economy.

'Biosecurity' covers the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and management of invasive alien species and genotypes. *Biosecurity* is a holistic concept of direct relevance to the sustainability of agriculture, food safety, and the protection of the environment, including biodiversity.

FAO TECHNICAL CONSULTATION ON BIOSECURITY AND ITS OUTCOME:

In order to broaden awareness of *Biosecurity* and to debate its relevance and practicality more widely, particularly in relation to the needs of developing countries and countries with economies in transition, FAO convened an international Technical Consultation in Bangkok, 13-17 January 2003, with the participation of 38 countries and eight international organizations, including *Codex Alimentarius*, the IPPC, OIE, and the CBD.

Need for Biosecurity

- Rapid transboundary movement of men and materials
- Removal of quantity restrictions in international trade
- Threats posed by incursion of pests and diseases of plants, animals and human
- Threats posed by LMO's
- Threats posed by bioterrorism

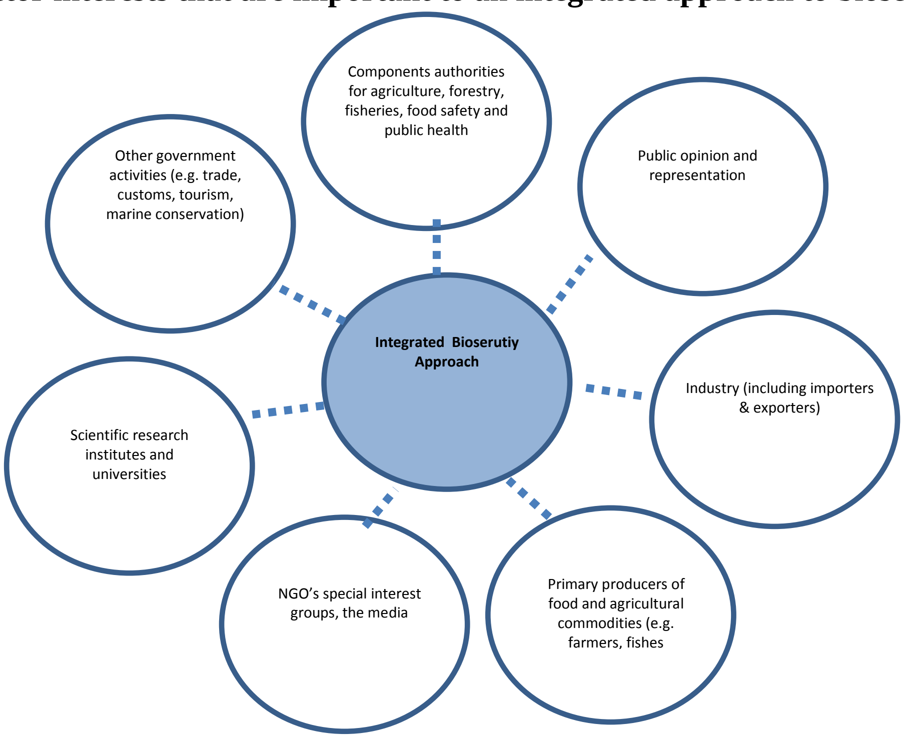
Basic Concepts of Biosecurity

- Biosecurity is a holistic concept of direct relevance to
  I. Sustainability of Agriculture
  II. Wide ranging aspects of public health
  III. Protection of environment including biological diversity

Some factors influencing biosecurity

- Globalization
- New agricultural production and food processing technologies
- Increased trade in food and agricultural products
- Legal obligations for signatories of relevant international agreements
- Increasing travel and movement of people across borders
- Advances in communications and global access to biosecurity information
- Greater public attention to biodiversity, the environment and the impact of agriculture on both
- Shift from country independence to country interdependence for effective biosecurity
- Scarcity of technical and operational resources
- High dependence of some countries on food imports

Sector interests that are important to an integrated approach to biosecurity



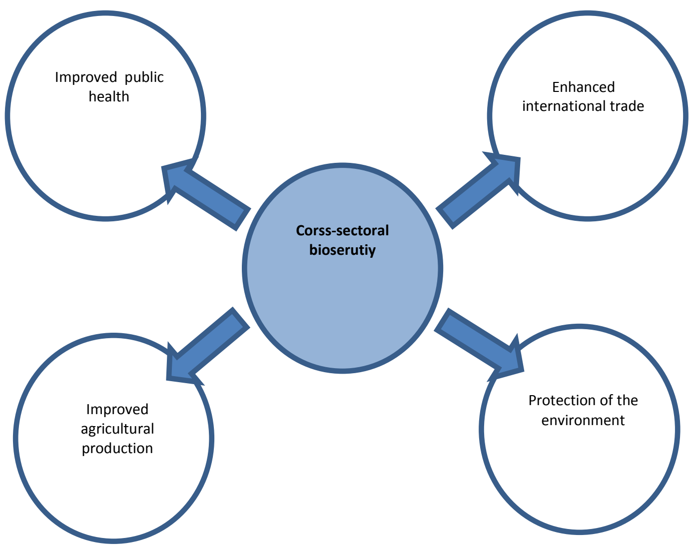
Relevant International Legal Instruments and Agreements

- In addition to the standards and related texts developed by the CAC (*Codex Alimentarius*), the OIE and the CPM, several other international **legal instruments, agreements and texts** are relevant to **biosecurity**.
- They are:
  - SPS (Sanitary and Phytosanitary)Agreement
  - TBT (Technical Barriers to Trade) Agreement
  - CBD (Convention on Biological Diversity)
  - CP (Cartagena Protocol on Biosafety)
  - International Health Regulations

Harmonized and Integrated Approach to Biosecurity

- Human, animal and plant life and health and protection of the environment are inextricably linked and this is the fundamental rationale for an integrated approach to biosecurity at the national level.
- Biosecurity hazards of various types exist in each sector and have high potential to move between sectors
  - Many animal pathogens readily infect humans
  - Animal feed may be contaminated with mycotoxins and plant toxins
  - Transfer of pests of plants between biosecurity sectors may occur on a lesser scale, inadequate control can have impacts well beyond plant health

Potential benefits associated with a cross-sectoral approach to biosecurity



Biosecurity Risk Analysis

- Many aspects of risk-based approach to biosecurity are shared by the different sectors concerned and this provides an essential impetus to risk analysis as a unifying discipline in biosecurity.
- Risk analysis is composed of three distinct but closely connected components:
  - Risk Assessment
  - Risk Management
  - Risk Communication

International level

- International legal instruments
- Intergovernmental organizations
- Risk analysis policy
- Scientific capability
- Development of standards and guidelines
- Monitoring and surveillance using international reporting systems
- Information servicing

National level

- Policy and legislation
- National biosecurity strategy
- Infrastructure
- Scientific and research capability
- Development of standards and guidelines
- Implementation of standards
- Emergency preparedness and response
- Monitoring and surveillance
- Communication systems
- Training

Basics of Risk Analysis

- The Risk analysis should determine:
  - What can go wrong?
  - How likely is it to go wrong?
  - How serious would it be if it went wrong?
  - What can be done to reduce the likelihood and/or seriousness of it going wrong?

CASE STUDY- BIOSECURITY SYSTEMS IN OTHER COUNTRIES:

- **Norway** has been through many fazes in relation to a reform process of the country's food safety administration. On 1 January 2004, the process culminated in the establishment of a 4-pillar reform, represented by the establishment of **a new authority**; the Norwegian Food Safety Authority, reorganized scientific support pertaining to the food chain through the establishment of an **independent risk assessment** body, **a new Food Law**, merging 13 separate Acts and a **new clarification** of the **relevant ministries' constitutional responsibilities**.
- **New Zealand**: The Government released New Zealand's first Biosecurity Strategy in August 2003 published by Biosecurity Council. With the bringing together of Biosecurity New Zealand with the border services functions of MAF in 2007, MAF Biosecurity New Zealand was created. The strategy raises public awareness and understanding of biosecurity. Number of other strategies such as Surveillance strategy, Science strategy, response foundations and border systems had been developed to support biosecurity system. New Zealand has played a role model in formulating a Biosecurity Act in 1993 itself, well ahead of the global need.
- **Australia**: Biosecurity Australia is the unit within the Biosecurity Services Group, in the Department of Agriculture, Fisheries and Forestry, responsible for recommendations for the development of Australia's biosecurity policy. Biosecurity Australia provides science based quarantine assessments and policy advice that protects Australia's pest and disease status and enhances Australia's access to international animal and plant related markets.
- In the US, agricultural biosecurity is looked after by the Animal and Plant Health Inspection Service (APHIS) headed by an 'Administrator' under the US Department of Agriculture. The APHIS constitutes various divisions including animal care, plant protection and quarantine, biotechnology regulatory services, wild life services etc. supported by the office of emergency management and homeland security as well. The Department of Homeland Security was created in 2002 with as many as 22 agencies including the US Department of Agriculture's Animal and Plant Health Inspection Service. The Homeland Security Advisory System is designed to give guidance on protective measures when specific information to a particular sector or geographic region is received.

AN INTRODUCTION TO PLANT QUARANTINE

Man even in nomadic period carried with him the required seeds and plants wherever he moved. This practice is still continuing in the civilized settlements of mankind. As a consequence, many plant types have moved from their centers of origin, to an entirely new regions / continents, where they got well established and naturalized. The pests associated with plants and seeds also moved along unnoticed into a new region, where they caused severe damage, not only to the plants with which they associated but started to infect / infests many other plant types in the introduced region. The realization of the economic, social consequences happened due to indiscriminate and unscientific movement or trade of plants, seeds and plant materials, necessitated the countries or provinces to start regulating the movement of plants and plant material.

In olden days the term "***Quarantine***" was originally applied to the period of detention of passengers arriving in ships from countries where epidemic diseases such as bubonic plague, cholera and yellow fever were prevalent. The ship's crew and passengers being compelled to remain isolated on board long enough to permit latent cases of diseases to develop and be detected before any persons were allowed to land. The word "**QUARANTINE**" is derived from the latin words ***"quarantum"*** or "***quaranta giorni***" meaning forty; that is to say a forty day period. In other languages – Italian: ***'quarantina'***; French: ***'quarante'***; Spanish: ***'cuarentena'*** all mean the same. Fixing of the period as forty has no scientific relevance at that time, but merely as practical measure based on necessity. Since the term Quarantine is so aptly fitted to and so firmly associated with an entirely unique situation, it was carried over from the human disease field into similar animal disease field and later adopted to cover protective efforts for the exclusion of pests and diseases of farm and horticultural crops, as well as forest and fruit trees. Thus arose the Plant Quarantine.

WHAT IS PLANT QUARANTINE?

The plant quarantine system is the first line of defense against the introduction and possible establishment of exotic plant pests. Plant Quarantine laws, regulations and services are based on national and international agreements, which evolved during nineteenth and twentieth centuries around the world. These were formulated on agricultural and economic needs. There is a historical background for the creation of PQ system.

WHY PLANT QUARANTINE?

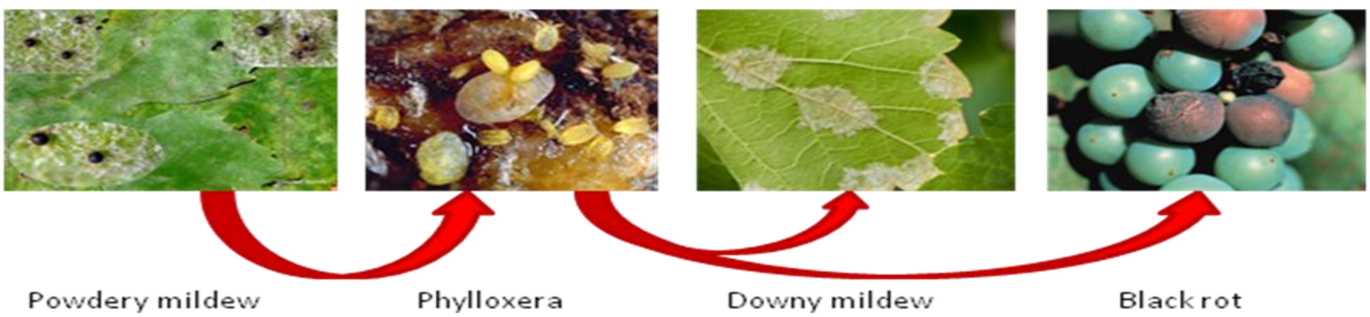
Since the dawn of civilization, man utilized his best possible efforts to domesticate the bounty of nature as per his needs. It is not just in recent years that the countries are being invaded by alien species, since time immemorial, man started to move the plants and animals wherever he fancied. In a way it paved way for species richness in newer area and domestication has become part of human settlement. It is not true that all alien species are harmful or dangerous, even the invasive species are not so dangerous in their place of origin, as the invasiveness is curtailed due to influence of many factors of the particular ecosystem. The alien species become invasive in newer area due to absence of natural enemies and congenial environmental parameters. Some alien species became beneficial and some became nuisance. To promote safe trade of agricultural materials across transboundary movement around the world implementation of plant quarantine system has become a necessity to safeguard biodiversity of a nation. Plant quarantine acts as a filter and not as a barrier of trade.

HISTORICAL BACKGROUND:

Few devastating incidences which had taken place in the late 17th and early 18th century lead to the creation of plant quarantine at global level.

Great Famine of Irish: Potato was introduced into Ireland as a garden crop and during late 17th century it was consumed as supplementary food. By early 18th century, it assumed the status of staple food for the poor during winter season and as well considered as agrarian economy as it fetched more money and hence grown in more acreage (<60%). In 1843-44, a new disease started to destroy the crops and was identified as late blight of potato, *Phytophthora infestans.* Late blight of potato infection completely destroyed potato crop in 1845, which lead to the starvation and death of 1 million people and migration of another 1 million from Ireland between 1845 to 1852. The unfortunate event of late blight devastation occurred due to incursion of *Phytophthora infestans* from USA, which caused loss of around £3,500,000 potatoes.

Toppling of Grapevine industry in Europe: Classical example of transboundary movement of plant pests is the introduction of Powdery mildew (*Oidium tuckeri*) into Europe with American grape-vines. Its pathogenecity on European grape vine was unknown at that time and the disease spread like wild fire



on European grape vines (1850). To control powdery mildew, root-stocks of resistant varieties were imported from America (1854). However, these grape vines carried *Phylloxera vastatrix*, a root inhabiting aphid of grape vines. To combat this pest, more American vines resistant to Phylloxera were introduced, but these additional introductions brought with them the downy mildew (*Plasmopara viticola*), and black rot (*Guignardia bidwellii*). In France, where the vine industry was thriving, had to face the burnt of these pest incursions and many business men abandoned vine production and emigrated to Algeria and other countries. Further, these incidences lead to the formulation of Bordeaux mixture pesticide.

INCURSION OF PESTS:

- **Colossal toad menace**: The cane toad, *Bufo marinus,* (Giant neotropical toad), native of central and south America, was introduced into Australia by the sugarcane industry to control two pests, the grey backed cane beetle (*Dermolepida albohirtum*) and frenchie beetle (*Lepidiota frenchi*). 101 toads were imported in June1935 and within 6 months the population exploded to 60000 and was released in the cane fields. Initially, the bio-control agent was so successful, whereas it became a environmental menace in a short period of time, causing ecological imbalance replacing the native frogs due to its over population, further, it became the reason for extinction of snake and fox species due to consumption of this poisonous toad. Even the tadpoles are poisonous.

- **Green Cancer of Tahiti**: The prolific tree *Miconia calvescens* has overrun Tahiti's native forests. Miconia is one of the most destructive invaders in tropical rain forest habitats. It is a serious threat to ecosystems in the Pacific because of its ability to invade intact native forests. Miconia has earned itself the descriptions such as the 'green cancer of Tahiti' and the 'purple plague of Hawaii'. Once miconia is established at a certain place it drastically changes the ecosystem and biodiversity of that environment.
- **Food turned foe**: Philippine rice farmers have lost nearly US$1 billion in crops to the invasive golden apple snail, *Pomacea canalicualata* which was originally introduced from South America to south-east Asia around 1980, as a local food resource and as a potential gourmet export item. The markets never developed; the snails escaped or were released, and became a serious pest of rice.

INCURSION OF PESTS INTO INDIA:

Similarly scores of pests have been introduced into India in the past, which are causing major crop loss, economical damage, environmental degradation and become major constraint in some of agricultural commodities. To site a few:

- **Potato**: Potato wart introduced from Netherlands, Potato cyst nematodes from UK, Potato tuber moth from Italy & Late blight of Potato from Europe
- **Coconut:** Eriophid mite from Sri Lanka
- **Banana:** Bunchy top of banana virus from Sri Lanka
- **Rubber**: Powdery mildew from Malaysia
- **Sunflower**; Downy mildew from USA
- **Apple**: Codling moth from Pakistan, Sanjose Scale from USA
- **Coffee**: Coffee berry borer from Sri Lanka

REGULATIONS

The Regulations, initially it started as prohibition of plants and plant parts from specific countries due to past experience of invasive species. The first effort towards international agreement on Plant Protection was made in 1914 under auspices of the International Institute of Agriculture in Rome. This was followed by an International Convention on Plant Protection by over 50 member countries of the Institute in 1919 and certain Agreement regarding the issue and acceptance of Phytosanitary Certificate were finalized. Appreciating the need for the Convention to strengthen such international efforts, FAO sponsored an International Plant Protection Convention in 1951. India became a member in 1956 and agreed to adopt legislative measures specified in the Convention for the purpose of securing common and effective action to prevent the introduction and spread of pests and diseases of plants and plant materials and to promote measures for their control. PQ regulations are entrusted with public authority to legally establish barriers against the dissemination of injurious pests. This has remained unchanged till today. The need for PQ being entrusted to public authority is considered as one of the fundamental principles of PQ. The following are few interesting years in PQ:

- ❖ The very first regulations were enacted by French Government in 1913 but came into effect only in 1923
- ❖ The German Government started to put ban on plants and plant products from USA in 1913

- ❖ In USA, the PQ work started well ahead in 1891 when the State of California initiated seaport inspection at San Pedro, probably the first in the world. The Federal Plant Quarantine Act was enacted in 1912.
- ❖ Indonesia enacted a law to prohibit importation of coffee plants and beans from Sri Lanka in 1877
- ❖ In Australia the first set of regulations governing PQ came into force on 1909 following introduction of the Quarantine Act of 1908
- ❖ In India the first regulation – the Destructive Insects and Pests Act, 1914 came into force

Now almost all the countries have PQ regulations in force.

The establishment of PQ regulations or orders is not simple or easy because the problems to be considered are of a complex nature involving not only biological factors, but those of economic, social and political as well. It is important that those involved in the establishment of PQ service and enforcement of PQ regulations possess an excellent knowledge of the various factors to be considered and strike a balance among them.

To achieve complete success against the invasive species it is needed to have complete liaison with Customs Service to implement PQ Regulations in Toto. If the Customs service overlooks a few dutiful items like liquor or electronic goods or even few bars of gold to enter illegally into our country, the result is loss of few thousands of rupees, whereas for a living invader such as an insect, mite, plant pathogen, nematode or weed, a high level of effectiveness is indispensable or else our country's agricultural programs may be jeopardized. India has varied agro-climatic zones, which has benefited the farming industry, an untoward introduction of exotic pest shall cripple the economy of the country.

Definition and Objective of PQ:
Plant Quarantine is defined as "All activities designed to prevent the introduction and/or spread of quarantine pests or to ensure their official control" *(*FAO).

Pest is defined as "Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products" (FAO)

Quarantine Pest is defined as "A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being Officially controlled". (FAO)

The Objectives of "Plant Quarantine" are two fold:

1. **to prevent the introduction and establishment of an exotic species of a plant pest or disease**
2. **to eradicate, control or retard the spread of any such pest or disease that already has been introduced.**

PQ IN INDIA
The DIP Act, 1914:
In Order to protect the agricultural and forest plants of our country, the Government of India has taken legislative steps as far back as 1914 and passed an Act called, "The Destructive Insects and Pests Act, 1914 (Act II of 1914) for regulation of import of plants and plant products. Prior to establishment of the Directorate of Plant Protection, Quarantine and Storage in May 1946, under the Ministry of Food and Agriculture, the various rules and regulations of the DIP Act were enforced by the Customs Department as if the rules were issued under the Sea Customs Act. The result was that many new pests

and diseases entered into India due to unscientific method of inspection and clearance. The Great Bengal Famine which wiped out 3 million people of India in 1942-43 acted as precursor for the establishment of Plant Protection Directorate in 1946 and the GOI decided to establish Plant Quarantine Stations at various international airports, seaports and land frontier check posts for effective implementation of plant quarantine regulations.

The Great Bengal Famine:

The Great Bengal Famine of 1943 occurred in undivided Bengal (Bangladesh and West Bengal). It is estimated that over three million people died from starvation and malnutrition, and related illnesses during the famine. In the rice growing season of 1942- 1943, weather conditions were exactly right to encourage an epidemic of the rice disease brown spot. Brown spot in rice is caused by the fungus *Helminthosporium oryzae*; the outbreak of the disease caused almost complete destruction of the rice crop (97%). Severe food shortages were worsened by the Second World War, with the British administration of India exporting foods to Allied soldiers and the ban of rice imports from Burma following the Japanese control of the country.

The Great Bengal Famine played a major role in opening of Plant Quarantine Stations in important entry points to prevent the entry of exotic pests into India. The GOI realized the importance of Plant Quarantine as first step of defense to control the entry of invasive species of plants and plant materials.

PLANT QUARANTINE STATIONS IN INDIA:

Though the Directorate was formed in 1946 with plant quarantine wing, the first Plant Quarantine Station was established at Mumbai in 1949 followed by the PQS at Chennai in 1950, Amritsar in 1954, Cochin in 1955, Kolkata in 1956, Visakhapattinam in 1957 and at Tuticorin and Bhavnagar in 1968.

Presently, there are 35 PQS's functioning at various Seaports, Airports and Land frontier stations, in addition to 61 In-land depots to carry out plant quarantine inspection and to facilitate safe import of plants/ plant materials. All member countries of IPPC need to establish National Plant Protection Organization (NPPO) for implementation of phytosanitary measures, import regulations to promote safe agricultural trade through plant quarantine system, DPPQS is the NPPO for India.

IMPORT REGULATIONS:

- **1914 – Destructive Insects and Pests Act, 1914**
- **1936 - Import Regulations**
- **1972 – Regulations to import cotton**
- **1984 – PFS Order, 1984**
- **1988 – National Policy on Seed Development**
- **1989 – PFS Order, 1989 (revised)**
- **1992 – Amendment to DIP Act – for levying import inspection fee**
- **2003 – Plant Quarantine (Regulation of Import into India) Order, 2003**

Plant Quarantine (Regulation of Import into India) Order, 2003 (PQ Order, 2003):

Notified under the DIP Act and came into force with effect from 1st January, 2004. The PQ Order, 2003 replaces all the preceding Orders / notifications of plant quarantine regulations. PQ Order, 2003 was formulated on the scientific basis of Pest Risk Analysis (PRA). The commodities are categorized into various Schedules based on associated pest risk either through pathway or from countries where the pest is known to be reported. In Toto, the order clearly spells out notified points of entry, list of prohibited, restricted, regulated commodities, quarantine weeds of concern to India, Inspection fee, authorities to issue import permits, to certify post entry quarantine facilities (PEQ) and the deposition of samples to gene bank of NBPGR.

PHYTOSANITARY TREATMENTS – AN OVERVIEW

There is a tremendous increase in international trade in the past two decades. The removal of quantity restrictions has enhanced bulk trade of agricultural materials across the globe. Bulk trade of agricultural material always pose great threat to the biosecurity of a nation, as exotic pests can easily enter into newer areas. Plant Quarantine acts as a filter but not as a barrier to trade. It is true that 'zero' tolerance can not be achieved in trade of agricultural materials and always an element of threat is hidden. It is the responsibility of the importing country to safeguard from incursion of exotic pests (Quarantine pests) to safeguard food security of that nation. Further, it the responsibility of the exporting country to take care that, there materials are not the vehicle or means for spreading pests into importing country. Thus it is important that both countries need to implement plant quarantine regulations and respect each others phytosanitary requirements and promote safe, smooth and predictable trade. "Phytosanitary measures" are the measures applied to plants and plant materials to promote trade of agricultural materials and at the same time prevent spread of exotic, harmful plant pests into newer areas. The appropriate phytosanitary measure depends biology and nature of pest. For example insect infestation on consumption materials such as pulses and cereals etc., can be managed by fumigation, whereas insect infestation on plants needs spraying with insecticide, as it can not be fumigated due to addition of chloropicrin in Methyl bromide as warning agent, which is phytotoxic to plants (cause death / deterioration).

There are many phytsanitary treatments in practice as of now. A gist of such phytosanitary treatments are covered in this lecture.

POST HARVEST QUARANTINE TREATMENTS:
HOT WATER IMMERSION TREATMENT (HWIT)

Hot water immersion is an efficient treatment for some fruits and vegetables infested with fruit flies, borers, sucking pests etc. HWIT is specifically an efficient phytsanitary treatment to disinfest mango fruit of fruit flies and is the most common quarantine heat treatment in use today due to the volume of fresh commodity being traded. Large commercial hot water treatment facilities are routinely used to treat mangoes with hot water immersion at a temperature of 115 to 116ºF (46.1 to 47ºC) for 65 to 110 minutes, depending on fruit weight and variety. DPPQS has brought out National Standard for Phytosanitary Measures (NSPM 15) for guidelines for certification of HWIT facilities.

VAPOR HEAT TREATMENT (VHT)

Vapor heat, the oldest of the three methods of quarantine heat treatment, consists of heating the host fruit by moving hot air saturated with water vapor over the fruit surface. Vapor heat treatment (VHT) is a high humidity air treatment. When the mango is at dew point temperature or lower temperature, the air will condense on the fruit surface and the condensate will conduct heat energy from the surface into the center of fruit flesh. Heat is transferred from the air to the commodity by condensation of the water vapor (heat of condensation) on the relatively cooler fruit surface. Fruit may be heated over time to a target temperature of 46 – 48^{o}C for a period of 30 mins. holding time that is required to kill the insect pests. Treatments usually take 3 to 4 hours from start to end of heating.

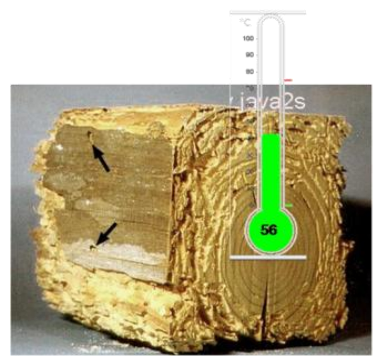
Dry HEAT TREATMENT:

Dry heat treatment of Niger seeds at 120^{o}C for 15 minutes for devitalization of contaminant noxious weeds or prohibited pathogens in accordance with the applicable provisions of USDA PPQ Treatment Manual is required to be carried out prior to export as phytosantary treatment.

FORCED HOT-AIR HEATING TREATMENT (FHAT)

For treating perishable commodities:

Forced hot-air, also known as high-temperature forced air, is a modification of the vapor heat treatment developed by Armstrong et al. (1989) to kill Mediterranean fruit fly, melon fly and oriental fruit fly eggs and larvae in papaya. It is essentially the same as vapor heat except that the fruit surfaces are dry during forced hot-air treatment. Improvements in temperature and moisture monitoring and air delivery have advanced forced hot-air treatments, leading forced hot-air treatments to be developed for commodities previously treated with vapor heat and also being developed for new commodities. Forced hot-air treatment appears to be as effective in controlling internal pests as vapor heat, and provides better fruit quality, becoming the treatment of choice for many fruit previously treated with vapor heat. The fruit skin temperature remains cooler during forced hot air treatments than during vapor heat treatment while the tissue just below the skin heats to lethal temperatures because of the occurrence of evaporative cooling on the fruit surface during forced hot air treatment at lower relative humidity. Forced hot air is the second most common method of quarantine heat treatment.



For treating Timber logs and Wood packaging Materials:

In order to protect the trees and forests, a number of countries have taken regulatory action to control the import of wood packaging materials. At present, **more than 50 countries** including **India** have taken such action. In an endeavour to bring some order to this situation and to control the spread of pests through wood packaging, the

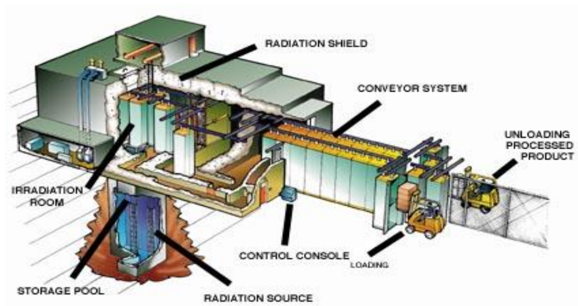
Secretariat of **IPPC** (International Plant Protection Convention), identified approved measures that significantly reduce the risk of the spread of pests, by way of an international standard for harmonized treatment protocol, i.e. **ISPM-15:** "***Guidelines for regulating wood packaging material in the international trade***". This ISPM-15, was adopted in 2002 and is now implemented by many of the trading nations. As per the ISPM-15, the raw wood packaging material required to undergo approved treatment such as heat treatment (FHAT) at 56^{0} C for 30 min and marked prior to export. In line with the ISPM 15, DPPQS has brought out NSPM-9 for accreditation of FHAT facilities in India to promote use of pest free packaging materials.

***COLD TREATMENT*:**

Cold treatment involves the refrigeration of produce over an extended period of time, according to treatment schedules established exporting / importing country requirements. Cold treatment is used to kill fruit flies in regulated articles as a prerequisite for movement of those articles out of fruit fly infested areas. Cold treatment is preferable to fumigation for commodities that are known to be damaged by methyl bromide. Cold treatment include exposing commodities to low temperatures (0^oC to 3^oC) for a certain period of days (i.e. 10 to 20 days), depending upon the life cycle of the fruit fly (i.e. egg to 3rd instar larval period). For example, cold storage of citrus fruits at temperatures of 2^oC or 3^oC can effectively kill Queensland Fruit Fly in citrus stored for 14 to 16 days.

IRRADIATION

Food irradiation is a process by which products are exposed to ionizing radiation to sterilize or kill insects and microbial pests by damaging their DNA. Radiation may be provided by gamma rays from cobalt-60 or cesium-137 sources, electrons generated from machine sources (e-beam), or by x-rays. Absorbed dose is measured as the quantity of radiation imparted per unit of mass of specified materials. The unit of absorbed dose is the gray (Gy) where 1 gray is equivalent to 1 joule per kilogram.



FUMIGATION:

Fumigation is the process of releasing and dispersing a toxic chemical so it reaches the target organism in a gaseous state. Chemicals applied as aerosols, smokes, mists, and fogs are suspensions of particulate matter in air and are not fumigants. The most effective way to reach pests in their most remote hiding places is through fumigation, the use of poisonous gases to kill pests in an enclosed area. To be effective, fumigants must reach target pests as gases. Fumigants are "wide-spectrum" pesticides, killing all species of arthropods and rodents that are likely to be found in a building. They are also volatile pesticides whose vapors enter the insect's body through the body wall or breathing system. Fumigants penetrate to many areas of a building not reached by sprays or dusts, even penetrating to the burrows of wood-infesting insects, as well as to the center of tightly packed commodities, such as cotton bales, cases or grain in large silos or bulk bins. A fumigant gas generally does not leave unsightly, odorous, or hazardous residues. In India the only authorized fumigants are Methyl bromide (98% MBr plus 2% Chloropicrin) and Aluminium phosphide. Fumigation by Methyl bromide (100% MBr) is being used for some fresh commodities as phytosanitary measure in few countries against insect pests, including fruit flies. In

India, Chloropicrin (2%) is added as a warning agent to MBr. Chloropicrin is phytotoxic and hence, MBr fumigation for fresh produce is not carried out in India. The approved fumigants in India are – Methyl bromide and Aluminium phosphide.

For treatment of perishable commodities:

Fumigation by Methyl bromide (100% MBr) is being used for some fresh commodities as phytosanitary measure in few countries against insect pests, including fruit flies. In India, Chloropicrin (2%) is added as a warning agent to MBr. Chloropicrin in phytotoxic and hence, MBr fumigation for fresh produce is not carried out in India.

For treatment of non-perishable commodities:

Commodities such as dry grains, pulses, cereals, timber logs, wood packaging materials, other plant materials can be fumigated with MBr or Aluminium Phosphide (AlP) to render pest free. Fumigation is the best option for bulk treatment of agricultural commodities. As per ISPM 15, MBr can be used for fumigating timber logs and wood packaging materials as a phytosanitary measure to prevent the spread of insect pests of concern to trees and forests. All stages of the wood boring insects are killed by MBr fumigation. NSPM-11 and 12 brought out by DPPQS directly deal with accreditation procedures for MBr facilities treatment of commodities either imported or exported.

DIPPING/ DRENCHING/ FOGGING/ DRESSING ETC USING PESTICIDES:

Wide variety of pesticides are used as phytosanitary treatment for export of planting materials. Dipping or Drenching or spraying of roots/ plants in pesticides to render pest free such as fungi, bacteria, insect, nematode are carried out prior to export either as precautionary measure or as per the requirement of the importing country. Seed dressing with fungicides are carried out as mitigation measure against fungal infections.

SYSTEMS APPROACH:

The appropriate level of protection for an importing country can be achieved by the application of combination of measures. System approaches integrate biological, physical and operational factors to meet quarantine requirements. A systems approach to mitigate risks could involve some of the following:

- certification of pest free areas, pest free places of production, or areas of low pest prevalence for certain quarantine pests, such as fruit flies;
- programs (e.g., cultural, mechanical, chemical) to control pests within orchards;
- packing-house procedures (e.g., washing, brushing, inspection of fruit) to eliminate external pests;
- quarantine treatments to disinfest fruit of internal and external pests;
- consignments inspected and certified by importing country phytosanitary officials and exporting country PQ officials to be free of quarantine pests;
- fruit traceable to state of origin, packing facility, grower, and orchard;
- consignments subject to sampling and inspection after arrival in the Importing country;
- limits on distribution and transit within the importing country.

ALIEN INVASIVE SPECIES – IMPACTS AND THREATS

INTRODUCTION

Since the dawn of civilization, man utilized his best possible efforts to domesticate the bounty of nature as per his needs. It is not just in recent years that the countries are being invaded by alien species, since time immemorial, man started to move the plants and animals wherever he fancied. In a way it paved way for species richness in newer area and domestication has become part of human settlement. It is not true that all alien species are harmful or dangerous, even the invasive species are not so dangerous in their place of origin, as the invasiveness is curtailed due to influence of many factors of the particular ecosystem. The alien species become invasive in newer area due to absence of natural enemies and congenial environmental parameters. Some alien species became beneficial and some became nuisance. In the past scores of plants and animals have been exchanged, moved or introduced to newer horizons due to human aided activities. The introduction of localized species to cross the physical boundaries is made possible only by means of human interference.

BENEFICIAL ALIEN SPECIES:

For example, coffee (from Yemen), Chilli (from Mexico), Rubber (by British), Soybean , Sunflower, etc. were brought to India and grown as beneficial crops. Vice-a-verse, there are lots of such economically valuable plant species which originated in India is now spread to all over the world. To site a few examples: Black pepper, Cardamom, Neem, Mango etc.

HARMFUL ALIEN SPECIES:

In the past scores of harmful alien species have entered into India and cause huge economic damage. They are categorized into two groups, namely alien species (exotic) and alien invasive species (exotic and invasive). To site a few:

ALIEN SPECIES (EXOTIC PESTS):

- Coffee pests such as Coffee rust, *Hemilia vastatrix,* coffee green scale (*Coccus viridis*), coffee berry borer (*Hypothenemus hampeii*) were intruded from Sri Lanka
- Coconut eriophid mite (*Aceria guerreronis*) probably from Sri Lanka

ALIEN INVASIVE SPECIES:

- Spiralling white fly (*Aleurodicus dispersus*) (Sri Lanka / Maldives).
- Papaya mealy bug (*Paracoccus marginatus)* (Thailand)
- Cotton mealy bug (*Phenococcus solenopsis*) (USA)
- *Phalaris minor* weed in wheat (USA)
- ***Parthenium hysterophorus*** is a major weed contaminated wheat imported from USA
- **Water hyacinth** (*Eichhornia crassipes*) is another such major weed clogging the waterways in India, brought as ornament from Mexico
- ***Lantana camara*** is another introduced, woody weed.
- **Mile-a-minute weed** (*Mikania micrantha*) is another invasive weed, which is smothering the forest and plantation vegetation in India.

- ***Salvinia molesta***, an aquatic weed native of Brazil
- ***Prosopis juliflora***, thorny, exotic weed introduced from Mexico and Caribbean Islands

RECENT TREND IN GLOBAL AGRICULTURAL TRADE:

Ever since the liberalization of trade has taken place in the post-WTO era, the term "Alien invasive species" has gained more emphasis among trading nations, as the impact of alien invasive species is the most dreaded in the context of climate change and the faster trade exchange between nations, which accelerates the crossing of boundaries of alien invasive species. The alien invasive species not only affect agriculture, horticulture, pasture lands and forests, they are also the cause for major impacts on environment and biodiversity of a nation. For example, weeds provide good proof to clarify what is meant by Invasive Species because most people understand what constitutes a 'weed'.

Definitions;

- **PEST** means *any species, strain or biotype of plant, animal or pathogenic agent injurious to plants and plant products* (PQ Order)
- **QUARANTINE PEST** means *a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled* (PQ Order)
- **ALIEN SPECIES -** (non-native, non-indigenous, foreign, exotic) means *a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce.* (IUCN,2000)
- **ALIEN INVASIVE SPECIES -** means *an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity.* (IUCN,2000)
- **ECOSYSTEM** means the *complex of a community of organisms and its environment*.
- **WEED** is defined as "*A plant considered undesirable, unattractive, or troublesome, especially one growing where it is not wanted*". Or in simple words "*A plant that interferes with management objectives for a given area of land at a given point in time"*.

INTERNATIONAL EFFORTS TO PREVENT ENTRY OF INVASIVE ALIEN SPECIES:

Scientific evidence indicates that biological invasions are growing at an unprecedented rate, posing increasing threats to the diversity of life, and also disrupting ecosystem functionality. Global economies, as well as water supply, food security and human health are impacted negatively. Despite the urgency to take action against invasions, public awareness on the issue is inadequate

IPPC: The **International Plant Protection Convention** (**IPPC**) is an international treaty organization that aims to secure coordinated, effective action to prevent and to control the introduction and spread of pests of plants and plant products. The Convention extends beyond the protection of cultivated plants to the protection of natural flora and plant products. It takes into consideration both direct and indirect damage by pests (including weeds). IPPC is essentially a "Phytosanitary Agreement" – a mechanism for protecting agriculture from pests that could spread through international trade in plants and plant produce. Member countries are supposed to maintain inspection procedures for export and undertake eradication and control measures in the event of new pest infestations occur. Member countries require to establish NPPO (National Plant Protection Organization) to promote safe agricultural trade and to protect natural flora.

CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora): CITES is intended to protect endangered species from being collected for export. CITES protects many rare plants and animals from over exploitation and trading. Hence, it is considered as landmark advance in conservation of rare plants and animals and helps to preserve of biodiversity.

CBD (Convention on Biological Diversity): its objective is to develop national strategies for the conservation and sustainable use of biological diversity. The Convention has three main goals:

1. conservation of biological diversity (or biodiversity);
2. sustainable use of its components; and
3. fair and equitable sharing of benefits arising from genetic resources

CP (Cartagena Protocol on Biosafety) : The Biosafety Protocol seeks to protect biological diversity from the potential risks posed by **living modified organisms (LMO)** resulting from modern biotechnology.

IUCN: The **International Union for Conservation of Nature and Natural Resources** (**IUCN**) is an international organization dedicated to finding pragmatic solutions to the most pressing environment and development challenges. The organization publishes the IUCN Red List, compiling information from a network of conservation organizations to rate which species are most endangered.

ISSG (Invasive Species Specialist Group) is established under **IUCN** (International Union for Conservation of Nature). ISSG's network of leading specialists provide technical advice to policy makers, and, ISSG disseminates the most current and reliable information on invasive species ecology, their impacts on biological diversity and ways to prevent and control their spread. Further, a global analysis of extinction risk for the world's plants, conducted by the Royal Botanic Gardens, Kew together with the Natural History Museum, London and IUCN, has revealed that the world's plants are as threatened as mammals, with one in five of the world's plant species threatened with extinction.

UN-FCCC (United Nations – Framework convention on Climate Change): The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases. The convention aims to stabilize and eventually reduce global Carbon emissions – an essential step in staving off a probable tidal wave of new invasions of pests that could be triggered by climate change.

Agenda 21 is an action plan of the United Nations (UN) related to sustainable development and was an outcome of the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in 1992. It is a comprehensive blueprint of action to be taken globally, nationally and locally by organizations of the United Nations System, governments, and major groups in every area in which humans directly affect the environment.

NATIONAL EFFORTS TO PREVENT ENTRY OF INVASIVE ALIEN SPECIES:

Plant Quarantine System: The Plant Quarantine (Regulation of Import into India) Order, 2003 is aimed at preventing the entry, establishment and spread of alien invasive species into India through plant quarantine mechanism. Plant quarantine acts as the first line of defense at the entry points.

Germplasm Exchange: The incursion of dangerous pests coming through the germplasm material is monitored by NBPGR (National Bureau of Plant Genetic Resources)

Research Institutes: The crop research institutes of ICAR (Indian Council of Agricultural Research) are responsible for monitoring the planting materials imported for research to prevent entry of alien invasive species.

Biosecurity Authority: There is an urgent need to bring all the relevant fields/ organizations under one umbrella to safeguard biosecurity of the nation. For this a National Agricultural Biosecurity Authority (NABS) needs to be setup. Government of India has taken initiative towards establishing NABS and in near future the same shall come into force.

Surveillance: As of now surveillance is carried out by individual departments, governments, institutes, NGOs, individuals etc. without much network and information sharing. Surveillance mechanism needs to be integrated with Biosecurity Authority to know pest status and carry out eradication programmes in the event of pest incursion.

Pest Diagnosis: Precise identification of pest is a major concern in the event of exotic pest incursion or new pest reports. Human resource and centralized pest repository are the major thrust area, which needs strengthening.

NEED OF THE HOUR TO COMBAT INVASIVE ALIEN SPECIES IN INDIA:

The past bitter and costly experiences learnt due to the impact of introduced invasive species has lead to the awakening of plant battle field to combat the entry of invasive alien weeds and other species which might topple the economy, destroy the ecology, and disturb the environment of India. Stringent legal regulations, public awareness, coordinated efforts by the scientific and farming community with administrative backup, preparedness with eradication measures in case of entry, instant sharing of notice of invasive weeds through network among states and central to take appropriate action at appropriate time etc. are all the need of the hour to combat entry of invasive weeds.

Some of the frustrating questions on incursion of Alien invasive species:

- We do not know **which** organisms will become successful invasive species
- We do not know **where** the invasion will take place
- We do not know **when** the invasion will occur
- We do not know **what** an invasion will do

Role of Ecological Engineering in Pest Management

"Ecological engineering" refer to the **"environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources**." More appropriately the **agro-ecological biodiversity is leading to concepts of *Agro-Ecological Engineering* approach which relies on the use of cultural techniques to effect habitat manipulation and enhance biological control".** Ecological engineering has recently emerged as a paradigm for considering pest management approaches that are based on cultural practices and informed by ecological knowledge rather than on high technology approaches such as synthetic pesticides and genetically engineered crops. The development of ecological engineering is explored; ranging from a simple first approximation that diversity is beneficial, to contemporary understanding that diversity can have adverse effects on pest management. This requires that the functional mechanisms that lead components of biodiversity to suppress pest activity are better understood and exploited. Pest suppression via ecological engineering is placed in the broader context of 'ecosystem services' provided by farmland biodiversity including nitrogen fixation and the conservation of pollinator species and wildlife. Maintaining balance in ecosystem components helps reducing the pest out breaks like managing population level of detritus herbivores for soil fertility management and managing population level of carnivorous for harmful herbivores etc. This is achieved through conservation of natural enemies involves "providing and protecting vegetation in and around agricultural areas so that beneficial arthropods can use this vegetation for food, shelter, or overwintering sites". EE employs the use of "Ecosystem services- consisting many biotic and abiotic organisms, elements coexist in an ecosystem" and it is formed by the interactions between all living and non-living things with the aims to provide the natural enemies of pests with resources such as nectar, pollen, physical refugia, alternative prey, alternative hosts and egg-laying sites. Many studies have demonstrated increased abundance of natural enemies associated with provisioned habitat. Studies demonstrating a reduction in pest pressure in agricultural crops by natural enemies because of habitat manipulation are less common.

The term "ecological engineering" was first used by Odum (1962) to refer to the "environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources." The concept of ecological engineering has continued to develop using crop habitat management utilizing pest-behavioral and the companion planting principals. Basically, the characteristics of approaches that are consistent with ecological engineering as defined by its early proponents are (1) low dependence on external and synthetic inputs, (2) a reliance on natural processes, (3) based on ecological principles, and (4) scope for refinement by ecological experimentation. It will contribute to the challenge of meeting the needs of humankind for agricultural products in a sustainable fashion.

Biodiversity is crucial to crop defenses: the more diverse the plants, animals and soil-borne organisms that inhabit a farming system, the more diverse the community of pestfighting beneficial organisms the farm can support. One group of partners – *beneficial predators* – chew up plant-eating insects and mites or sucks out their juices. Another group – *beneficial parasites* – lay eggs inside pest eggs and/or larvae. A third group – *beneficial disease-causing organisms* that include fungi, bacteria, viruses, protozoa and nematodes – fatally sicken pests or keep them from feeding or reproducing. Plants also form complex associations with organisms around their roots, which offer protection against disease. Soil fungi and ground beetles can destroy the seeds of weeds that compete with plants. In addition the rich soil fauna play key roles in breaking up and decomposing organic matter thus making nutrients available to plants. Biodiversity in the form of polycultures may also make plants less "apparent" to pests; crops growing in monocultures may be so obvious to pests that the plants' defenses fall short of protecting them.

Farmers can enhance biodiversity on their farms by:

- **increasing plant diversity with crop rotations or with "polycultures" of cash and cover crops grown on the same land at the same time;**
- **managing vegetation surrounding fields to meet the needs of beneficial organisms;**
- **providing beneficial organisms with supplemental resources, such as artificial nesting structures, extra food and alternative prey;**
- **designing "corridors" of plants that usher beneficial from nearby forests or natural vegetation to field centers selecting non-crop plants grown as strips in fields, whose flowers match beneficials' requirements.**

Healthy soils are also essential to plant defenses. Unhealthy soils hinder crops' abilities to use their natural defenses and leave them vulnerable to potential pests. In contrast, healthy soils arm plants chemically with defenseboosting nutrients and are physically conducive to optimum root development and water use. Reduced susceptibility to pests is usually a reflection of differences in plant health as mediated by soil fertility management. Many studies document lower abundance of several insect pests in low-input systems and they attribute partly such reductions to the lower nitrogen content of organically farmed crops. In addition, the rich supplies of beneficial organisms that inhabit healthy soils can intensify nutrient uptake, release growthstimulating chemicals and antagonize disease-causing organisms.

Healthy soils can also expose weed seeds to more predators and decomposers, and their slower release of nitrogen in spring can delay small-seeded weeds – which often need a flush of nitrogen to germinate and begin rapid growth – thereby giving larger-seeded crops a head start.

Farmers can improve soil health by:

- **diversifying crop rotations including legumes and perennial forages • keeping soils covered year-round with living vegetation and/or crop residue**
- **adding plenty of organic matter from animal manures, crop residues and other sources**
- **reducing tillage intensity and protecting soils from erosion and compaction**
- **using best-management techniques to supply balanced nutrients to plants without polluting water**

When farmers adopt agricultural practices that increase the abundance and diversity of above- and below-ground organisms, they strengthen their crops' abilities to withstand pests. In the process, farmers also improve soil fertility and crop productivity.

Habitat or Biodiversity in farms and its function

Biodiversity in farms refers to all plant and animal organisms (crops, weeds, livestock, natural enemies, pollinators, soil fauna, etc) present in and around farms. Biodiversity can be as varied as the various crops, weeds, arthropods, or microorganisms involved, according to geographical location, climatic, edaphic [soil-related], human, and socioeconomic factors.

In general the degree of biodiversity in agroecosystems depends on four main characteristics of the agroecosystem:
• the diversity of vegetation within and around the agroecosystem;
• the permanence of the various crops within the agroecosystem;
• the intensity of management;
• the extent of the isolation of the agroecosystem from natural vegetation

How diverse is the vegetation within and around the farm, how many crops comprise the rotation, how close is the farm to a forest, hedgerow, meadow or other natural vegetation, are all factors that contribute to a particular farm's level of biodiversity. The biodiversity components of farms can be classified in relation to the role they play in the functioning of cropping systems.

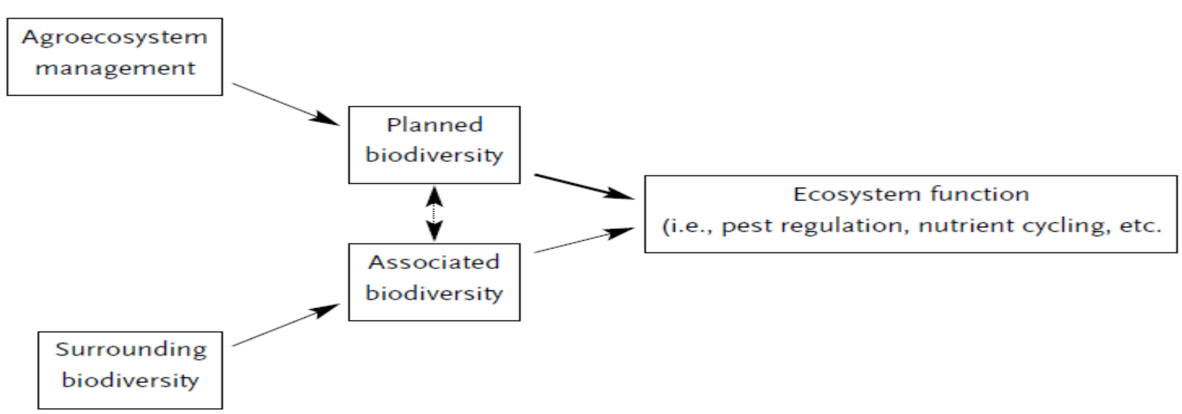
Agricultural biodiversity can be grouped as follows:

- **Productive biota:** crops, trees, and animals chosen by farmers that play a determining role in the diversity and complexity of the agroecosystem**;**
- **Resource biota:** organisms that contribute to productivity through pollination, biological control, decomposition, etc;
- **Destructive biota:** weeds, insect pests, microbial pathogens, etc., which farmers aim at reducing through cultural management.

Two distinct components of biodiversity can be recognized in agroecosystems. The first component, *planned biodiversity*, includes the crops and livestock purposely included in the agroecosystem by the farmer, and which will vary depending on the management inputs and crop spatial/ temporal arrangements. The second component, *associated biodiversity*, includes all soil flora and fauna, herbivores, carnivores, decomposers, etc. that colonize the agroecosystem from surrounding environments and that will thrive in the agroecosystem depending on its management and structure. The relationship of both types of biodiversity components is illustrated in Figure 1. Planned biodiversity has a direct function, as illustrated by the bold arrow connecting the planned biodiversity box with the ecosystem function box. Associated biodiversity also has a function, but it is mediated through planned biodiversity.

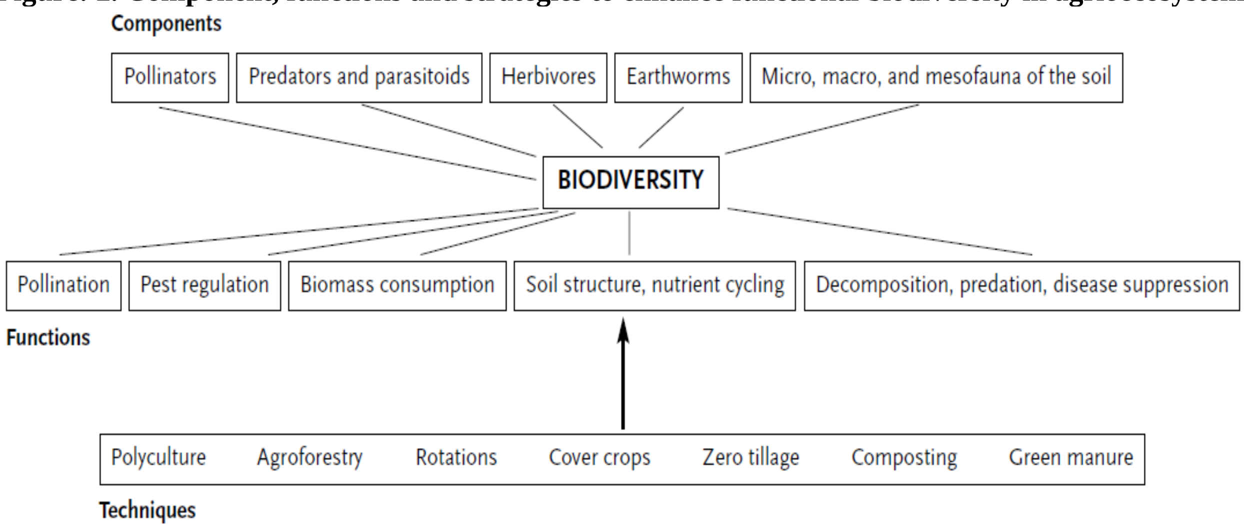
Thus, planned biodiversity also has an indirect function, illustrated by the dotted arrow in the figure, which is realized through its influence on the associated biodiversity. For example, the trees in an agroforestry system create shade, which makes it possible to grow only sun-intolerant crops. So, the direct function of this second species (the trees) is to create shade. Yet along with the trees might come wasps that seek out the nectar in the tree's flowers. These wasps may in turn be the natural parasitoids of pests that normally attack crops. The wasps are part of the associated biodiversity. The trees then create shade (direct function) and attract wasps (indirect function).

Figure 1. Relationships between several types of biodiversity and their role in agroecosystem function



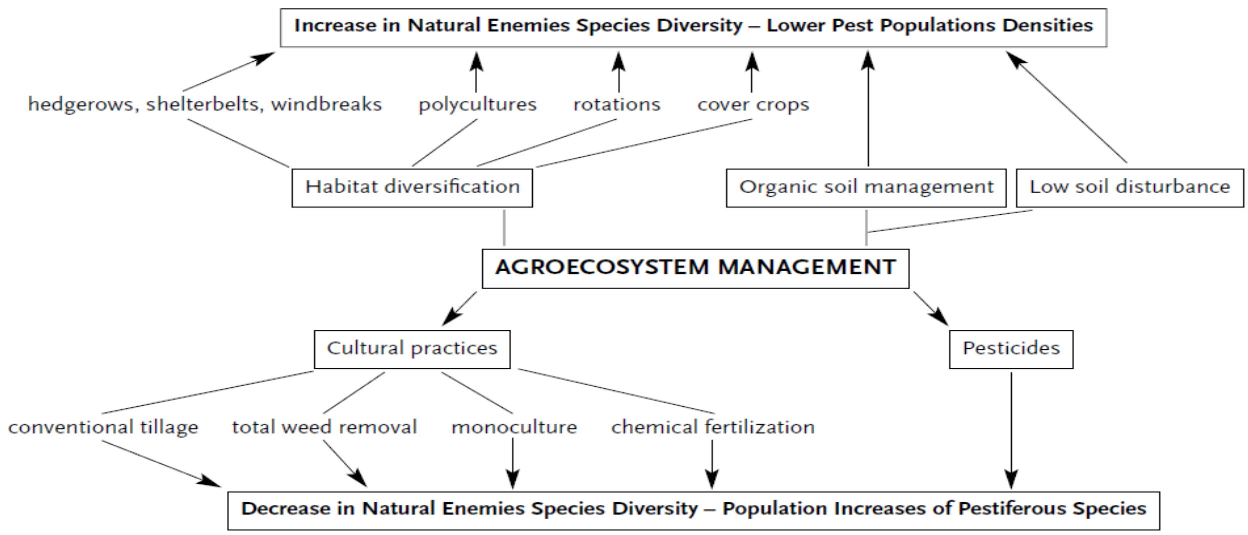
Complementary interactions between the various biodiversity components can also be of a multiple nature. Some of these interactions can be used to induce positive and direct effects on the biological control of specific crop pests, soil fertility regeneration and/or enhancement and soil conservation. The exploitation of these interactions in real situations involves novel farm designs and management and requires an understanding of the numerous relationships between soils, microorganisms, plants, insect herbivores, and natural enemies. In fact the optimal behavior of agroecosystems depends on the level of interactions between the various biotic and abiotic components. By assembling a functional biodiversity (that is a collection of interacting organisms that play key functions in the farm) it is possible to initiate synergisms which subsidize farm processes by providing ecological services such as the activation of soil biology, the recycling of nutrients, the enhancement of beneficial arthropods and antagonists, and so on, all important in determining the sustainability of agroecosystems (Figure 2). In modern agroecosystems, the experimental evidence suggests that biodiversity can be used for improved pest management. Several studies have shown that it is possible to stabilize the insect communities of agroecosystems by designing diverse cropping systems that support populations of natural enemies or have direct deterrent effects on pest herbivores. The key is to identify the type of biodiversity that is desirable to maintain and/or enhance in order to carry out ecological services, and then to determine the best practices that will encourage the desired biodiversity components.

Figure: 2. Component, functions and strategies to enhance functional biodiversity in agrioecosystem.



There are many agricultural practices and designs that have the potential to enhance functional biodiversity, and others that negatively affect it. The idea is to apply the best management practices in order to enhance or regenerate the kind of biodiversity that can subsidize the sustainability of agroecosystems by providing ecological services such as biological pest control, nutrient cycling, water and soil conservation, etc. The role of farmers and researchers should be to encourage those agricultural practices that increase the abundance and diversity of above- and below-ground organisms, which in turn provide key ecological services to agroecosystems (Figure 3)

Figure 3. The effects of agroecosystem management and associated cultural practices on the diversity of natural enemies and the abundance of insect pests



Thus, a key strategy in farming is to exploit the complementarity and synergy that result from the various combinations of crops, trees, and animals in agroecosystems that feature spatial and temporal arrangements such as polycultures, agroforestry systems and crop-livestock mixtures. In real situations, the exploitation of these interactions involves farming system design and management and requires an understanding of the numerous relationships among soils, microorganisms, plants, insect herbivores, and natural enemies.

Biological pest control: a strategy to increase biodiversity in farms

Studies show that farmers can indeed bring pests and natural enemies into balance on biodiverse farms. One of the most powerful and long-lasting ways to keep pests from causing economic damage on your farm is to boost existing or naturally occurring beneficial organisms to effective levels by supplying them with appropriate habitat and alternative food sources. Fewer beneficial organisms – predators, parasites and pest-sickening "pathogens" – live in monocultures or in fields routinely treated with pesticides than on more diverse farms where fewer pesticides are used.

In general farms sharing many of these characteristics host bountiful beneficials:

- fields are small and surrounded by natural vegetation;
- cropping systems are diverse and plant populations in or around fields include perennials and flowering plants;
- crops are managed organically or with minimal synthetic agrichemicals;
- soils are high in organic matter and biological activity and – during the off-season – covered with mulch or vegetation.

Naturally occurring beneficials, at sufficient levels, can take a big bite out of pest populations. To exploit them effectively, farmers must:

- identify which beneficial organisms are present;
- understand their individual biological cycles and resource requirements.

With this information, farmers can devise management schemes that will increase the size and diversity of naturalenemy complexes and decrease pest problems.

Predators

Biodiverse farms are rich in predatory insects, spiders and mites. These beneficial arthropods prey on other insects and spider mites, and are critical to natural biological control. Most predators are "generalist" feeders, attacking a wide variety of insect species and life stages. Predators occur in most orders of insects but primarily in *Coleoptera, Odonata, Neuroptera, Hymenoptera, Diptera and Hemiptera.* Their impacts have been highlighted worldwide by eruptions of spider mite pests where chemical insecticides have eliminated the mites' predators. Tetranychid mites, for example, are usually very abundant in apple orchards where pesticides have destroyed natural predator populations. The diversity of predator species in particular agroecosystems can be impressive. Researchers have reported more than six hundred species – from forty-five families – of predaceous arthropods in Arkansas cotton fields and about 1,000 species in Florida soybean fields. Such diversity can apply major regulatory pressures on pests. Indeed, many entomologists consider native, or indigenous, predators a sort of balance wheel in the "pest-natural enemy complex" because they tend to feed on whatever pest is overabundant. Even where predators can't force pest populations below economically damaging levels, they can and do slow down the rate at which potential pests increase. In sprayfree apple orchards in Canada, five species of predaceous true bugs were responsible for 44 to 68 percent of the mortality of codling moth eggs.

Parasitoids

Most parasitoids – parasitic insects that kill their hosts – live freely and independently as adults; they are lethal and dependent only in their immature stages. Parasitoids can be specialists, targeting either a single host species or several related species, or they can be generalists, developing in many types of hosts. Typically, they attack hosts larger than themselves, eating most or all of their hosts' bodies before pupating inside or outside them. With their uncanny ability to locate even sparsely populated hosts using chemical cues, parasitoid adults are much more efficient than predators at ferreting out their quarry.

Most parasitoids used in the biological control of insect pests are either *Diptera* flies – especially from the family *Tachinidae* – or *Hymenoptera* wasps from the superfamilies *Chalcidoidea, Ichneumonoidea, and Proctotrupoidea.* Parasitoid diversity is directly related to plant diversity: different crops, ground covers, weeds and adjacent vegetation support different pests, which in turn attract their own groups of parasitoids.

In large-scale monocultures, parasitoid diversity is suppressed by vegetational simplification; in less-disturbed and pesticide-free agroecosystems, it is not unusual to find eleven to fifteen species of parasitoids hard at work. In many cases, just one or two species of parasitoids within these complexes prove vital to the natural biological control of primary insect pests. In California's alfalfa fields, the braconid wasp *Cotesia medicaginis* plays a pivotal role in regulating the alfalfa caterpillar. This pristine butterfly-wasp system apparently moved into irrigated alfalfa from native clovers.

Major characteristics of arthropod predators:		Major characteristics of insect parasitoids:
• Adults and immatures are often generalists rather than specialists • They generally are larger than their prey • They kill or consume many prey • Males, females, immatures, and adults may be predatory • They attack immature and adult prey • They require pollen and nectar and additional food resources		• They are specialized in their choice of host • They are smaller than host • •Only the female searches for host • Different parasitoid species can attack different life stages of host • Eggs or larvae are usually laid in, on, or near host • Immatures remain on or in host; adults are free-living, mobile, and may be predaceous • Immatures almost always kill host • Adults also require pollen and nectar

Enhancing beneficial insects by designing biodiverse farms

Natural enemies do not fare well in monocultures. Normal cultural activities like tilling, weeding, spraying and harvesting take their toll, and overly simplified systems lack many of the resources essential to beneficials' survival and reproduction. To complete their life cycles, natural enemies need more than prey and hosts: they need refuge sites and alternative food, hosts and prey which are usually absent in monocultures. For example, many adult parasites sustain themselves with pollen and nectar from nearby flowering weeds while searching for hosts. Predaceous ground beetles – like many other natural enemies – do not disperse far from their overwintering sites: access to permanent habitat near or within the field gives them a jump-start on early pest populations. Farmers can minimize the disruptive impacts of modern crop production by understanding and supporting the biological needs of natural enemies. With this same knowledge, they can also design crop habitats that are friendlier to natural enemies.

Ecological Engineering by Habitat Manipulation:

- Improving crop habitats for natural enemies
- Providing supplementary resources
- Increasing within-field plant diversity
- Managing vegetation surrounding the field
- Creating corridors for natural enemies
- Selecting the right flowers

Improving crop habitats for natural enemies

To conserve and develop rich complexes of natural enemies, farmers should avoid cropping practices that harm beneficials. Instead, they should substitute methods that enhance their survival. Start by reversing practices that disrupt natural biological control: these include insecticide applications, hedge removal and comprehensive herbicide use intended to eliminate weeds in and around fields.

Providing supplementary resources

Natural enemies benefit from many kinds of supplementary resources. In North Carolina, erecting artificial nesting structures for the red wasp *Polistes annularis* intensified its predation of cotton leafworms and tobacco hornworms. In Ca'[lifornia alfalfa and cotton plots, furnishing mixtures of hydrolyzate, sugar and water multiplied egg-laying by green lacewings six-fold and boosted populations of predatory syrphid flies, lady beetles and soft-winged flower beetles. Farmers can increase the survival and reproduction of beneficial insects by allowing permanent populations of alternative prey to fluctuate below damaging levels. Use plants that host alternative prey to achieve this: plant them around your fields or even as strips within your fields. In cabbage, the relative abundance of aphids helps determine the effectiveness of the general predators that consume diamondback moth larvae. Similarly, in many regions, anthrocorid bugs benefit from alternative prey when their preferred prey, the western flower thrip, is scarce. Another strategy – enhancing levels of a beneficial's preferred host – has controlled cabbage white butterflies in cole crops. Supplemented with continual releases of fertile females, populations of this pest escalated nearly ten-fold in spring. This enabled populations of two of its parasites –*Trichogramma evanescens* and *Apanteles rebecula* – to build up early and maintain themselves at effective levels all season long. Because of its obvious risks, this strategy should be restricted to situations where sources of pollen, nectar or alternative prey simply can't be obtained.

Increasing within-field plant diversity

By diversifying plants within agroecosystems, farmers can expand environmental opportunities for natural enemies and thereby improve biological pest control. One way to do this is to plant polycultures of annual crops – two or more crops simultaneously growing in close proximity. Farmers can also let some flowering weeds reach tolerable levels or use cover crops under orchards and vineyards. Numerous researchers have shown that increasing plant – and thereby habitat – diversity favors the abundance and effectiveness of natural enemies. For example in cotton fields strip-cropped with alfalfa or sorghum, intensified populations of natural enemies have substantially decreased plant bugs and moth and butterfly pests. Beneficials reduced pest insects below economic threshold levels in Georgia cotton that was relay-cropped with crimson clover, eliminating the need for insecticides. In Canadian apple orchards, four to eighteen times as many pests were parasitized when wildflowers were numerous compared to when they were few. In this research, wild parsnip, wild carrot and buttercup proved essential to a number of parasitoids. In California organic vineyards, the general predators and *Anagrus* leafhopper egg parasites that control grape leafhoppers and thrips thrive in the presence of buckwheat and sunflowers. When these summer-blooming cover crops flower early, they allow populations of beneficials to surge ahead of those of pests. When they keep flowering throughout the growing season, they provide constant supplies of pollen, nectar and alternative prey. Mowing every other row of cover crops – an occasionally necessary practice – forces these beneficials out of the resource-rich cover crops and into vines.

In polycultures, apart from the evident increase in plant species diversity, there are changes in plant density and height, and therefore in vertical diversity. All these changes affect density of pests and other organisms. The combination of tall and short crops can also affect dispersal of insects within a cropping system. For example, in Cuba farmers grow strips of corn or sorghum every ten meters within vegetables or beans in order to provide physical barriers to reduce the dispersion of thrips (*Thrips palmi*). In China, researchers working with farmers in ten townships in Yumman, China, covering an area of 5350 hectares, encouraged farmers to switch from rice monocultures to planting variety mixtures of local tall rice with shorter hybrids. Tall plants provided a barrier for inoculum dispersal, but in addition enhanced genetic diversity reduced blast incidence by ninety-four percent and increased total yields by eighty-nine percent. By the end of two years, it was concluded that fungicides were no longer required.

Managing vegetation surrounding the field

Hedgerows and other vegetation in field margins can serve as reservoirs for natural enemies. These habitats can be important overwintering sites for the predators of crop pests. They can also provide natural enemies with additional pollen, nectar and other resources. Many studies have shown that beneficial arthropods do indeed move into crops from field margins, and biological control is usually more intensive in crop rows near wild vegetation than in field centers:

- In Germany, parasitism of the rape pollen beetle is about 50 percent greater at the edges of fields than in the middle.
- In Michigan, European corn borers at the outskirts of fields are more prone to parasitism by the ichneumonid wasp *Eriborus terebrans*.
- In Hawaiian sugar cane, nectar-bearing plants in field margins improve the numbers and efficiency of the sugar cane weevil parasite *Lixophaga sphenophori*.

Practical management strategies arise from understanding these relationships. A classical example comes from California, where the egg parasite *Anagrus epos* controls the grape leafhopper in vineyards adjacent to French prunes. The prunes harbor an economically insignificant leafhopper whose eggs provide *Anagrus* with its only winter food and shelter.

Creating corridors for natural enemies

Sowing diverse flowering plants into strips that cut across fields every 165 to 330 feet (50–100 meters) can provide natural enemies with highways of habitat. Beneficials can use these corridors to circulate and disperse into field centers. European studies have confirmed that this practice increases the diversity and abundance of natural enemies. When sugar beet fields were drilled with corridors of tansy leaf (*Phacelia tanacetifolia*) every twenty to thirty rows, destruction of bean aphids by syrphids intensified. Similarly, strips of buckwheat and tansy leaf in Swiss cabbage fields increased populations of a small parasitic wasp that attacks the cabbage aphid. Because of its long summer flowering period, tansy leaf has also been used as a pollen source to boost syrphid populations in cereal fields. On large organic farms in California, strips of *Alyssum* are commonly planted every fifty to one hundred meters within lettuce and cruciferous crop fields to attract syrphid flies that control aphids.

Some grass species can be important for natural enemies. For example, they can provide temperature-moderating overwintering habitats for predaceous ground beetles. In England, researchers established “beetle banks” by sowing earth ridges with orchard grass at the centers of cereal fields. Recreating the qualities of field boundaries that favor high densities of overwintering predators, these banks particularly boosted populations of *Dometrias atricapillus* and *Tachyporus hypnorum,* two important cereal aphid predators.

A 1994 study found that the natural enemies the beetle banks harbored were so cost-effective in preventing cereal aphid outbreaks that pesticide savings outweighed the labor and seed costs required to establish them. The ridges can be 1.3 feet high, 5 feet wide and 950 feet long (0.4 meters by 1.5 meters by 290 meters). For more extended effects, it is recommended to plant corridors with longer-flowering shrubs. In northern California, researchers connected a riparian forest with the center of a large monoculture vineyard using a vegetational corridor of sixty plant species. This corridor, which included many woody and herbaceous perennials, bloomed throughout the growing season, furnishing natural enemies with a constant supply of alternative foods and breaking their strict dependence on grape-eating pests. A complex of predators entered the vineyard sooner, circulating continuously and thoroughly through the vines. The subsequent food-chain interactions enriched populations of natural enemies and curbed numbers of leafhoppers and thrips. These impacts were measured on vines as far as one hundred to one hundred fity feet (thirty to forty-five meters) from the corridor.

Selecting the right flowers

When choosing flowering plants to attract beneficial insects, note the size and shape of the blossoms. That's what dictates which insects will be able to access the flowers' pollen and nectar. For most beneficials, including parasitic wasps, the most helpful blossoms are small and relatively open. Plants from the aster, carrot and buckwheat families are especially useful. It should also be noted when the flower produces pollen and nectar: timing is as important to natural enemies as blossom size and shape. Many beneficial insects are active only as adults and only for discrete periods during the growing season: they need pollen and nectar during these active times, particularly in the early season when prey are scarce (Table 1). One of the easiest ways farmers can help is to provide them with mixtures of plants with relatively long, overlapping bloom times. Current knowledge of which plants are the most useful sources of pollen, nectar, habitat and other critical needs is far from complete. Clearly, many plants encourage natural enemies, but scientists have much more to learn about which plants are associated with which beneficials, and how and when to make desirable plants available to target organisms. Because beneficial interactions are site-specific, geographic location and overall farm management are critical variables. In lieu of universal recommendations, which are impossible to make, farmers can discover many answers by investigating the usefulness of alternative flowering plants on their farms.

Enhancing biodiversity – checklist for farmers:

- Diversify enterprises by including more species of crops and livestock.
- Use legume-based crop rotations and mixed pastures.
- Intercrop or strip-crop annual crops where feasible.
- Mix varieties of the same crop.
- Use varieties that carry many genes – rather than just one or two – for tolerating the same disease.
- Emphasize open-pollinated crops over hybrids for their adaptability to local environments and greater genetic diversity.
- Grow cover crops in orchards, vineyards and crop fields.
- Leave strips of wild vegetation at field edges.
- Provide corridors for wildlife and beneficial insects.
- Practice agroforestry; where possible, combine trees or shrubs with crops or livestock to improve habitat continuity for natural enemies.
- Plant microclimate-modifying trees and native plants as windbreaks or hedgerows.
- Provide a source of water for birds and insects.
- Leave areas of the farm untouched as habitat for plant and animal diversity.

Key information needed in crafting a habitat management plan:

1) ecology of pests and beneficials

- What are the most important (economic) pests that require management?
- What are the most important predators and parasites of the pest?
- What are the primary food sources, habitat, and other ecological requirements of both pests and beneficials? (From where does the pest infest the field, how is it attracted to the crop, and how does it develop in the crop? From where do the beneficial come, how are they attracted to the crop, and how do they develop in the crop?)

2) Timing

- When do pest populations generally first appear and when do these populations become economically damaging?
- When do the most important predators and parasites of the pest appear?
- When do food sources (nectar, pollen, alternate hosts, and prey) for beneficials first appear?
- How long do they last?
- What native annuals and perennials can provide such habitat needs?

Designing a habitat-management strategy

To design an effective plan for successful habitat management, first gather as much information as you can. Make a list of the most economically important pests on your farm. For each pest, try to find out:

- what are its food and habitat requirements;
- what factors influence its abundance;
- when does it enter the field and from where; what attracts it to the crop;
- how does it develop in the crop and when does it become economically damaging;
- what are its most important predators, parasites and pathogens;
- what are the primary needs of those beneficial organisms;
- where do these beneficials overwinter, when do they appear in the field, where do they come from, what attracts them to the crop, how do they develop in the crop and what keeps them in the field;
- when do the beneficials' critical resources – nectar, pollen, alternative hosts and prey – appear and how long are they available; are alternate food sources accessible nearby and at the right times; which native annuals and perennials can compensate for critical gaps in timing, especially when prey are scarce.

Rolling out the strategy

This paper presents some ideas and principles for designing and implementing healthy, pest-resilient farming systems. It has been explained why reincorporating complexity and diversity is the first step towards sustainable pest management, and the paper describes the two pillars of agroecosystem health (Figure 4):

• fostering crop habitats that support beneficial fauna
• developing soils rich in organic matter and microbial activity

Well-considered and well-implemented strategies for soil and habitat management lead to diverse and abundant – although not always sufficient – populations of natural enemies. As farmers develop a healthier, more pest-resilient system for their farms they may ask themselves:

- How can species diversity be increased to improve pest management, compensate for pest damage and make fuller use of resources?
- How can the system's longevity be extended by including woody plants that capture and recirculate nutrients and provide more sustained support for beneficials?
- How can more organic matter be added to activate soil biology, build soil nutrition and improve soil structure?
- Finally, how can the landscape be diversified with mosaics of agroecosystems in different stages of succession and with windbreaks, living fences, etc?

Once farmers have a thorough knowledge of the characteristics and needs of key pests and natural enemies, they are ready to begin designing a habitat-management strategy specific for their farm. *Choose plants that offer multiple benefits* – for example, ones that improve soil fertility, weed suppression and pest regulation – and that don't disrupt desirable farming practices. *Avoid potential conflicts:* in California, planting blackberries around vineyards boosts populations of grape leafhopper parasites but can also exacerbate populations of the blue-green sharpshooter that spreads the vinekilling Pierce's disease. In placing selected plants over space and time, *use the scale – field- or landscape-level – that is most consistent with intended results.* And, finally, *keep it simple:* the plan should be easy and inexpensive to implemented maintain, and should be easy to modify as needs change or results warrant change.

Figure 4. Pillars of agroecosystems health

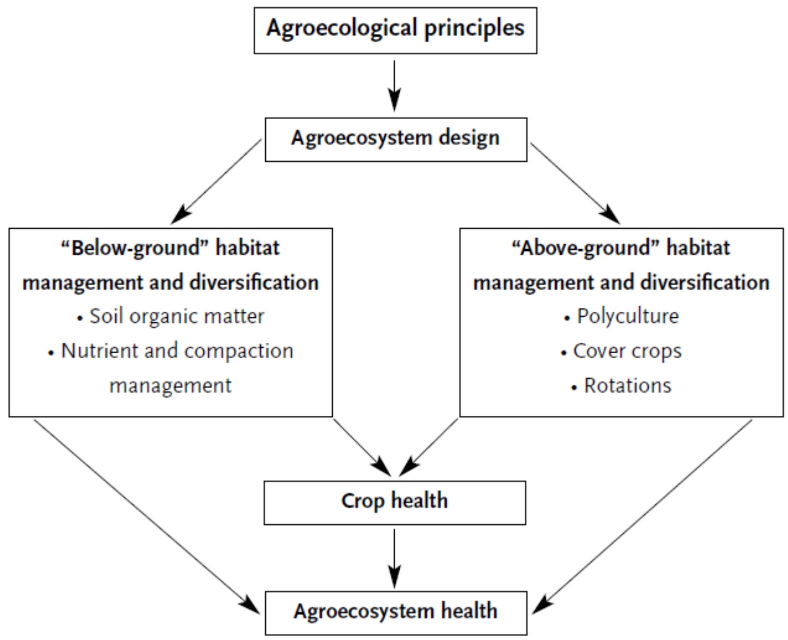
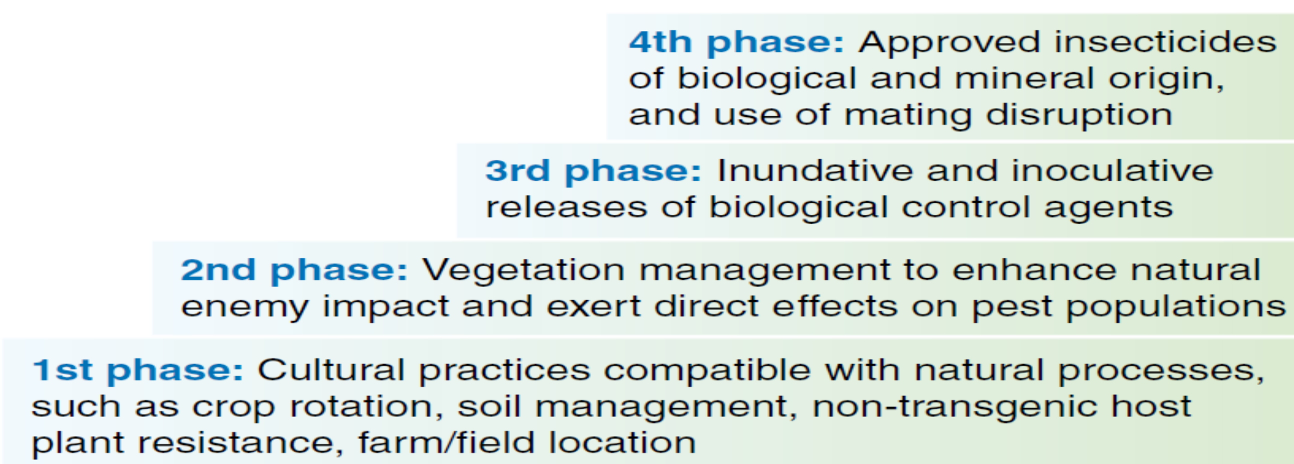


Table 1. Plants that attract beneficial insects

spider	many insects	Caraway, dill, fennel, cosmos, marigold, spearmint
spider mite destroyer	spider mite	Carrot family (goldenrod, yarrow), bishop's weed; maintain permanent plantings
Syrphid fly (hover flies) (*Syrphidae* family)	aphid	Carrot family (Queen Anne's lace, dill, fennel, caraway, tansy, parsley, coriander, bishop's weed), the sunflower family (*coreopsis*, Gloriosa daisy, yarrow, cosmos, sunflower), marigolds, candytuft, sweet alyssum, *ceanothus*, holly-leaved cherry *(Prunus ilicifolia)*, buckwheat, scabiosa, spearmint, coyote brush *(Baccharis pilulari)*, knotweed *(Polygonum aviculare)*, California lilacs *(Ceanothus spp.)*, soapbark tree, meadow foam *(Linnanthes douglasii)*, baby-blue-eyes *(Nemophila)*
Tachinid fly *(Tachinidae* family)	cutworm, armyworm, tent caterpillar, cabbage lopper, gypsy moth, some attack sawfly, Japanese beetle, May beetle, squash bug, green stink bug, sowbug	Carrot family (caraway, bishop's weed, coriander, dill, parsley, Queen Anne's lace, fennel), goldenrod, sweet clover, *Phacelia spp.*, sweet alyssum, buckwheat, amaranth, buckthorn, *Heteromeles arbutifolia*
Tiger beetle (*Cicindelidae* family)	many insects	Maintain permanent plantings and some exposed dirt or sand areas
Minute Pirate Bug (*Anthocoridae* family), (*Orius* spp)	Thrips, spider mite, leafhopper, corn earworm, small caterpillars, many other insects	Effective predators of corn earworm eggs. Carrot family (Queen Anne's lace, tansy, coriander, bishop's weed, chervil), sunflower family (cosmos, tidy tips *(Layia)*, goldenrod, daisies, yarrow), baby-blue-eyes *(Nemophila)*, hairy vetch, alfalfa, corn, crimson clover, buckwheat, blue elderberry *(Sambucus caerulea)*, willows, shrubs. Maintain permanent plantings or hedgerows.
Parasitic nematodes	Nematodes	Marigolds, chrysanthemum, gaillardia, helenium, *Eriophyllus lanatum*, horseweed *(Conyza canadensis)*, hairy indigo, castor bean, *Crotalaria* spp., *Desmodium* spp., sesbania, Mexican tea *(Chenopodium ambrosioides)*, shattercane *(Sorghum bicolor)*, lupines, *Phaseolus atropurpurens*
Praying mantis (*Mantis* spp)	Any insect	Cosmos, brambles. Protect native species by avoiding pesticides.
Predatory mites (*Typhlodromus* spp)	Spider mite	There are many species of predatory mites with ecological requirements, especially with respect to humidity and temperature, that are particular to the species. Avoid use of insecticides. Provide beneficial refugia for non-crop habitat of non-crop mite prey.
Predatory thrips (*Thripidae* family)	Spider mites, aphid, other thrips, Oriental fruit moth, codling moth, bud moth, peach twig borer, alfalfa weevil, whitefly, leafminer, scale	There are several types of predatory thrips. Predatory thrips populations may be conserved/maintained by having non-crop populations of plant-feeding mites (e.g. European red mite, two-spotted spider mite), scales, aphids, moth eggs, leafhoppers and other thrips.
Rove beetle (*Staphylinidae* family)	Aphid, springtail, nematodes, flies; some are parasitic on cabbage-root maggot	Permanent plantings; interplant strips of rye, grains, and cover crops; mulch beds; make stone or plant walkways in garden to provide refuges.
Aphid midge *(Aphidoletes aphidimyza)* (Larvae are aphid predators)	Aphid	Dill, mustard, thyme, sweet clover. Shelter garden from strong winds; provide water in a pan filled with gravel.
Aphid parasites (*Aphidius matricariae* and others)	Aphid	Nectar-rich plants with small flowers (anise, caraway, dill, parsley, mustard family, white clover, Queen Anne's lace, yarrow)
Assassin bug (*Reduviidae* family)	Many insects, including flies, tomato hormworm, large caterpillars	Permanent plantings for shelter (e.g., hedgerows)

Big-eyed bugs (*Geocoris* spp) (*Lyagaidae* family)	Many insects, including other bugs, flea beetles, spider mites, insect eggs and small caterpillars. Will also eat seeds.	Can build up in cool-season cover crops such a berseem clover *(Trifolium alexandrium)* and subterranean clovers (*Trifolium subterraneum*). Can be found on common knotweed *(Polygonum aviculare)*.
Braconid wasp (*Braconidae* family)	Armyworm, cabbage worm, codling moth, gypsy moth, European corn borer, beetle larvae, flies, aphid, caterpillars, other insects	Nectar plants with small flowers (caraway, dill, parsley Queen Anne's lace, fennel, mustard, white clover, tansy, yarrow), sunflower, hairy vetch, buckwheat, cowpea, common knotweed, crocuses, spearmint)
Damsel bug (*Nabidae* family)	Aphid, thrips, leafhoppers, treehopper, small caterpillars	Anything in the sunflower family (incuding goldenrod, yarrow), alfalfa.
Ground beetle (*Carabidae* family)	Slug, snail, cutworm, cabbage-root maggot; some prey on Colorado potato beetle, gypsy moth and tent caterpillar	Permanent plantings, amaranth; white clover in orchards, mulching.
Lacewing (*Neuroptera* family) (*Chrysoperla and Chrysopa* spp)	Soft-bodied insects including aphid, thrips, mealybug, scale, caterpillars, mite	Carrot family (caraway, Queen Anne's lace, tansy, dill, angelica), sunflower family (coreopsis, cosmos, sunflowers, dandelion, goldenrod), buckwheat, corn, hollyleaf cherry *(Prunus ilicifolia)*, flowering bottle tree *(Brachychiton populneum)*, soapbark tree *(Quillaja saponaria)*. Provide water during dry spells.
Lady beetle or ladybug (*Hippodamia* spp and others) (*Coccinellidae* family)	Aphid, mealybug, spider mite, soft scales	Once aphids leave a crop, lady beetles will also. To retain active lady beetles, maintain cover crops or other hosts of aphids or alternative prey. Carrot family (fennel, angelica, dill, tansy, bishop's weed, Queen Anne's lace), sunflower family (goldenrod, coreopsis, cosmos, golden marguerite (*Anthemis*), dandelion, sunflower, yarrow), crimson clover, hairy vetch, grains and native grasses, butterfly weed *(Asclepias)*, black locust, buckwheat, euonymus, rye, hemp sesbania *(Sesbania exaltata)*, soapbark tree, buckthorn *(Rhamnus)*, saltbush (*Atriplex* spp.), black locust *(Robinia pseudoacacia)*.
Mealybug destroyer *(Cryptolaemus montrouzieri)* (*Coccinellidae* family)	Mealybug	Carrot family (fennel, dill, angelica, tansy), sunflower family (goldenrod, coreopsis, sunflower, yarrow)

Cultural practices for pest management



Role of Companion Planting in Pest Management

Habitat manipulation aims to provide the natural enemies of pests with resources such as nectar, pollen, physical refugia, alternative prey, alternative hosts and egg-laying sites. This require the use of "Ecosystem-consisting many biotic and abiotic organisms, elements coexist in an ecosystem" and it is formed by the interactions between all living and non-living things. Many studies have demonstrated increased abundance of natural enemies associated with provisioned habitat. Studies demonstrating a reduction in pest pressure in agricultural crops by natural enemies because of habitat manipulation are less common. In particular for Agriculture there is a need to understand how living and non-living things affect each other in their environment? and how living things especially "plants" found in a community can benefit other plants?

Plants, like people, influence one another. Some get along better together than others. Black walnut and butternut have an antagonistic relationship with tomatoes, for example. The toxin juglans exuded from the trees' roots is quite toxic to several plants, including those of the nightshade family such as tomato, pepper, and eggplant. Plant neighbor relationships might take several forms. First, they may improve the health or flavor of a companion. Second, they may interfere with the growth of a neighbor. Third, they may repel or trap an undesirable critter. Companion plant may also attract a beneficial insect.

Moreover, in a plant community, certain plants grow better near some companions than they do near others or when alone. The resigns may be many i.e. **competition for rhizosphere, phyllosphere, root zone, nutrition uptake, crop canopy space, environment, insect-pest repellence, attraction of beneficial insects, disease reduction, soil fertility enhancement etc. As some plant work together to mutual benefits and this phenomenon is known as companion and non-companion plants**. Companion planting can be described as "**the establishment of two or more plant species in close proximity so that some cultural benefit (pest control, higher yield, etc.) is derived**".

Companion planting observations collected by Richard Gregg were first shared in his 1943 leaflet Companion Plants and How to Use Them. In North America, Indians historically planted corn, beans and squash together in an intercropping system called "Three Sisters". Beans are nitrogen-fixers and continually supply this macronutrient to the soil. Corn stalks provide structure for beans to climb, and squash vines provide a living mulch with their broad leaves that shade the soil, reducing evaporation and inhibiting weed seed germination. These three species have similar environmental requirements and don't outcompete each other for water and nutrients, thus allowing all three species to survive.

Later Louise Riotte wrote books like "Carrots Loves Tomatoes: Secrets of Companion Planting for Successful Gardening" (1975, 1998) and "Roses Loves Garlic: Companion planting and Other secretes of Flowers" (1983, 1998). The concept embraces a number of strategies that increase the biodiversity of agro ecosystems.The concept embraces a number of strategies that increase the biodiversity of agro ecosystems. A more general mixing of various crops and varieties provides a degree of security to the grower. If pests or adverse conditions reduce or destroy a single crop or cultivar, others remain to produce some level of yield e.g. Mixing of cultivars in broccoli can reduce aphid infestation in a crop. Although, companion planting has a long history, the mechanisms of beneficial plant interaction have not always been well understood. ? The magic and mystery of companion planting have intrigued and fascinated humans for centuries, yet it is a part of the gardening world that has never been fully explored.

Traditional recommendations used by gardeners have evolved from an interesting combination of historical observation, horticultural science, and a few unconventional sources. **The companion planting has many benefits:**

- **Help each other grow:** Tall plants, for example, provide shade for sun-sensitive shorter plants.
- **Prevent pest problems:** Plants like onions repel some pests. Other plants can lure pests away from more desirable plants;
- **Attract beneficial insects:** Every successful garden needs plants that attract the predators of pests.
- **Use garden space efficiently:** Veining plants cover the ground, upright plants grow up. Two plants in one patch; use garden soil efficiently

- **Help reduce disease** inoculum efficiently : Cereal crops like sorghum, maize and rice for wilt causing pathogens
- **Help enhance fertility** : leguminous crops used as inter or mulch crops
- **Help reduce weeds**: maize, pigeon pea, mulch crops
- **Protect from heat, wind and even winter**: Tall perennial plants planted on the boarder
- **Repel insect-pests**
- **Trap insect-pests**

The major characteristics of companion plants to be considered during selection of species for Agro-ecological engineering should be as follows:

1.) **Hazards factor**: Weed status of plant being considered; Act as an alternative host for a pathogen of the crop; Poison livestock; Potential for contamination of the crop;

2.) **Economic factors:** Dual crop status; Cost and availability of seed; Does not compete with the crop and reduce yields;

3.) **Biological factors:** Pollen production (total/temporal pattern); Nectar production (total/temporal pattern); Competitive ability (with weeds and the crop); Agronomic compatibility with the crop; Flowering periods that do not coincide with the crop and divert pollinating insects Information that they are able to provide important resources for natural enemies (e.g., food or shelter); Agronomic tractability (e.g., ability to survive with little maintenance)

For example, tall-growing, sun-loving plants may share space with lower-growing, shade-tolerant species, resulting in higher total yields from the land. Spatial interaction can also yield pest control benefits. The diverse canopy resulting when corn is companion-planted with squash or pumpkins is believed to disorient the adult squash vine borer and protect the vining crop from this damaging pest. In turn, the presence of the prickly vines is said to discourage rodents from ravaging the sweet corn.

Tall or dense-canopied plants may protect more vulnerable species through shading or by providing a windbreak. Nurse crops such as oats have long been used to help establish alfalfa and other forages by supplanting the more competitive weeds that would otherwise grow in their place. In many instances, nurse cropping is simply another form of physical-spatial interaction.

Some plants exude chemicals from roots or aerial parts that suppress or repel pests and protect neighbouring plants. The African marigold, releases thiopene—a nematode repellent—making it a good companion for a number of garden crops. The manufacture and release of certain biochemicals is also a factor in plant antagonism. Allelochemicals such as juglone—found in black walnut—suppress the growth of a wide range of other plants, which often creates a problem in home horticulture. A positive use of plant allelopathy is the use of mow-killed grain rye as mulch crop. The allelochemicals that leach from rye residue prevent weed germination but do not harm transplanted tomatoes, broccoli, or many other vegetables.

To utilize the benefits of companion plants in ecological engineering which ultimately help reduce the insect-pests and improve plant health many different ways of planning can be adopted depending upon the purposes, nature of the crop plant and the strategy for the management of specific agriculture problem.

1) **Companion Plant -** Mixing different species of plants within rows or beds

2) **Strip Planting / Strip Cropping** – Growing two or more crops in different strips across the field wide enough for independent cultivation

3) **Inter-planting** – planting a mix or combination of plant species at interval in an area

4) **Intercropping –** a variation of inter planting where at least two different crops are planted either in the same row or in alternate of paired rows in the same area.
5) **Poly-cropping (Mixed cropping) -** planting two or more species combined at random
6) **Multiple Cropping -** production of at least two crops on the same land within a year
7) **Trap Cropping** – crop planted to lure insect pests away from cash crops
8) **Cover Crop** – cultivation of a second type of crop mainly to improve the production system for a primary crop
9) **Green Manure cropping**– a growing crop incorporated into the soil to improve soil quality and fertility
10) **Hedgerow, Windbreak, Shelterbelt/ Alley Crop -** linear plant barriers (e.g., trees, shrubs, non-woody plants and grasses) planted along field edges or other areas not used for crop production.
11) **Permanent Border cropping**– strip of permanent vegetation bordering the field

Coupled with the recent development of new methods and theoretical insights, this is an exciting period for the discipline of CBC. Increasingly, this branch of arthropod biocontrol is taking a rigorous, directed approach, 'ecological engineering', rather than relying on a crude approximation that diversifying vegetation in a 'shotgun' manner will tend to reduce pest numbers.

Use of companion planting for insect-pest management

Companion plants provide a desirable environment for beneficial insects and other arthropods especially those predatory and parasitic species which help to keep pest populations in check. These plant may be insectary or attractant plants both for beneficial (intercrop/attractant plants) and harmful insects (as trap plants) as well as repellent plants (used as intercrop). There are many ornamental plants which discourage the insect-pest population on the main crops. Habitat manipulation for enhanced pest control has also been referred to by critics as '**chocolate-box ecology**' because of the picturesque/pretty/charming nature of some of the tools used; strips of flowers are an example. These approaches reflect the notion that it is the quality, not the quantity, of diversity that is important and this requires the selection of the 'right kind' of diversity. Thus, habitat manipulation is important for enhancing biological control of arthropod pests, but identification of selective food plants that benefit only natural enemies is required in order to avoid inadvertently exacerbating pest damage.

Examples of companion planting:

Tomato – Tomatoes and all Cole crops should be kept apart. Tomatoes also dislike potatoes and fennel. Tomatoes are compatible with chives, onion, parsley, marigold, nasturtium and carrot. Garlic planted between tomato plants protects them from red spider mites. Tomatoes protect roses against blackspot. A spray for roses: make a solution of tomato leaves in your blender by adding 4 or 5 parts of water and 1 tablespoon of cornstarch. Strain and spray on roses where it is not convenient to plant tomatoes as companions.
The best way to see how companions interact with each other is first follow the given guidelines. Secondly, and most importantly, keep careful records of your successes and failures. Learn the basic combinations and then experiment with your own. Just as every person is different, no two gardens are alike. That is why personal observation is so important.
Cabbage – Cole crops such as cabbage, kale, kohlrabi, broccoli, and Brussels sprouts as well as collards, rutabagas and turnips. They do well when planted with aromatic plants such as dill, celery, chamomile, sage, peppermint, and rosemary. Do not plant with tomatoes, pole beans or strawberries.
Carrots – Onions, leeks and herbs such as rosemary, wormwood, and sage act as repellents to the carrot fly.
Corn – Sweet corn does well with potatoes, peas, beans, cucumbers, pumpkin, and squash. Melons, squash, pumpkin and cukes like the shade provided by corn.
Beans – Generally, beans thrive when interplanted with carrots, cauliflower and beets. They also aid cucumbers and cabbage. A Summer Savory companion improves growth and flavor as well as repelling bean beetles. As a bonus, cook both together for a great flavor. Beans don't like members of the onion family and they dislike being planted near gladiolas.
Beets – Beets grow well near bush beans, onions, and kohlrabi, but dislike *pole* beans. In addition, lettuce and brassicas are good companions.

Cucumbers – Cucumbers seem to be offensive to raccoons, so it's good to plant them near your corn. Thin strips of cucumbers also repel ants. Sow 2 or 3 radish seeds in cucumber hills to repel cucumber beetles. Don'tpull the radishes even if they go to seed. Cucumbers and potatoes are antagonistic. Cucumbers do not grow well with aromatic herbs.
Lettuce – Lettuce grows well with strawberries, cucumbers and carrots. Radishes grown with lettuce are especially good.
Onion – Onions and all members of the cabbage family get along well together. They also like beets, strawberries, tomatoes, lettuce, summer savory and a sparse planting of chamomile. They do not like peas and beans. Ornamental relatives of the onion are helpful as protective companions for roses. Since onion maggots travel from plant to plant when set in a row, scatter your onion plants throughout the garden.
Sweet Pepper – Basil and sweet peppers have similar general requirements. They work well when planted together.

The examples of **repellent plants for harmful insect-pests are as follows**:		**Examples of plants which attracts insect-pest and reduce the pest population on main crop**
• Basil/Osmium- flies, mosquito, tomato borer • Garlic - beetles, aphids, weevils, spider mites, carrot fly • Radish - cucumber beetle • Mint - cabbage moth • Marigold - beetles, cucumber beetles, nematodes • Nasturtium - aphid, beetle, squash bug, • Rosemary- cabbage moth, been beetle, carrot flies • Tansy - beetle and flying insects • Petunia - Beetles on beans • Peppermint - Whitefly • Molasses grass/ Desmodium- stem borer		• Okra – white fly • Cowpea- Aphid & thrips • Castor- Spodoptera • Marigold- Heliothis • Poplar – Spodoptera • Eggplant – potato beetle • Radish- Flea beetle • Napier grass/Sudan grass- sugarcane & cereal stem borer • Maize/molasses grass- sugarcane stem borer

VEGETABLE	FRIENDS	FOES
Artichoke	Brassica family	
Asparagus	basil, marigold, nasturtium, parsley, tomato	allium family
Bean-Bush	beets, celery, corn, cucumber, nasturtium, peas, radish, strawberry, summer savory	allium family, fennel
Bean-Pole	carrot, catnip, celery, chamomile, corn, cucumber, garlic, marigold, nasturtium, oregano, peas, potato, radish, rosemary, spinach, squash, summer savory	allium family, beets, brassica family, fennel
Beets	Allium family, beans (bush), lettuce, brassica family, tomato	beans (pole)
Broccoli	artichoke, beets, candy tuft, catnip, celery, chamomile, cucumber, dill, garlic, hyssop, mint, nasturtium, onion, oregano, pennyroyal, peppermint, potato, radish, rosemary, sage, southernwood, thyme, wormwood,	basil, beans (pole), peas (snap), strawberry, tomato
Brussels sprouts	artichoke, beans (bush), beets, celery, chamomile, garlic, nasturtium, onion, peas, pennyroyal, potato, rosemary, sage, southernwood, spinach, thyme, wormwood	basil, kohlrabi, beans (pole), strawberry, tomato
Cabbage	artichoke, beets, celery, chamomile, cucumber, dill, garlic, nasturtium, onion, peas, pennyroyal, peppermint (potted), potato, rosemary, sage, southernwood, spinach, thyme, wormwood	basil, beans (pole), tomato
Carrots	beans, candy tuft, chives, leeks, lettuce, onion, parsley, peas, pepper, radish, rosemary, sage, tomato, wormwood	celery, dill
Cauliflower	artichoke, beans (bush), beets, cabbage, celery, chamomile, garlic, lettuce, nasturtium, onion, peas, potato, rosemary, sage, southernwood, spinach, thyme, wormwood	basil, beans (pole), strawberry, tomato
Celery	beans, Brassica Family, chives, cilantro, garlic, leeks, nasturtium, spinach, tomato	carrot, parsnip
Collards	artichoke, beets, celery, chamomile, rosemary, southernwood, thyme, tomato, wormwood	basil, beans (pole)
Corn	alfalfa, beans, cucumber, geranium (white), jerusalem artichoke, marigold (odorless), melon, parsley, peas, potato, pumpkin, squash, sweet potato	tomato
Cucumber	beans, broccoli, cabbage, catnip, chives, corn, dill (use sparingly), eggplant, kale, kohlrabi, lettuce, marigold, nasturtium, onion, oregano, peas, radish, sunflower, tomato	basil, marjoram, potato, rosemary, sage, summer savory
Eggplant	beans, cilantro, cucumber, marigold, pepper, potato	
Garlic	beets, Brassica family, celery, chamomile, lettuce, radish, roses, tomato	beans, peas
Kale	artichoke, beets, beans (bush), celery, chamomile, cucumber, dill, garlic, lettuce, mint, nasturtium, onion, peas, potato, rosemary, sage, southernwood, spinach, thyme, wormwood	basil, beans (pole), strawberry, tomato
Kohlrabi	artichoke, beets, brassica family, celery, chamomile, cucumber, garlic, nasturtium, onion, aromatic plants, late cabbage, late potato, radish, rosemary, sage, southernwood, spinach, thyme, wormwood	basil, beans (pole), pepper, strawberry, tomato
Leek	carrot, celeriac, celery, onion	beans, peas
Lettuce	beets, carrot, cauliflower, cucumber, dill (use sparingly), kale, radish, strawberry	allium family, brassica family (except cauliflower and kale)
Melon	corn, radish, squash, sunflower, tomato	potato
Mustard	artichoke, beets, celery, chamomile, garlic, kohlrabi, nasturtium, radish, rosemary, sage, southernwood, thyme, wormwood	basil, beans (pole), tomato
Onion	beets, brassica family, carrot, chamomile, cucumber, dill, leeks, pepper, potato, roses, spinach, squash, strawberry, summer savory, tomato	asparagus, beans, peas, sage
Peas	aromatic herbs, beans, brassica family, carrot, cilantro, corn, cucumber, mint, radish, spinach, tomato	allium family, gladiolas
Peppers	basil, carrot, catnip, eggplant, nasturtium, okra, onion, parsley, tomato	fennel, kohlrabi
Potato	beans, brassica family, catnip, cilantro, corn, eggplant, horseradish, marigold, nasturtium, onion, peas	Foe: cucumber, pumpkin, spinach, squash, sunflower, tomato
Radish	beans, beets, broccoli, carrot, chervil, cucumber, garlic, kohlrabi, lettuce, melon, mustard, nasturtium, peas, squash, tomato	hyssop
Spinach	beans, Brassica family, celery, onion, peas, strawberry	potato
Squash	beans, borage, catnip, celeriac, celery, corn, marigold, melon, mint, nasturtium, onion, radish	potato, pumpkin
Strawberry	beans (bush), borage, lettuce, onion, sage, spinach, thyme	Brassica Family
Tomato	asparagus, basil, bee balm, beets, borage, carrot, chives, cilantro, cucumber, garlic, marigold, melon, mint, nasturtium, parsley, peas, pepper, onion, radish, sage	brassica family, corn, dill, fennel, potato
Turnip/Rutabaga	artichoke, beets, celery, garlic, peas, rosemary, sage, southernwood, spinach, thyme, wormwood	basil, beans (pole), hedge mustard, tomato

Squash – As with cucumbers, 2 or3 icicle radishes planted in each hill help prevent insects on squash. Again, let them grow and go to seed. Nasturtiums repel squash bugs. Also, squash planted either earlier or later than usual will often remain insect free.

Table1. Examples of plants useful in attracting beneficial insect for pest management in vegetables

Companion plant	Natural enemies/biocontrol agent	Insect-Pest
Dill, mustard, sweet clover; Shelter garden from strong winds	Aphid midge (*Aphiodoletes aphidimyza*)	Aphid
Nectar-rich plants with small flowers e.g. dill, mustard family, white clover,	Aphid parasites (*Aphidius matricariae* and others)	Aphid
cover crops such as berseem clover (*Trifolium alexandrium*) and subterranean clovers (*Trifolium subterraneum*). Found on common knotweed (*Polygonum aviculare*)	Bigeyed Bugs (*Geocoris* spp. Of Lygaeid Family)	Bugs, flea beetles, spider mites, insect eggs and small caterpillars.
Nectar plants with small flowers e.g. dill, parsley, fennel, mustard, tansy, sunflower, hairy vetch, buckwheat, cowpea, etc	Braconid wasp	Armyworm,cabbageworm, codling moth, gypsy moth, European corn borer, beetle larvae, flies, aphid, caterpillars, etc
sunflower family as well as alfalfa.	Damsel bug	Aphid, thrips, leafhopper, treehopper, small caterpillars
Permanent plantings, amaranth; white clover in orchards, mulching.	Ground beetle	Slug, snail, cutworm, cabbage-root maggot; some prey on Colorado potato beetle, gypsy moth and tent caterpillar
Carrot family, tansy, dill, sunflower family, buckwheat, corn etc	Lacewing, Neuroptera Family (*Chrysoperla* and *Chrysopa* spp.)	Soft-bodied insects including aphid, thrips, mealybug, scale, caterpillars, mite
Carrot,dill, tansy, sunflower, cosmos, dandelion, sunflower, hairy vetch, grains and native grasses, buckwheat, euonymus, rye, hemp sesbania (*Sesbania exaltata*),	Ladybird beetle or ladybug (*Hippodamia* spp. and others)	Aphid, mealybug, spider mite, soft scales
Carrot &, sunflower family plants	Mealybug destroyer (*Cryptolaemus spp*)	Mealybug
Permanent hedge grow Carrot &, sunflower family plants , hairy vetch, alfalfa, corn, crimson clover, buckwheat, blue elderberry	Minute Pirate Bug (Anthocorid Family, *Orius* spp.)	Thrips, spider mite, leafhopper, corn earworm, small caterpillars,
Marigolds, chrysanthemum, gaillardia, helenium, *Eriophyllus lanatum*, horseweed (*Conyza canadensis*), castor bean, *Crotalaria* spp., *Desmodium* spp., sesbania, mexicantea (*Chenopodium ambrosioides*), shattercane (*Sorghum bicolor*), lupines, *Phaseolus atropurpurens*	Parasitic nematodes	Nematodes

Cosmos, brambles	Praying mantis (*Mantis* spp.)	Insect-pests
Strips of rye, grains, and cover crops; mulch beds	Rove beetle (Staphylinidae family)	Aphid, springtail,nematode, flies; some are parasitic on cabbage-root maggot
Dill, fennel, cosmos, marigold	Spider	Many pests
Carrot and mustard family	Spider mite destroyer (*Stethorus* spp.)	Spider mite
Carrot, coriander, cosmos, sunflower, candytuft, sweet alyssum,	Syrphid fly (Hover flies)	Aphid
Carrot family, sweet clover, *Phacelia* spp., sweet alyssum, buckwheat, amaranth,	Tachinid fly	Cutworm, armyworm, tent caterpillar, cabbage looper, gypsy moth; some attack sawfly, Japanese beetle, May beetle, squash bug, green stink bug, sowbug
Carrot & sunflower	Whitefly parasitic wasp (*Encarsia formosa*)	Greenhouse whitefly, sweet potato whitefly

The goal of habitat manipulation is to ensure that natural enemies are present in sufficient numbers when pests become established so that pests are suppressed below economically damaging densities. Through the "selective" food plants those have the potential to increase parasitoid activity without positively affecting pest species are one of the important components of habitat manipulation and thus important tool for ecological engineering. Mechanisms by which food plant selectivity works include temporal coincidence between nectar availability and insect foraging, differential attractiveness and morphometric compatibility between the inflorescence and the insect. Prospects for finding flower species that meet the needs of natural enemies, while denying benefit to pests, appear good because of the rapid recent advances in our understanding of selectivity mechanisms. Cover crops of various types can attract natural enemy species by providing plant foods, moderating the microclimate, and supporting nonpest herbivores that serve as alternative host/prey. Examples of **attractant or insectary plants used as trap crop for beneficial or harmful crops**:

- Alyssum & buckwheat- *Trichogramma*
- *Phacelia tanacetifolia* againt *Frankliniella occidentalis*,
- *Tagetes sp.* against nematodes (*Meloidogyne spp.*).
- Oilseed radish could be a potential trap crop for cyst nematode (*Heterodera spp.).*
- Legume as inter / alternate crops in sugarcane enhances the population of fungal and bacterial BCA for the management of nematodes & other soil borne diseases.
- Inter crop rows of *Tridex procumbens* in paddy crop enhances the natural parasite and predators populations.

The "Push-Pull" strategy for insect-pest management

Using the knowledge of companion planting in crop habitat management and by understanding the insect behavior for their damage to certain plants many different systems have been evolved and been successful in crop pest management. Though traditional pest management methods such as companion planting, trap cropping, and other forms of polyculture have a long history, it is only in recent years that researchers have attempted to underpin such practices with ecologically driven research. "Ecological engineering" for pest management has emerged from conservation biological control and habitat manipulation and is characterized by being based more comprehensively on ecological theory and by being developed via rigorous experimentation. The process of development typically aims to identify and provide the most functional components of biodiversity, rather that simply increasing diversity in an untargeted fashion. One of such examples of behavioral manipulation is known as "Push-Pull strategy". This involve the behavioral manipulation of insect pests and their natural enemies via the integration of stimuli that act to make the protected resource unattractive or unsuitable to the pests (push) while luring them toward an attractive source (pull) from where the pests are subsequently removed. The principles of the push-pull strategy are to maximize control efficacy, efficiency, sustainability, and output, while minimizing negative environmental effects. The strategy is based on the use of repellent and attractive stimuli (**semiochemicals:** natural signal chemicals mediating changes in insect behaviour and development {repellent/attractant}), deployed in tandem, to manipulate the distribution targeted pests thereby reducing reliance on insecticides, and the chances to become pesticide resistance insects. The push and pull components are generally nontoxic. Therefore, the strategies are usually integrated with methods for population reduction, preferably biological control. Push-pull strategies maximize efficacy of behavior manipulating stimuli through the additive and synergistic effects of integrating their use. The field layout and the companion plants are utilized in the following manner which ultimately become as "Push-pull strategies". **Push-pull habitat manipulation for control of maize stemborers and the witchweed *Striga has been very successful.*** 'Pull' : The grasses are planted in the border around the maize and sorghum fields where invading adult moths become attracted to chemicals emitted by the grasses themselves. Instead of landing on the maize or sorghum plants, the insects head for what appears to be a tastier meal. These grasses provide the "pull" in the "Push-Pull" strategy. They also serve as a haven for the borers' natural enemies. Good trap crops include well-known grasses such as **Napier grass (*Pennisetum purpureum*) .** Napier grass has a particularly clever way of defending itself against the pest on slaught: once attacked by a borer larva, it secrets sticky substance that physically traps the pest and effectively limits its damage. The natural enemies lurking among the grasses go into action and dispatch the borers in both maize or sorghum and grass hosts plants.

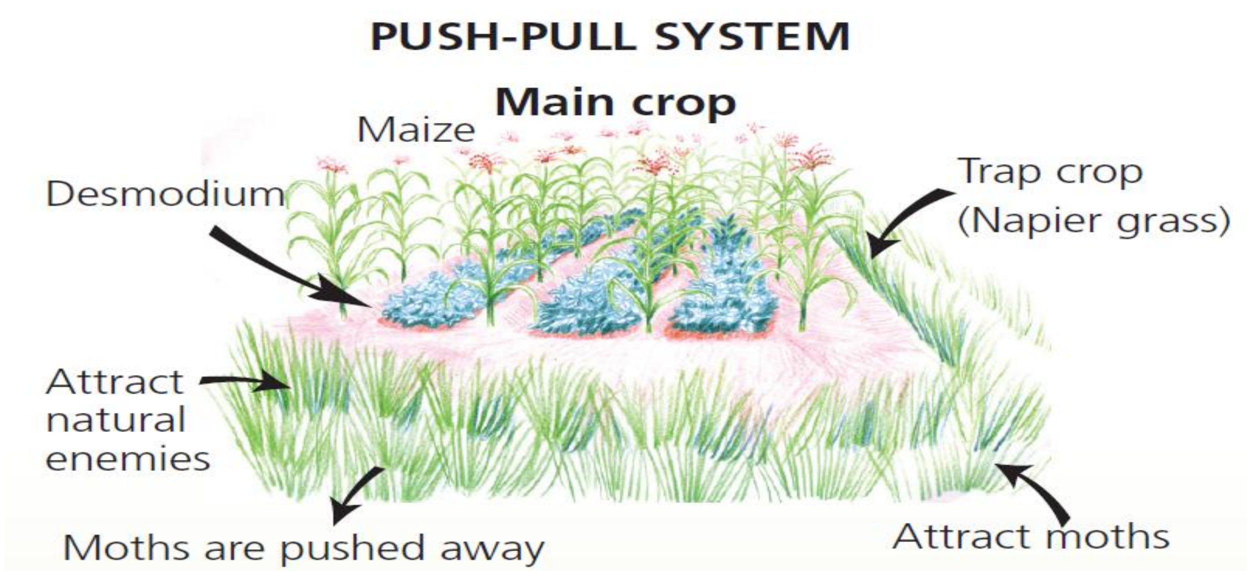


Fig. 1. Push-Pull strategy layout for maize crop pest management (Boarder/trap crop-Napier grass; intercrop/repallent-Desmodium)

'Push': The "push" in the intercropping scheme is provided by the plants that emit chemicals (kairomones) which repel stemborer moths and drive them away from the main crop (maize or sorghum). The best candidates discovered so far with the repellent properties are members of leguminous genus ***Desmodium spp*.** Desmodium is planted in between the rows of maize or sorghum. Being a low-growing plant it does not interfere with the crops' growth and, furthermore, has the advantage of maintaining soil stability, improving soil fertility through enhanced soil organic matter content and nitrogen-fixation. It also serves as a highly nutritious animal feed and effectively suppresses striga weeds. Another plant showing good repellent properties is **molasses grass (*Melinis minutiflora*),** a nutritious animal feed with tick-repelling and stemborer larval parasitoid attractive properties (Fig.1).

In this "Push-Pull" strategy under the ecological engineering system the following are the main considerations for maize stem borer and striga management:

1. The forage grasses, *Pennisetum purpureum* (Napier grass) and *Sorghum vulgare sudanense* (Sudan grass), attract greater oviposition by stem borers than cultivated maize.
2. Non-host forage plants, *Melinis minutiflora* (molasses grass) and *Desmodium uncinatum* (silver leaf) repel female stalk borers (*Chilo*sp.).
3. Intercropping with molasses grass (*Melinis minutiflora*) increases parasitism, particularly by the larval parasitoid, *Cotesia sesamiae*, and the pupal parasitoid *Dentichasmis busseolae*. Melinis contains several physiologically active compounds. Two of these inhibit oviposition (egg laying) in *Chilo*, even at low concentrations.
4. Molasses grass also emits a chemical, (E)-4,8-dimethyl-1, 3,7-nonatriene, which summons the borers natural enemies.
5. Napier grass also has its own defense mechanism against crop borers: when the larvae enter the stem, the plant produces a gum-like substance kills the pest.
6. Sudan grass also increases the efficiency of the natural enemies (the parasitism rate on larvae of the spotted stemborer, *Chilo partellus* more than tripled, from 4.8 percent to 18.9 percent when the grass was planted around maize in a field and from 0.5 percent to 6.2 percent on *Busseola fusca*, another important pest).
7. Intercropping maize with the fodder legumes *Desmodium uncinatum* (silver leaf) and *D. intortum* (green leaf) reduced infestation of parasitic weed, *Striga hermonthica* by a factor of 40 compared to maize monocrop. Reduction in Striga infestation by intercropping maize with the two species of *Desmodium* was significantly more than intercropping maize with soybean, sun hemp and cowpea.

PESTS OF RICE

RICE STEM BORER / YELLOW STEM BORER

Scirpophaga incertulas

Pyralidae: Lepidoptera

The pest is widely distributed in all Asian countries, monophagous and is a major pest on rice in India. Other stem borers on rice include dark headed borer, Chilo suppressalis; white stem borer, Tryporyza innotata; pink rice borer, Sesamia inferens. In South India, incidence of S.incertulas is serious during October-January.

The female moth has bright yellowish brown forewings with a clear single black spot and the anal end having tuft of yellowish hair. The male is pale yellow and the spots on the forewings are not conspicuous. Male is smaller than female.

Eggs are laid near the tip on the upper surface of tender leaf in small masses, covered with a felt like buff coloured mass of hair and scales. Single female lays 2 or 3 clusters of eggs, each having 15-80 eggs. Eggs hatch in about 5-8 days.

Newly hatched larvae which are pale white with dark brown head and prothoracic shield, move downward and wander about on plant surface for 1-2 hours. They hang down by silk thread, get blown off to other clumps or land on water, swim freely and get to the plants. They enter leaf sheath and feed on green tissues for 2-3 days, then bore into the stem near nodal region to feed. They disperse from one plant to another. Usually one larvae is found inside a stem. There are 6 larval instars and full grown larva measures 20 mm long and is white or yellowish white with a well developed prothoracic shield. Larval duration is 33-41 days. Before pupation, the larva prepares an exit hole with thin webbing.

Pupation takes place inside the stem near base in a white silken cocoon. Moth emerges in 6-10 days or in about a month depending on climate. Moths are attracted to light. There are 3-5 generations in South India. Cold weather, high humidity and low temperature in October-December are favourable.

The pest can be identified with the aid of following symptoms

- v “Dead-heart” at vegetative stage which turns brownish, curls and dries off
- v “White ears” at heading stage with empty, partially filled grains
- v Presence of egg masses near the tips of tender leaf blades
- v Activity of moths in the vicinity
- v Frass at the feeding site

MANAGEMENT

Monophagous nature and peculiar boring habits of yellow stem borer make control with insecticides difficult.

- Harvesting of crop close to soil surface, ploughing or flooding the field after harvest
- to kill hibernating larvae in the stubbles
- Selection of varieties resistant to yellow stem borer : Swarnamukhi (NLR 145),
- Pothana (WGL 22245), Varsha (RDR 355)
- Clipping the tips of the seedlings prior to transplantation aids in the elimination of egg masses
- Seedling root-dip with chlorpyriphos (0.02%) @ 200 ml in 200 litres of water in a plot of 3 m x 3 m for 12-14 hours. If 3 kg urea is added, 3 hours is sufficient. Seedlings thus treated are sufficient to transplant one acre. Seedling root-dip is effective for 30 days in the main field against stem borer, gall midge, BPH and GLH.
- Setting light traps or pheromone traps for monitoring the pest
- Collection and elimination of egg masses
- Encouraging natural enemies

Egg parasitoids: Tetrastichus schoenobii, Telenomus beneficiens, Trichogramma chilonis, T.japonicum,
Larval parasitoids: Goniozus indicus, Apanteles ruficrus, A. schoenobii, Bracon chinensis
Pupal parasitoids: Elasmus albopictus, Tetrastichus ayyari, Xanthopimpla emaculata
Predator : a carabid, Chlaenius sp.
• Economic threshold levels (ETL)
• Nursery : 1 egg mass or 1 moth / m2
• Main crop : 1 egg mass or 1 moth / m2 , 5% dead hearts
1% white ears
• Vulnerable stages of the pest to the insecticides are at brood emergence when moths and eggs are observed and when majority of eggs hatch and larvae in wandering stage.
• Need based application of insecticides on ETL basis
Nursery:
• 5 days before pulling the nursery application of carbofuran 3G @ 200 g/cent of nursery in a little water (seedling root-dip not required) (or)
• Foliar sprays with monocrotophos 1.6 ml/l or chlorpyriphos 2.0 ml/l at 10 and 17 DAS
Main field:
• Foliar sprays with chlorpyriphos 2.5 ml/l or phosphamidon 2.0 ml/l or acephate 1.5 g/l or cartap hydrochloride 2.0 g/l or chlorantra niliprole 0.4 ml/l
• At panicle initiation stage: cartap hydrochloride 4 g @ 8 kg/acre,
• Carbofuran 3 g @ 10 kg/acre

RICE GALL MIDGE

Orseolia oryzae

Cecidomyiidae: Diptera

The pest is endemic and is distributed in most parts of India. It is a major pest in Telangana, North Coastal region of Andhra Pradesh and mainly a pest of kharif.

Fly is mosquito like and is 3-3.5 mm long. Female has bright orange red abdomen, swifter with a reddish telescopic body. Male is darker and smaller. Adult longevity is 1-3 days.

Eggs are laid singly or in groups of 2-6 just below or above ligule i.e., on leaf blade or leaf sheath. Single female lays 100-300 eggs. The reddish, elongate eggs hatch in 3-4 days.

Maggot which is pale reddish, apodous moves down to the shoot apex without boring into plant tissue. Throughout its development it feeds at the base of the apical meristem leading to suppression of apical meristem, formation of radial ridges from inner most leaf primordium and elongation of leaf sheath. The symptoms of attack are

- Hollow whitish to pale green cylindrical tube in tillers known as gall / silver shoot/onion shoot bearing at its tip a green, reduced leaf blade complete with ligules and auricles. Gall is a modified leaf sheath.
- Igorous subsidiary tillering if infested in early growth period

The pest infests even nursery but prefers tillering stage. Infested tillers do not bear panicles. At panicle initiation stage, the maggot cannot cause damage. Only one larva develops at shoot apex, remains throughout its development inside the gall. Larval duration is 15-20 days. The full grown larva is 3 mm long and pale red in colour

Pupation is at the base of the gall, but the pupa wriggles up to the tip projecting halfway out. Pupal period is 2-8 days. The gall dries up after fly emergence. It spends its entire larval and pupal period inside a single tiller.

The fly gets active at the onset of monsoon, completes 1-2 generations breeding on ratoon grasses like Cynodon dactylon, Eleusine indica, Ischaeum ciliare, Panicum sp., Paspalum scrobiculatum and then migrates to newly planted rice.

Early rains making flies active and subsequent dry spell and delayed plantings will favour the pest. It is mostly confined to first crop. Light rainy or cloudy weather during July – September coupled with high RH favours build up of the pest.

MANAGEMENT

- Avoid late transplanting in endemic areas. Early planted kharif crop escapes pest
- Selection of variety resistant to a biotype of the region is imperative since six biotypes of rice gall midge have been identified in India.
- Biotype is a biological strain of an organism morphologically indistinguishable from other members of its species but exhibiting distinctive physiological characteristics, particularly in its ability to utilize pest resistant host successfully. According to Kogan (1994), the term biotype is generally used to describe a population capable of damaging and surviving on plants previously known to be resistant to other populations of the same species.

Geographical distribution of gallmidge biotypes

Biotype 1: Hyderabad, Warangal, Maruteru (A.P)
Sambalpur (Orissa), Raipur (M.P)
Biotype 2: Cuttack, Bubaneswar (Orissa)…..East coast
Mangalore (Karnataka), Goa……..West coast
Sakholi (Maharastra)………………Central India
Biotype 3: Ranchi (Bihar)……………………...North
Wangbal (Manipur)………………… North East
Jagityala (A.P)
Biotype 4: Srikakulam and Vizianagaram (A.P)
Bhadra (Sakholi) (Maharastra)
Biotype 5: Moncompu (Kerala)
Biotype 6: Manipur

Varieties resistant to different biotypes of gallmidge

Boitype	**Varieties**
Biotype 1	Kakatiya, Potana, Kavya, Dhanyalakshmi (BPT 1235), Phalguna, Vikram, Surekha, IR 36, Lalat.
Biotype 2	Phalguna, Vikram, Vikramatya, Lalat.
Biotype 3	Surekha
Biotype 4	IR 36
Biotype 5	Phalguna, Kavya, Dhanyalakshmi, Kakatiya, Divya.
Biotype 6	

Some varieties resistant to gall midge in AP: Phalguna (RPW 6-17), Vasundhara (RGL 2538), Suraksha, Srikakulam sannalu (RGL 2537), Surekha, Sumathi (RNR 18833),Pothana (WGL 22245), Kavya (WGL 48684), Divya (WGL 44645), Kesava (WGL 3825), Rudrama (RDR 7555), Pelala Vadlu (RDR 8702), Jagatial Sannalu (JGL 1798), Polasa Prabha (JGL 384), Varalu (WGL 14377), Vorugallu (WGL 3962), Bhadrakali (WGL 3962), Siva (WGL 3943), Varsha (RDR 355), Indur samba (RDR 763), Srikurma (RGL 2332)

• Seedling root dip with chlorpyriphos 0.02%

• The larvae are naturally parasitized by Platygaster oryzae, Polygnotus sp., and Propicroscytus mirificus

ETL

Nursery : 1 gall / m2

Main field in tillering stage: 5% affected tillers, 1 gall /hill

• Application of granules in nursery 5 days before pulling the nursery – phorate 10 G 60 g/cent or carbofuran 3G @ 200 g/cent

• Application of granules in the main field at 10-15 DAT: phorate 5 kg/ac or carbofuran 10 kg/ac in endemic areas.

BROWN PLANTHOPPER

Nilaparvata lugens

Delphacidae: Hemiptera

This is distributed in most of the rice tracts of India. Adults are ochraceous – brown dorsally and deep brown ventrally. The female is 5 mm long and male 4.5 mm. Female exists in two forms, the fully winged macropterous and the truncated – winged brachypterous.

Eggs are thrust within parenchymatous tissues of the plant along the midrib of leaves in bunches of 2-12 eggs, A female lays, about 232 eggs. The egg is white elongated and shaped like a curved club. It hatches in 7-9 days.

Brownish nymph undergoes five instars during a nymphal period of 10-18 days. Both nymphs and adults suck sap from basal portion of plant clustering at the base of rice clump. They inject toxic saliva while feeding which results in "hopper burn". Population of white backed plant hopper (WBPH), Sogatella furcifera is commonly seen in association with that of BPH on rice. WBPH dominates during vegetative phase while BPH dominates from PI stage.. the symptoms include

- Premature yellowing of leaves and drying of plants in isolated circular patches
- Drying of plants spreads in a circular fashion
- Sooty mould
- Exuviae at the base of plants
- Affected stems turn soft and are unfit for use as straw

BPH is reported as vector of grassy stunt and ragged stunt virus. Apart from rice, it infests Cyperus rotundus and Panicum repens. The pest is serious from PI to booting till post flowering. Higher doses of N and high plant density per unit area invite the pest problem. Thick vegetation and direct sown rice preferred.

Detection of BPH biotypes worldwide

Biotypes	Region	Countries
1	South East Asia	Philippines, China, Japan, Malaysia, Taiwan, Thailand
2	South East Asia	Philippines, Solomon Islands, Vietnam
3	South East Asia	Philippines, Taiwan
4	South Asia	Bangladesh, India, Srilanka
5	South East Asia	Philippines

MANAGEMENT

• Avoiding monoculture of susceptible varieties

• Growing resistant varieties like Chaitanya (MTU 2067), Godavari (MTU 1032), Krishnaveni (MTU 2077), Indra (MTU 1061), Vajram (MTU 5249), Vijetha (MTU 1001), Pratibha (MTU 5293), Cottondora Sannalu(MTU 1010), Nandi (MTU 5182), Surya (BPT 4358), Deepti (MTU 4870), Chandan (RNR 74802), Tolakari (MTU 1031), Pushyami (MTU 1075)

• Seedling root dip with chlorpyriphos 0.02%

• Formation of alleys or pathways of 20 cm width for every 2 metres of planting to facilitate aeration, light, basal spraying, monitoring and other farm operations.

• Draining the field during the middle of the season to suppress the pest population

• Conservation of natural enemies

Spider : Lycosa pseudoannulata

Mirid bug : Cyrtorhinus lividipennis

Aquatic bug : Gerris tristan

Coccinellids : Coccinella arcuata

Egg parasitoids : Anagrus sp., Oligosita sp.,

Nymphal and Adult parasitoid : Haplogonatopus orientalis

• ETLs

Tillering stage : 10 hoppers / Hill
Heading stage : 20-25/Hill
• Foliar sprays (directing the spray towards base of plants) with any of the following insecticides viz.,ethofenprox 2 ml/l;acephate 1.5 g/l; BPMC 2 ml/l; imidacloprid + ethiprole 80 WG 0.25 g/l; monocrotophos 2.2 ml/l; carbofuran 3G 10 kg/ac

RICE GREEN LEAFHOPPER

Nephotettix nigropictus

N.virescens

Cicadellidae: Hemiptera

These are small, active wedge shaped leafhoppers, distributed in all rice tracts in India. N.nigropictus is about 5 mm long and possesses two black spots in the males which extend up to the black distal portion of the forewings. Males have a black tinge along anterior margin of pronotum and black submarginal band on the crown of the head. Female is generally entirely green without any black tinge on pronotum.

N.virescens can be easily distinguished by the black spots in the male not extending up to black distal portion of forewings and the absence of black tinge on the pronotum and black band on the crown. It causes more damage to rice than N.nigropictus.

Yellowish eggs are laid in rows under epidermis of leafsheath @ 53 eggs per female. Incubation period is 6-7 days. Nymph passes through 5 instars, becomes adult in about 18 days and it takes about 24 days to complete the life cycle. Both nymphs and adults suck sap from leaves causing the following symptoms.

- Yellowing, stunting and withering of plants
- Leaves turning brown with small scratch like marks on leaf in severe infestation
- Uniform yellowing from mid half of leaf

Serious damage is inflicted when leafhoppers transmit virus diseases. N.nigropictus is known to transmit rice dwarf, rice yellow dwarf, rice transitory yellowing and rice tungro, while N.virescens transmits rice tungro, rice transitory yellowing and rice yellow dwarf. Rice green leafhoppers are abundant during rainy season. Optimum temperature and high humidity favour the pest.

MANAGEMENT

• Early clipping of infested leaf tips to prevent virus transmission
• Removal of left over nursery
• Removal of alternative hosts during off season such as Panicum spp., Echinocloa spp., Cyperus spp., and other grasses
• Seedling root dip with chlorpyriphos 0.02%
• Varieties resistant to green leafhopper IR-20, Vani, Vikramarya
• Eggs are parasitised by Oligosita nephotetticum
• ETLs : Nursery: 1-2 hoppers/m2
Tillering: 10/hill,
Heading: 20/hill,
Tungro endemic areas: 1/hill
• Same insecticides recommended for BPH are effective. For immediate knockdown of high population monocrotophos 2 ml/l + dichlorvos 1 ml/l

RICE HISPA

Dicladispa armigera

Hispidae: Coleoptera

This is known to occur in all rice tracts in India, especially in Andhra Pradesh, West Bengal and Bihar. It is serious on young rice, it also infests sorghum, maize, bajra, sugarcane and grasses.

Beetle is a small 4.5 – 5 mm long, square shaped, bluish black and shiny with spines on thorax and elytra. Adults scrape green matter on upper surface of leaf blade causing.

- Whitish leaf tips of young leaves giving dried up appearance
- White, rectangular streaks parallel to veins on older leaves, which initially appear glistening, membranous, papery white, later turning pale reddish, straw coloured

Eggs are laid singly, partially inserted beneath the epidermis of tender leaves generally towards the tip @ 55 eggs/ female. The egg hatches in 4-5 days. Small, yellowish, flattened grubs feed on leaf tissue inside the leaf mine causing

- Blister spots towards leaf tip

After feeding for 7-12 days, it pupates in leaf mine or grub tunnel and the beetle emerges in 3-5 days. Adult longevity is about 78 days. Heavy rains in July, abnormally low rainfall in Aug-Sept., steady temperatures coupled with high RH is congenial for build up of the pest.

MANAGEMENT

• Clipping of leaf tips of seedlings while transplanting eliminates eggs laid towards the tip
• Removal of left over nursery
• Grubs are parasitized by Bracon sp.,
• ETLs
2 adults / hill
2 damaged leaves / hill
• Foliar sprays with profenophos 2 ml/l or monocrotophos 1.6 ml/l or chlorpyriphos 2.5 ml/l.

RICE LEAF FOLDER

Cnaphalocrocis medinalis

Pyralidae: Lepidoptera

This is widely distributed in India occurring in all rice growing tracts. Moth is small with a wing span of 15 mm, brownish orange coloured with light brown wings having two distinct dark wavy lines on forewings and one line on hind wings. Both wings have dark brown band on their outer margin. Adult longevity is 3-4 days.

Flat oval, yellowish eggs are laid singly on the under surface of tender leaves which hatch in 4-7 days. The larva folds 3-4 leaves of young plants feeding from within. In grown up plants, it folds leaf longitudinally from tip downwards bringing together the margins with silken threads, lives in tubes thus formed feeding on chlorophyll. Single larva damages several leaves causing the following symptoms.

- Whitish membranous folded leaves with typical white streaks
- Faecal pellets when leaf opened
- Reduced vigour of the plant

The pest causes more loss at boot leaf stage. Pale yellowish green larva measuring 16-20 mm long becomes full grown in 15-27 days.

Pupation is inside the leaf fold and the moth emerges in 6-8 days. Total life cycle takes 26-42 days. The pest is abundant during rainy season with optimum temperature and high RH.

MANAGEMENT

It is better to manage effectively the first generation of the pest to prevent the buildup of the population at boot leaf stage.

• Early clipping of infested, folded leaf tips
• Removal of alternative hosts Echinocloa spp., and Panicum spp., and other grasses
• The ichneumonid, Xanthopimpla emaculata is parasitic on the pest larvae
• Passing a rope 2-3 times over the crop at tillering stage mechanically to dislodge caterpillars
• ETL : 1 larva/hill
2 damaged leaves/hill

• Foliar sprays with chlorpyriphos 2.5 ml/l or acephate 1.5 g/l or cartap hydrochloride 2 g/l or granules of cartap hydrochloride 4 G 8 kg/ac

RICE EARHEAD BUG/GUNDHI BUG

Leptocorisa oratorius

Coreidae: Hemiptera

This is present in all rice growing tracts and is a regular pest in certain parts of Telangana and Rayalaseema regions of Andhra Pradesh. The bugs emit characteristic unpleasant odour indicative of their presence in the field, hence the name, gundhi bug.

The pest appears on rice just before flowering stage and continues until panicles ripen. The adult is active, diurnal, elongated bug with long legs. It is olive brown and ventrally green measuring 15.5-17 mm long.

Eggs are laid in single or double rows close to midrib on the upper surface of leaves @ 10-20 per cluster. Each female lays about 100 eggs. Dark reddish brown egg is boat shaped. Egg hatches in about 7 days.

Nymphs are pale yellowish green possessing odoriferous glands on the fifth abdominal segment. Nymph passes through 5 instars in about 15-21 days. The total life cycle takes about a month. After the harvest of rice, the bug over- winters in millets and wild grasses.

Both nymphs and adults suck juice from grains in milky stage, also from peduncle, leaves and stem causing the following symptoms

- Affected grains become shrivelled and chaffy
- Brown spot is observed at the feeding site where sooty mould develops
- Lower grain quality and broken grains when infested at soft dough stage

MANAGEMENT

• Clean cultivation
• Collection of bugs by hand nets
• ETL : 1 or 2 bugs/hill
• Foliar sprays in the evening hours at milky stage starting from borders of the crop with dichlorovos 1 ml/l + endosulfan 2 ml/l or chlorpyriphos 2 ml/l or malathion 2 ml/l
• Dusting with endosulfan 4 D 10 kg/ac or carbaryl 10 D 10 kg /ac.

GRASSHOPPERS

Rice large grasshopper : Hieroglyphus banian

Rice small grass hopper : Oxya nitidula,

Acrididae: Orthoptera

Nymphs and adults feed on foliage by irregularly cutting leaf margins. In severe cases only midribs and stalks remain. They also cut the panicle at heading stage and are very active at night time.

Scraping field bunds and summer ploughings to destroy eggs, dusting cabaryl 10D or malathion 5D @ 10 kg/ac or foliar spraying with fenitrothion 2 ml/l or endosulfan 2 ml/l found effective in their management.

RICE ROOT WEEVIL

Ehinocnemus oryzae

Curculionidae: Coleoptera

It is semi aquatic in habit. Newly hatched grubs feed on stem epidermis initially, enter soil and attack tender roots of transplanted crop causing poor tillering and stunted growth. Upon investigation, grubs can be seen adhering to roots.

Seedling root dip with chlorpyriphos 2.5ml/l, application of neem cake @ 100 kg/ac or superphosphate @ 80 kg/ha to deter grubs at active feeding zone of roots are effective in its management.

RICE SWARMING CATERPILLAR

Spodoptera mauritia

Noctuidae: Lepidoptera

Caterpillar nibble at first, later become voracious feeder eating the seedlings in the nursery and reducing the plants to mere stumps. They migrate from field to fieldm feeding at night and hiding during the day.

Flooding the nursery brings out hiding larvae which are picked up by birds. Foliar sprays with dichlorvos 1 ml/l or chlorpyriphos 2 ml/l are effective.

CLIMBING CUTWORM

Mythimna separata

Noctuidae: Lepidoptera

It appears in swarms at earhead stage in Nov-Dec. Late instars have the characteristic habit of climbing and cutting earheads in addition to defoliation. The pest becomes serious in certain years of heavy rainfall.

In nature, population is suppressed by natural infections by entomogenous fungus, Nomuraea rileyi. Foliar sprays with chlorpyriphos 2.5 ml or endosulfan 2 ml in combination with dichlorvos 1 ml per litre of water in the evening hours following irrigation are effective.

RICE CASEWORM

Paraponyx stagnalis

Pyralidae: Lepidoptera

Larva cuts the leaf blades into short lengths and constructs a tubular case inside which it remains and feeds on the foliage scraping green matter in streaks. Damage appears ladder like with alternate dark and light rows of green patches.

Sprinkling kerosene on water and passing a rope over the crop to dislodge and kill the larvae in the cases. Stagnant water along with leaf cases is drained. Monocrotophos 1.6 ml/l or chlorpyriphos 2.5 ml/l is effective.

RICE WHORL MAGGOT

Hydrellia philippina

Ephydridae: Diptera

Maggots attack the leaf blades even before unfurling and the initial damage is characterised by the presence of narrow stripes of whitish area in the blade margins.

Boot leaf and spikelet damage has also been noticed. The maggots feed on spikelets and cause shrivelling.

Maintenance of irrigation water during initial establishment stage of seedlings and application of carbofuran 3 G @ 33 kg/ha is effective.

PADDY LEAF MITE / YELLOW MITE

Oligonychus oryzae

Tetranychidae: Acarina

Nymphs and adults congregate on lower surface of leaf and suck sap resulting in pale whitish blotches on upper side of leaf which later turn yellow to orange colour. Thin webs are seen on the undersurface of leaves. In heavy incidence mites can be seen on upper side of leaf also.

Foliar sprays of wettable sulphur 3 g/l or dicofol 5 ml/l are found effective.

PANICLE MITE / SHEATH MITE

Steneotarsonemus spinki

Tarsonemidae: Acarina

At vegetative phase, both nymphs and adults colonise midribs of leaves and lacerate tissues up to maximum tillering stage causing brown necrotic patches on midribs. At panicle initiation stage mites move to leaf sheath to feed causing brown necrotic lesions on leaf sheath. Maximum incidence occurs at boot leaf stage. At panicle emergence, mites enter florets, feed on ovaries and stamens causing sterile and discoloured grains in the panicle. Later these grains turn black invaded by saprophytic fungus.

`Dicofol 5 ml/l or profenophos 2 ml/l once at maximum tillering stage when brown lesions on midribs appear and second spraying at panicle emergence are recommended in its management.

INTEGRATED PEST MANAGEMENT (IPM)

There are many definitions of IPM, but the basic concept is the containment of a pest below economically damaging levels, using a combination of control measures.

Following four primary components of IPM are usually recognized.

1. Host plant resistance
2. Manipulation of the farming system to minimise pest infestation or damage
3. Enhanced natural control practice
4. Selective use of biorational and synthetic pesticides

IPM Practices in Rice:

Various approaches in the management of pests of rice fit into the above primary components of IPM.

- Harvesting of crop close to soil surface and deep ploughing or flooding after harvest
- Selection of resistant / tolerant varieties against key pests suitable to local situations
- Protection of nursery from pests
- Application of carbofuran 200 g/cent of nursery in a little water 5 days before pulling nursery for protection against stem borer, gall midge, brown planthopper and green leafhopper for 30 days in the main field
- Clipping tips of leaf blades before transplanting to eliminate eggs of rice stem borer and hispa
- Early planting in gall midge endemic areas
- Formation of alleys or path ways of 20 cm width for every 2 metres of planting to facilitate basal spraying and for aeration and light
- Avoiding of excessive doses of nitrogen
- Ensuring proper drainage and water management
- Weed management
- Monitoring incidence of pests through light traps or pheromone traps for rice stem borer, leaf folder
- Monitoring pest and natural enemy ratio (2:1)
- Passing a rope over the crop in vegetative phase against leaf folder and caseworm
- Inundative release of Trichogramma egg parasitoids @ 20,000/ac three times within 30-45 DAT
- Use of botanical pesticides such as neem seed kernel extract, neem oil etc.
- Application of insecticides on ETL basis
- Community approach in rodent management.

PESTS OF WHEAT

GHUJIA WEEVIL

Tanymecus indicus

Curculionidae: Coleoptera

It is a common pest of young wheat and other crops in Uttar Pradesh, Bihar and Punjab. It is grey or greyish brown weevil measuring 5 mm long. Adults hide during brighter part of the day and get active in the morning and evening hours. Adults are destructive. The weevil cuts and feeds on the plumule of the young seedlings. Older seedlings of more than 6 cm in height are not attacked. In severe cases of attack, it necessitates resowing. The damage results in the following symptom.

- Seedling stems severed and wilting plant lying on ground.

Adults become sexually mature by the end of October (4-5 months after emergence from soil during June-July).

Eggs are laid singly under clods of soil @ 80 eggs/ female. Eggs hatch in 1550 days depending on climate. Larvae develop in soil in about 3 months. After 2 months of pupation, adults are formed during April – May but adults remain in soil till June and come out with rains in June and when sorghum is available in field.

MANAGEMENT

• Deep ploughing during April-May to destroy pupae

• Dusting the soil with carbaryl @ 10-12 kg/ac and raking it into the soil at the time of sowing is effective.

RAGI PINK BORER

Sesamia inferens

Noctuidae: Lepidoptera

It is a polyphagous pest infesting rice, wheat, maize besides other millet crops. On wheat, damage is caused by larvae which bore into the stem killing the central shoot and causing dead hearts.

Moth is medium sized, straw coloured with forewings having marginal black streaks. Hindwings and thorax are white. The female lays about 100 yellowish pearl like eggs between the stem and the leaf sheath in 1-3 rows. The incubation period is 7-12 days.

Caterpillars bore into the stem and kill the central shoot causing

- Dead hearts
- Chaffy earheads later

There may be up to five larvae inside a stem. A single caterpillar can damage number of plants. Oblong and elongate shot holes can be seen on unfolding leaves. The full grown larva measures 20-26 mm and is pale yellow with a purple pink tinge and reddish brown head. The larval period lasts for 25-54 days. Pupation is inside the stem and the adult emerges in 8-12 days.

MANAGEMENT

• Pull out and destroy by burning dead hearts and affected plant parts

• Placement of granules in central whorls as detailed under sorghum stem borer

• Foliar spray with endosulfan 2 ml/l

TERMITES

Microtermes obesi

Odontotermes obesus

Termitidae: Isoptera

These are the most important pests of wheat in India and are present wherever wheat is cultivated. M.obesi causes up to 25% destruction of the germinating grains O.obesus includes both mound builders and subterranean forms. These termites are polyphagous, widely distributed in Andhra Pradesh. Loamy soils or sandy loams are more suitable.

Soon after first monsoon showers winged forms (reproductive castes) leave colony for flight to select mates. Majority perish due to predations by birds and othe rnatural enemies. Survivors alight again on the soil, shed wings and enter soil in royal pairs. They are confined to royal chamber at enormous depth, copulate several times and start a colony. These are primary reproductives. In case one or both royal members die, supplementary reproductives develop to run the colony.

Queen, after fertilization enlarges in size to a length of 11 cm. Eggs are laid @ 30,000/day and the longevity of the queen is 5-15 years, even up to 50 years. Males undergo little morphological changes but become more flattened. Egg period lasts for 30-90 days and nymphal period 6-12 months.

Members that develop first in the colony are workers (sterile caste) which constitute 75-80% of colony. Workers take care of eggs, young ones till they live independently. They feed and tend the queen. They forage for food and cultivate fungal gardens. Workers are whitish yellow, soft bodied, flat and wingless. They only are injurious to crops. They feed on roots, stem of growing plants, even dead tissues of plants feeding on cellulose. As a result of damage, there will be

- Wilting and drying at all stages of wheat crop
- Plants may succumb

Soldiers (sterile caste) can be readily identified with powerful mandibles and are found at damaging site.

MANAGEMENT

• Locating termitarium, digging out queen and destroying is the only permanent remedy
• Fumigation of ant hill with carbon disulphide or chloroform mixture
• Destruction of crop residues which form sources of infestation
• Seed treatment with chlorpyriphos @ 6 ml/kg of seed
• Soil application of chlorpyriphos 50 EC @ 10 ml/l as a soil drench at sowing time in termite prone soils.

INSECT PESTS OF COTTON

The cotton crop in its early stage of crop growth is generally subjected to the attack of sucking pests. From flowering till harvest, the bollworms cause appreciable damage. The losses in cotton from insect attack affect both yield and quality of the lint.

SPOTTED BOLLWORM

Earias vitella
Earias insulana
Noctuidae: Lepidoptera

Earias vitella and E. insulana are serious pests of cotton. These insects are very widely distributed These pests attack a number of other plants of the family malvaceae viz., bhendi Hollyhock, Hibiscus cannabinus, Abutilon indicum and other malvaceous plants.

Adult of E. vitella has pale whitish fore wings with a broad greenish band in the middle while E. insulana has completely green forewings. The adult body length is about 1 cm while the wing span is about 2.5 cm.

The female moth lays spherical, sculptured bluish eggs singly or in groups on tender parts of the plant viz., fresh leaves, fresh squares (flower buds), and flowers. On an average each female moth lays 60-80 eggs. Egg stage is about 2-10 days.

The spotted bollworm appears about 6 weeks after sowing and initially damages the tender shoot by boring into it resulting in “drying of central shoots” which withers and drops down. The larvae later bore into the flower buds, squares and bolls. The larva inserts its head inside the boll and feeds by filling the boll with excreta. A larva may move out and feed on another bud or boll. The feeding causes severe shedding of early formed flower buds and bolls. The damage results in

- Presence of wilting, withering and drooping or drying of tender shoots in early stageof crop growth.
- Presence of bored flower buds (squares), bored bolls with larval frass at theentrance holes
- Premature dropping of affected bolls
- Premature opening of damaged bolls, which remain on plants.
- Presence of badly damaged tissues including lint and seed in damaged bolls.

The caterpillars of both the species have a number of black and brown spots on the body and hence the name spotted boll worm. Full grown larva measures 14 mm in length. The larval stage lasts for about 9-25 days.

Pupation takes place generally in fallen material, outside the boll, on plant surfaces and in cracks and crevices of the soil. Before pupation however, the larva spins a dirty, white silken cocoon of boat shaped one. Pupal period is about 6-25 days.

MANAGEMENT

- Destruction of plants, crop residues and alternative weed hosts which harbour pests in off season
- Collection and destruction of infested shoots, squares and bolls and the fallen material.
- Adopting crop rotation
- Deep ploughing in summer
- Intercultivation with sorghum, greengram, cluster bean, jowar etc.
- Setting of pheromone traps @ 12/ha
- Conservation and use of natural enemies like Trichogramma evanescens which parasitises the eggs and Bracon lefroyi, B. greeni, B. hebetor, B. brevicornis, Apanteles sp and Elasmus sp which parasitise the larval stage and Chelonus and Chalcis species that parasitise pupal stages.
- Release of first instar larvae of Chrysoperla sp.@ 1,00,000/ha
- Foliar spray with Bacillus thuringiensis @2g/l of water
- ETL 10% damaged shoot (or) 5% damaged bolls
- The parasitoid activity in the field should be carefully assessed before the insecticidal application

• Foliar spray with endosulfan 2.0 ml; quinalphos 2.5 ml; chlorpyriphos 2.5 ml; acephate 1.5 g; triazophos 2 ml; thiodicarb 1.5 g and profenphos 2 ml/l
• The insecticidal application should coincide with the peak of hatching of eggs, so that the just hatched larvae may get the fatal dose before entering the plant tissue.

AMERICAN BOLLWORM

Helicoverpa armigera
Noctuidae: Lepidoptera

American bollworm has a world wide distribution in all the cotton growing regions of the world. It is a polyphagous, infesting gram, lablab, safflower, chillies, groundnut, tobacco, tomato etc.

Moth is stout, medium sized with brownish/greyish forewings with a dark cross band near outer margin and dark spots near costal margins, with a wing expanse of 3.7 cm.

The spherical, yellowish eggs are laid singly on tender parts and buds of plants. The egg period lasts for 2-4 days. Caterpillars are of varying colour, initially brown and later turn greenish with darker broken lines along the side of the body.

Young larva feeds on the leaves for sometime and then attacks squares and bolls. Internal tissues are eaten severely and completely hollowed out. While feeding, the caterpillar thrust its head inside leaving the rest of the body out side.

- Fed leaves shoot and buds.
- “Flared or open” squares. Bolls are bored at the base of flower buds which are hollowed out, bracts of damaged flower buds spread out and curl down wards.
- Premature boll opening and shedding

The larval period lasts for 18-25 days. Body covered with radiating hairs. When full grown, they measure 3.7 to 5 cm in length. The full grown caterpillar pupates in the soil in an earthen cell and emerges in 16-21 days.

The activity of Helicoverpa starts on greengram, summer vegetables and maize and continues their generation by Aug-Sept months synchronizing with cotton crop. It thrives on cotton crop even in the subsequent generation until the pigeonpea crop comes to flowering (second fortnight of Nov.) then it continues on chickpea, tomato, sunflower, castor during Jan-Feb. months.

MANAGEMENT

• Destruction of crop residues
• Hand picking up of the grown up larvae
• Encouraging new crop rotation
• Nipping terminal buds when 16 to 18 sympodias are present in the plant within 80 – 100 days to reduce the egg load
• Growing intercrops such as cowpea, onion, maize, coriander, urdbean in 1:2 ratio for conservation of natural enemy population.
• Growing sorghum or maize in 4 rows all around cotton crop as guard crop.
• Use of ovipositional trap crops such as marigold @ 100 plaants / acre and collection of larvae from flowers.
• Erecting of bird perches for encouraging predatory birds such as king crow, mynah, drongo etc.
• Growing early maturing and tolerant varieties such as Abadita, LK 861, LPS 141, NA 1280 and G 27.
• Installing pheromone traps @ 4 / ac (ETL 10 moths/trap/day)
• Releasing of egg parasitoid Tricogramma chilonis at weekly interval @ 1.5 lakhs/ ha or release of 2nd instar larvae of Chrysoperla carnea @ one lakh/ha at 75 and 90 days after sowing
• Application of HaNPV @ 200 LE/ac in combination with jaggery 1 kg, sandovit 100 ml or Robin Blue 50 g thrice at 10-15 days interval on observing the eggs or first instar larvae in the evening hours.
• Larval parasitoid such as Campoletis chloridae (Ichneumonidae); Eriborus angenteopilorus; Diadegma fenestalis; Bracon brevicornis; Peribaca orbata etc.

- ETL 10% of damaged buds (or) 5% of damage bolls or one egg / plant or one larva / 10 plants
- In severe incidence, sprays with indoxacarb 1 ml/l or spinosad 0.3 ml/l or emamectin benzoate 0.5 g/l after collecting late instars.

PINK BOLLWORM

Pectinophora gossypiella

Gelechiidae: Lepidoptera

The pink bollworm is a very widely distributed and probably the most serious cotton pest on a world basis. The American cottons in India are damaged much more by the pink bollworm than the indigenous varieties. It is distributed in parts of India, Pakisthan, America, Africa, Australia and Asia. Besides cotton, bhendi, hollyhock, mesta, Abutilon indicum, hibiscus and other malvaceous crops are infested.

Moth is small about 5-6 mm in length and has wing span of 12.5 mm. Body is dark brown in colour with numerous small black spots on the wings. The first segment of the antenna bears 5-6 long stiff hairs and the palpi are pointed and curved upwards. The moths are active during night. Female lays flattish scale like whitish eggs singly on various parts of young shoots. However, half developed bolls are preferred when available. Egg period ranges from 4-25 days.

The freshly hatched larvae are white and turn pink as they grow older. The larvae do most spectacular damage to practically mature cotton bolls which they enter mostly at such a tiny stage of just hatched larvae that their entry holes get healed and in which they remain, devouring both seed and fiber forming tissues. The infestation at times is so severe that up to 10 larvae are found in each boll and 75-100 per cent bolls are found infested. The damage results in

- "Rosette" flowers
- Attacked flowers drop prematurely and the seeds are destroyed in advanced stage
- The lint development is retarded and is weakened.
- It causes premature opening of the boll leading to invasion of saprophytic fungus.
- Stain the lint both in the gin and in the boll, thus the ginning percentage and quality of lint is greatly reduced.
- Poor germination capacity of seeds in the attacked boll.

Larva is full grown in 25 – 30 days. The full grown, uniformly pinkish larvae measures about 8-16 mm with dark brown head and prothoracic shield. The larva undergoes generally only 3 moults.

Pupation occurs in flimsy cocoon in boll, often in seed hollowed out by larva. The pupation period lasts for about 6-20 days depending on the season.

MANAGEMENT

Since eggs are mostly protected by calyx and the newly hatched larva bore into the bolls immediately, it is difficult to manage this pest with insecticides alone. Therefore the following methods are suggested.

- Growing early maturing varieties: bolls mature before heavy population builds up
- Taking up timely sowings. Avoid staggered sowings.
- Use acid delinted seeds: soak seed in concentrated sulphuric acid (80 – 100 ml / kg seed) for 2 – 3 minutes, wash with water 2 – 3 times followed by washing with lime supernatant, shade dry.
- Use of organic manures, recommended doses of N
- Keeping the crop free of weeds
- Monitoring through field scouting and pheromone traps (Gossyplure)
- Destroying PBW in rosette flowers and periodically remove and destroy dropped squares dried flowers and premature bolls.
- Avoiding ratooning and summer cotton.
- After final picking, allowing cattle, sheep and goats to graze upon immature green bolls to prevent carry over of pest to next season.
- Destroying cotton stubbles to prevent carryover.

- Restrict the movement of cotton seed from other areas / states.
- Seed fumigation with methyl bromide @ 0.4 kg / 1000 cu ft. or aluminium phosphide (Quickphos, Phosfume, Phostoxin) @ 50 tablets (each 3 g)/ 1000 cu ft.
- Need based use of insecticides. ETL: 10 % PBW infested rosette flowers. In particular, persistent insecticides like quinalphos 2.5 ml/l; chlorpyriphos 2 ml/l; at 15 days interval.
- In severe incidence cypermethrin 2 ml/l or lamda cyhalothrin 1.5 ml/l or thiodicarb 1.5 g/l on need basis towards the end of crop season.
- Even at ginning mills, burning the stained kapas is suggested.

TOBACCO CATERPILLAR

Spodoptera litura

Noctuidae: Lepidoptera

It is found through out the tropical and sub tropical parts of the world, wide spread in India. Besides tobacco, it feeds on cotton, castor, groundnut, tomato, cabbage and various other cruciferous crops.

Moth is medium sized and stout bodied with forewings pale grey to dark brown in colour having wavy white crisscross markings. Hind wings are whitish with brownpatches along the margin of wing. Pest breeds throughout the year. Moths are active at night. Female lays about 300 eggs in clusters. The eggs are covered over by brown hairs and they hatch in about 3-5 days.

In early stages, the caterpillars are gregarious and scrape the chlorophyll content of leaf lamina giving it a papery white appearance. Later they become voracious feeders making irregular holes on the leaves and finally leaving only veins and petioles. During flowering and boll formation stage, the caterpillars also feed on the internal contents of bolls causing irregular holes.

ETL: 1 egg mass/10 plants.

- Irregular holes on leaves initially and later skeletonisation leaving only veins andpetioles
- Heavy defoliation.
- Presence of bored bolls.

Caterpillar measures 35-40 mm in length, when full grown. It is velvety, black with yellowish – green dorsal stripes and lateral white bands with incomplete ring – like dark band on anterior and posterior end of the body. It passes through 6 instars. Larval stage lasts 15-30 days

Pupation takes place inside the soil, pupal stage lasts 7-15 days.

Adults live for 7-10 days. Total life cycle takes 32-60 days. There are eight generations in a year.

MANAGEMENT

- Collection and destriction of the infested material from the field.
- Plucking of leaves harbouring egg masses / gregarious larvae and destroying.
- Setting up light traps for adults.
- Setting up of pheromone traps @ 12/ha
- Spraying NSKE 5 % against eggs and first instar larva.
- Spraying NPV @ 200LE/ac in combination with jaggery 1 kg, sandovit 100 ml or Robin Blue 50 g thrice at 10-15 days interval on observing the eggs or first instar larvae in the evening hours.
- Release of egg parasitoid Trichogramma @ 50,000/ha/week four times
- ETL: one egg mass / 10 plants.
- Foliar spraying with endosulfan 2ml/l or thiodicarb 1.5 g/l or quinalphos 2.5ml/l. in severe incidence novaluran 1 ml/l or lufenuron 1 ml/l.
- Baiting with rice bran 10kg + jaggery 2 kg+ chlorpyriphos 750 ml or thiodicarb 300g in sufficient quantity of water in form of small balls and broadcasting in evening hours in one acre.

LEAFHOPPERS

Amrasca biguttula biguttula

Cicadellidae: Hemiptera

They are distributed in all cotton growing regions of India. They are mostly confined to leaf surface infesting okra, potato, brinjal, castor, tomato, hollyhock, Abutilon indicum besides cotton.

It is a small insect, varying from less than 1 mm to about 3 mm. Its adult stage is subjected to seasonal changes in colour. It is reddish in winter and greenish yellow in summer. The adult is a wedge shaped insect about 3.5 mm in length. There is a black spot on each forewing and two small black spots on the vertex. Both nymphs and adults move diagonally, when disturbed.

Female lays about 30 eggs. The eggs are usually inserted full length into the spongy parenchymatous tissue between the vascular bundles and the epidermis. The eggs hatch in 4-11 days.

Nymphs are also pale greenish in colour like the adults but are wingless and are found in large numbers on lower surface of leaves. The nymph moults five times and the nymphal period last for 7-21 days. The whole life cycle is completed in about two weeks to more than a month and a half, depending on environmental conditions. There are 8-10 overlapping generations.

At the nymphal stages as well as the adult, they inflict the same type of damage. They suck the cell sap from the plant tissue. During desapping the plant, they also inject a toxin through saliva into the plant tissue, resulting in hopperburn. In susceptible varieties, the attack results in mottling accompanied by the curling of the entire lamina with brown necrotic patches. Thus, the entire photosynthetic activity of the plant is very seriously interfered with.

- Hopper burn i.e., the leaf margins turning yellowish initially and subsequently turning reddish and curling up.
- Stunted growth of the plant.
- Brown necrotic patches on the leaves.

`Irrigated conditions in the north and humid conditions in the south; high humidity and high temperature are favourable.

ETL: 2-3 nymphs/leaf

MANAGEMENT

• Growing resistant / tolerant varieties against leafhoppers.

- ➢ L603 Saitha
- ➢ L 604 Narasimha (NA 1325)
- ➢ LRA 5166 NHH 44
- ➢ NHH 390 H 8
- ➢ Lam hybrid – 4

• For sap feeders in general

• Seed treatment (after acid delinting) with

- ➢ Carbosulfan - 40 g/kg
- ➢ Imidacloprid 70 WS - 5 g/kg
- ➢ Thiamethoxam 70 WS - 4 g/kg gives protection for 30 days against sap feeders

• Soil application carbofuran 3G 33 kg/ha (1 kg a.i./ha) at sowing

• Stem application (if seed is not treated) with insecticides using brush

- ➢ Monocrotophos or methyl demeton 1:4 with water
- ➢ Imidacloprid 200 SL 1: 20 with water

Three times at 20 – 25, 30 – 35, 40 – 45 Days after sowing.

• ETL: 2 – 3 nymphs / leaf.

- ➢ Foliar sprays with monocrotophos 1.5 ml/l or imidacloprid 0.4 ml/l or methyldemeton 2 ml/l or acetamiprid 0.2 g/l or acephate 1.5 g/l or phosalone 2 ml/l or phosphamidon 0.5 ml/l at 15 & 30 DAS

WHITEFLY

Bemisia tabaci

Aleyrodidae: Hemiptera

It is known to infest about 50 different species of plants but it becomes quite a serious pest of cotton in certain regions of the country. The infestation by this pest adversely affects the physiology of the cotton plant at all its stages of growth.

It is distributed in all cotton growing regions of the world. It also infests radish, water melon, cucumber, chillies, brinjal, tomato, potato, tobacco etc

Adult is minute insect measuring about 0.5 mm in length having white or grayish wings, a yellowish body and red medially constricted eyes. A single female of this species lays about 70 stalked eggs singly on the undersurface of leaves, mostly on the top and middle leaves of plant. The insect can often breed parthenogenetically. The eggs are light yellow in the beginning but turn brown later on. Egg period ranges from 3-33 days.

Nymphs are oval shaped, scale like, greenish yellow with marginal bristle like fringes. The nymphs remain stationary once they settle down. Nymphs moult thrice. Nymphal period lasts for 9-18 days. There are about a dozen overlapping generations in a year. Both nymphs and adults suck sap from lower side of leaves resulting in

- Chlorotic spots which later coalesce forming irregular yellowing of leaves which extends from veins to outer edges.
- The vegetative growth retarded and boll formation seriously hampered.
- Shedding of the bolls accentuated and proper opening of the bolls interfered with.
- Low quality lint and low oil content.
- Sooty mould development due to honey dew excretion on infested parts. It is vector of leaf curl virus.

The maximum infestation on cotton occurs during July. High temperature and low humidity are reported to be conducive to the multiplication of this pest.

MANAGEMENT

- A chalcid parasite attacks the older nymphs and the parasitisation is at times more than 30 per cent. Also, there are a few predators like some species of Chrysopa and coccinellids, which feed on the whitefly stages.
- Growing of tolerant varieties such as Kanchana (LPS 141); LK 861; NA 1280.
- ETL 5-10 nymphs/leaf
- Chemical control same as under cotton leaf hopper.

COTTON APHID

Aphis gossypii

Aphididae: Hemiptera

It is of worldwide distribution. It is a polyphagous species. However on cotton, often it causes appreciable damage during severe drought conditions. It also infests brinjal, chilies, amaranthus etc.

Adult is small, soft, yellowish, green or greenish brown in colour. It is found in colonies of hundreds on the tender shoot and the undersurface of tender leaves. They are characterized by the presence of two tubes like structures called cornicles, on the abdomen. They are wingless normally but winged forms are often found mostly in the beginning and towards the end of season. Wings are thin, transparent and are held like a roof over the body. They reproduce both sexually and parthenogenetically. Parthenogenetic females give rise to females ovo - viviparously.

Nymphs are light yellowish green or brownish or greenish black in colour. They colonise growing points, lower surface of leaves and tender shoots. There are four instars. Nymphal period is about 7-9 days Both nymphs and adults suck the sap by remaining on the lower surface of the leaves.

- Curled, faded and dried leaves.
- Development of black sooty mould due to honeydew excretion on infested parts.

MANAGEMNT: Same as in cotton leafhopper.

MITES

Tetranychus telarius, T. bioculatus (Tetranychidae)
Hemitarsonemus latus, (Tarsonemidae)
Eriophyes gossypii (Eriphyiidae)

The mite is a polyphagous and is known to infest on 183 species of plants including cucurbits, brinjal and bhendi on which it is sometimes very serious.

Adult female body is oval and is variable in colour i.e., red, green, amber or rusty green and with two large pigmented spots on the body. The large scale use of chlorinated hydrocarbon insecticides for the control of other pests led to the multiplication of the mites as they are less toxic to mites but more toxic to natural enemies. It is active from March – October and passes winter as gravid female. It lays 6080 eggs. Egg period lasts 2-6 days.

Nymph is light brown in colour and has two eye spots and four pairs of legs and quite active. Both nymphs and adults cause damage by feeding on the lower surface of the leaf underneath a web.

- On close examination of the lower leaf surface, mites smaller than a pinpoint may be seen.
- The infested leaves rapidly curl up, become hard and crisp and ultimately shed.
- Bolls ripen prematurely and in serious infestation shed.

Mite infestation begins in the seedling stage and extends to harvest. Nymphs grow to maturity in 2 stages within 4-9 days and adults live for 9-11 days. Total life cycle in active period takes 9-19 days.

MANAGEMENT: Foliar sprays with sulphur 50 WP 3 g/l or dicofol 5 ml/l

COTTON THRIPS

Thrips tabaci, Scirtothrips dorsalis
Thripidae: Thysanoptera

Cotton thrips is a highly cosmopolitan form and is found on all kinds of vegetation. Onion and garlic, amaranthus, guava, solanaceous and cucurbitaceous plants, groundnut, chilies, mango, cabbage, bhendi etc.

Nymphs and adults suck sap from leaves and flower buds. Margins of affected leaves get slightly curled up and the leaf blades show uneven surface, when attack occurs in flowering stage, the affected flowers may wither away.

It is a vector of yellow spot virus and spotted wilt virus

RED COTTON BUG

Dysdercus cingulatus
Pyrrhocoridae: Hemiptera

In India, the bug infests cotton in all cotton growing regions. Also infests bhendi, maize, mesta etc., are other host plants.

The nymphs and adults suck sap from tender leaves, petioles and shoots in early stages and then infest flower buds and immature bolls and bolls that have just opened. Resulting plants loose their vigour and bolls open prematurely with stained lint. Infested seeds get shriveled, underdeveloped, become unfit for sowing and oil content gets reduced. From the spot of injury on the bolls, a bacterium – Nematospora gossypii gains entry and spoils the lint. Some times cannibalism exists in this insect. The reduvid bug Harpactor costalis is predacious on red cotton bugs, dusting of methyl parathion 2D or carbaryl 10D @ 10 – 12 kg/ac are effective against this pest.

DUSKY COTTON BUG

Oxycarenus hyalinipennis

Lygaeidae: Hemiptera

It is found in all cotton regions in India.Both nymphs and adults suck sap from immature seeds and strain the lint. The seeds do not ripen and get damaged. Seeds get lighter in weight and loose their germination capacity.

The anthocoreid bug - Orius tantilus is predaceous on the nymphs and dusting of methyl parathion 2D or carbaryl 10D @ 10 – 12 kg/ac is found effective.

COTTON LEAF ROLLER

Sylepta derogata

Pyralidae: Lepidoptera

Besides cotton, bhendi and several other malvaceous plants are infested by this pest. It is primarily a sporadic pest of cotton in India. The larva rolls the leaf and feeds on the green tissue in the early stage and eats up a large portion of the leaf as it grows. Severe attack results in the presence of a large number of leaf rolls and the plants become stunted ultimately.

Natural enemies viz., egg parasitoid: Trichogramma sps; larval parasitoids: Brachymeria bengalinsis pulchellae; Elasmus indicus; Apanteles spp.; Bracon lefroyi; Microbracon recinicola; and Pupal parasitoids: Trichospilus pupivora and Xanthopimpla spp., and foliar spraying with carbaryl 3 g/l or monocrotphos 1.5 ml/l are effective measures.

COTTON STEM WEEVIL

Pempherulus affinis

Curculionidae: Coleoptera

Cotton stem weevil is a serious pest of cotton and is known from India, Burma, Thailand and Philippines

This pest is a serious one of Cambodian cotton, particularly on summer crop. Adults generally feed on the bark of plants. Grub bores into the stem above the ground level and makes tunnels. Attacked plants show characteristic gall like swellings on the stem. In severe cases plant may succumb during early stage of crop growth. Infestation starts on 12-15 days old cotton plants.

Removal and destruction of attacked plants. Euderus pempheriphilla is parasitic on grubs and foliar sprays with chlorpyriphos 2.5 ml/l or endosulfan 2.5 ml/l from three weeks after sowing were effective.

GRASSHOPPERS

Cyrtacanthacris ranacea; Chrotogonus oxypterus;

Catantops annexus; Aeolopus tamulus

Acrididae: Orthoptera

Cotton crop is often damaged in the early stage by these grasshoppers. Both nymphs and adults feed on leaves. Heavy infestation results in complete defoliation of plants.

Deep ploughing after the harvest of crop so as to expose the egg masses in the soil, dusting the bunds with methyl parathion immediately after the hoppers are noticed and check their migration and dusting the crop in the early stage with methyl parathion dust @ 10-12 kg/ac or spraying with methyl parathion 2 ml/l carbaryl 3 g/l found effectictive.

MEALYBUG

Phenacoccus solenopsis

Maconellicoccus hirsutus

Pseudococcidae: Hemiptera

It is a minor pest with isolated incidence. Of late the pest has been reported to infest cotton in alarming proportions sucking sap from all aerial parts of the plant. B.t. cotton is severely infested with P. solenapsis. The pest initially is restricted to a few plants. If the infestation is not checked in a few isolated spots, it spreads to all corners of the field.

Initial infestation should be checked by spot treatment with insecticides by stem application with monocrotophos / methyl demeton or imidacloprid as detailed earlier. Foliar sprays with methyl parathion / malathion / triazophos / monocrotophos each at 3 ml/l in combination with dichlorvos 1 ml/l are effective.

INTEGRATED PEST MANAGEMENT IN COTTON

Number of sucking pests like aphids, leahoppers, thrips and whiteflies infest cotton during early vegetative growth. Of these leafhoppers and whiteflies occur more regularly and predominently. Hence strategies for managing sucking pests have direct impact on success of IPM strategies for boll worms which emphasize survival and build up of natural enemies in cotton ecosystem.

IPM FOR SUCKING PESTS

- Growing toterant / resistant varieties or hybrids against leafhoppers and white flies.
  - Leafhoppers: Many varieties like MCU – 5, LRA 5166, L 604, L 603, Narasimha (NA1325) & hybrids like NHH 44, Saritha, H8, jk Hy – 1, LAHH – 1
  - Whiteflies: glabrous varieties like Kanchana (LPS 141), LK 861, L615, NA 1280, Supriya

- Soak the seed in concentrated sulphuric acid (100 ml/kg seed) for 2 – 3 minutes, wash with water 2 – 3 times followed by washing with lime supernatant, shade dry and treat with carbosulfan 40 g or imidacloprid 5 g along with little gum to protect against early season sucking pests.
- If untreated seed is sown, apply carbofuran 3G 12 – 14 kg/ac or phorate 10G 4 – 5 kg/ac nearer to the base of seedlings when the soil is moist.
- If the seed treatment is not done or granules are not applied, stem application using small brush with
  - Monocrotophos or methyl demeton in 1:4 dilution
  - Imidacloprid in 1:20 dilution at 20, 40, 60 DAS against sucking pests up to 75 days without harming natural enemies and environment and minimizing insecticide quantity.

- Growing intercrops like blackgram, greengram, soybean, clusterbeans, cowpea, groundnut, Setaria contribute to build up of natural enemies and give extra income.

  High yielding varieties in two rows with 90 cm spacing, hybrids in three rows with 120 cm spacing.
- In whitefly endemic areas, keeping yellow empty tins smeared with greese as trap. Wipe out trapped whiteflies every day and apply greese again.
- In non IPM plots, spray monocrotophos 1.6 ml/l or dimethoate 2.0 ml/l or triazophos 2.5 ml/l or methyl demeton 2 ml/l or imidacloprid 0.4 ml/l
  - When there are 5 – 10 whiteflies / leaf
  - 1 – 2 leafhoppers / leaf
  - 15 – 20 % aphid infested plants

- For mealy bug, dichlorvos 1 ml/l or methyl parathion 1 ml/l.
- For mites, sulphure 3 g/l or dicofol 5 ml/l

IPM FOR BOLLWORMS

- Deep ploughing exposes and eliminates hibernating insects and expose pupae to sun and predating birds.
- Balanced organic fertilization keeps crop healthy and tolerant to pest attack.
- Border crop with jowar, maize in 2 or 3 rows not only serves as a barrier for migration of insect pests but also pollen of maize helps in attraction of beneficial Chrysoperla to the field.
- Growing trap crops @ 100 plants/ acre.
  - Castor as an ovipositional trap crop against S. litura: egg masses, gregarious larvae of S. litura on castor should be removed once in a week and destroyed.
  - Marigold as ovipositional trap crop against Helicoverpa
  - Okra (bhendi) against spotted bollworm moths.

Spray marigold / okra plants with endosulfan or phosalone to minimize larval population

- Keep 10 – 15 pheromone traps / ha to attract male moths. Egg scouting from square initiation stage is desirable.
  - ETLS – PBW: 8 moths, ABW: 10 moths, S. litura: 20 moths, SBW: 15 moths per trap per night.
- Topping (removal of leaf terminals) for 80 – 100 days old crop during October – November since tender leaves and tips are preferred for egg laying.
- Spray 5% neem seed kernel extract (NSKE) (soak 10 kg neem seed powder in 200 litres of water for 24 h and filter through muslin cloth) to repel moths from egg laying and to kill eggs and early instar larvae.
- Install 'T' shaped or long dried twigs as bird perches to attract predatory birds @ 20 / ac.
- Spray NPV @ 200 LE / ac in combination with jaggery 1 kg, sandovit 100 ml or Robin Blue 50 g thrice at 10-15 days interval on observing the eggs or first instar larvae in the evening hours. The diseased larvae die after 4 – 5 days showing tree top symptoms.
- Spray commercially available B. t formulations (DIPEL, DELFIN, BIOBIT, HALT) @ 400 g or 400 ml/ac against Helicoverpa
- On the basis of ETLs spray the following insecticides, endosulfan 2 ml/l or chlorpyriphos 2 ml/l or quinalphos 2 ml/l or methylparathion 1 ml/l or carbaryl 3 g/l or triazophos 2 ml/l or thiodicarb 1.5 g/l or profenophos 2 ml/l
- Mixing mustard oil with endosulfan 1:2 or chlorpyriphos 1:4 improves toxicity
- In the entire schedule of spray, do not spray synthetic pyrethroids for more than two rounds.
- Role of B.t Cotton: Advances in biotechnological approaches facilitated introduction of B.t transgenic cotton which offered greatest protection against American bollworm. Oflate B.t cotton have dramatically changed the plant protection scenario in cotton worldwide. Growing of B.t cotton has been highly successful against bollworms. This is evident in increased area under B.t cotton in India from 72,000 acres in 2002 to 10.15 m. ha in 2009 -10. B.t cotton varieties with Cry IAc toxin protein (B.t. 1) have been targeting American bollworm, Spotted bollworm and Pink bollworm but not tobacco caterpillar. However gene pyramiding of Cry IAc and Cry IIAb (B.t. 2) could offer protection against tobacco caterpillar.in addition to bollworms.

PESTS OF PULSES

All the pulse crops are infested by a variety of insects and mite pests. These pests are responsible for both direct and indirect losses. Based on growth habit, redgram is divided into determinant (clustering) and indeterminate (branching types). Damage to pods of early and mid maturing cultivars of determinate habit by lepidopterous borers is very severe. Pod fly is much more important in late maturing cultivars.

GRAM CATERPILLAR

Helicoverpa armigera

Noctuidae: Lepidoptera

Redgram in southern states of India suffers heavy losses due to the lepidopterous borers, especially by H. armigera, a notorious polyphagous pest with wide distribution. Variation in adult and larval phases is observed due to its polyphagous nature. Damage ranges from 46 to 67 per cent on redgram due to this pest. If one larva per plant infeststhen the damage caused will be about 34 per cent. Helicoverpa readily adjusts with any newly introduced variety. It is observed throughout the year on one or the other crops viz., peas, tomato, cotton, maize, tobacco, safflower, groundnut, chillies etc.

Moth is stout with dark yellow olive grey or brown wings crossed by a dark band near outer margin and a dark spot near costal margin of forewings and hindwings pale with a dark apical border.

Yellowish shiny, sculptured eggs are laid singly on tender parts of plants. Eachm female lays 300-400 eggs. Egg period is 2-4 days.

The young caterpillars feed on the tender foliage and as they grow they bore into the pods and destroy the seeds, while feeding it thrusts its head inside the pod leaving the rest of its body outside.

- Large round on each locule

Full grown caterpillar is cylindrical 40 – 48 mm in length with variable colour, dark green or reddish brown or brownish and marked with a white broken lines and a prominent white line along lower part of sides. Larval period 18-25 days.

Full grown caterpillar drops down and pupates in soil. Pupa is dark brown and adult emerges in 6-21 days.

IPM

It is a major pest on redgram and gram. Hence IPM is important.

A. Initial crop growth phase

• Deep summer ploughing to expose pupae in soil

• Crop rotation with less favourable crops like jowar, gingelly, blackgram,n horsegram, dry paddy (in redgram)

B. Raising intercrops like greengram, blackgram in 7 rows in kharif redgram and jowar in 2 rows in rabi redgam encourage and conserve natural enemies viz., Campoletis chloridae, Carcelia illote, Apanteles sauros, Microbracon brevicornis, Chelonus narayani, Tetrastichus Israeli, Exorista fallox, Eucelatoria sp.(Diptera), NPV, Nomuraea rileyi, B.t.

• Raising jowar in 4 rows all around redgram crop will serve as guard crop

• In bengalgram, mustard, coriander as intercrops

• Selection of tolerant varieties like ICPL – 332, LRG – 41 and varieties with recuperating ability like LRG – 30.

• Clipping of a terminal twig upto one foot at 90 – 100 DAS to remove ovipositional niches (depending on moisture availability in soil)

• Raising of rabi redgram to avoid pest.

C. From flowering

• Erect pheromone traps @ 10/ha to monitor the pest. Light traps during August – September; November – December

• Erect bird perches @ 50/ha to attract predatory birds like Drongo.

• When eggs and early instar larvae are noticed spray NSKE 5 % or neem based insecticides

• Use of microbial insecticides
  - NPV 200 LE/ha
  - B.t formulation 400g or 400 ml/ac thrice at weekly interval in evenings in winter.

• Mechanical shaking of redgram plants and collection and destruction of dislodged grown up larvae
• Avoid indiscriminate use of insecticides, synthetic pyrethroids and mixtures.
• On need basis spray
  - Chlorpyriphos 2.5 ml/l at initiation of flowers
  - Quinalphos 2 ml/l or acephate 1.5 g/l at flowering and fruiting using 750 – 1000 l of spray fluid with High Volume sprayer.
  - In severe incidence, indoxacarb 1 ml/l or spinosad 0.3 ml/l

• Adopt community approach.

REDGRAM PLUME MOTH

Exelastis atomosa; Spenarches caffer

Pterophoridae: Lepidoptera

It is a specific pest of redgram in India, AP. Assam, Bihar, Maharashtra and Tamilnadu.

Moth is slender, less than 12 mm long and are grey with long narrow wings. The forewings are divided into two parts and hindwings into three parts and provided with a fringe like border.

Minute, single eggs are laid on flower buds and pods. Egg period is 4-5 days.

Tiny caterpillar scrapes the pod surface and cuts a hole and thrusts the head into it and feeds on seed by remaining outside. The caterpillars bore into green pods and feed on the developing seeds which are more or less completely devoured or eaten away. Also feeds on flower buds. This pest is usually found at flowering and known to cause heavy damage to redgram. Attack by this pest can cause severe bud, flower and pod drop. The larva never enters inside the pod and feeds remaining outside the pod. The damage results in the following symptoms

- v Small hole on seeds.
- v Dropping of flower buds and flowers in severe cases.
- v Completely eaten and devoured seeds.

The full grown caterpillar is about 12 mm long greenish brown, and are fringed with short hairs and spines all over the body. Larval period is 14-30 days.

Pupation is on pod surface or burrows of infested pods. Pupa is also fringed with short hairs. Pupal period is 4-8 days. Pupa looks like larva except for the colour which is brown.

MANAGEMENT

• Collection of caterpillars by shaking shoots and their destruction in initial stages.
• Apantels sp parasitise larvae.
• Foliar sprays should commence at 50% flowering with endosulfan 2 ml/l or quinalphos 2 ml/l or carbaryl 3 g/l

REDGRAM POD FLY

Malanagromyza obtusa

(Agromyzidae: Diptera)

It is a major pest of redgram, soybean and cowpea. Attack is more in north and central India and Karnataka. In North India 80 per cent damage to crop is reported. The other hosts are sorghum, cowpea, safflower, bhendi etc.

Adult is a black fly with strong legs and ovate abdomen. Its eye are distinct, wings are clear veined, brownish yellow at their bases. Small black fly thrusts its minute eggs into the tissues of the tender pod and flower buds. Fly pierces pericarp with ovipositior and lay eggs which are seen like needles projecting inwards from the pods. Female fly lays 4 eggs per pod and 80 eggs in its life time. Egg period is 3 days.

Tiny maggots burrow into pods and feed on young seeds. In affected pods, no visual symptoms are observed regarding its entrance. Initially larva bores into epidermis without rupturing the seed coat. In the second and third instar stages, the larva bores into cotyledons and in most instances one seed is sufficient for the maggot to complete its development. The final instar larva leaves the seed and prior to pupation, windows the pods and pupates either in the pod cavity or in the pod wallm tissue.The damaged seeds are unfit for consumption. Diagnostic symptoms are

- Discolouration of the infested pods visible in green podded varieties.
- At the later stage of infestation, the holes about 1mm in diameter covered with a thin membrane readily seen on the infested pod.
- Exit holes visible after the adult emergence.

The pest infestation can be identified only after adult emergence of first generation. Maggot is creamy white in colour. Larval period is 6-10 days. Under abundant moisture condition, two broods can be seen in a year.

Full grown maggot pupates inside larval grooves in pods. Pupal period is 8-12 days. Adults emerge by cutting the thin spot already made by maggot.

MANAGEMENT

• Early sowing in endemic areas
• Removal of affected pods of first brood during winter.
• Pre-pupal stage is parasitized by Euderus agromyzae and pupa is parasitized by Euderus lividus.
• Foliar sprays with monocrotophos 1.5 ml/l or dimethoate 2 ml/l are effective against larva and endosulfan 2 ml/l against adult flies.

STEM FLY

Ophiomyia phaseoli

Agromyzidae: Diptera

The pest attacks the crop at early stage. It is a major pest of cowpea, soybean, blackgram and greengram.Eggs are thrusts into tender part of the stem/ petiole. Maggot tunnels the stem and feeds on the internal contents. When the stem is split open the distint tunnel can be observed along with excreta. Drooping of the first two leaves and wilting of the plants are observed due to the damage.

Growing varieties like LBG-611, LBG-402 are promising against stem fly, high seed rate, seed treatment with carbosulfan @ 40g/kg seed or thiamethoxam @ 4g/kg and foliar application of monocrotophos 1.6ml/l or acephate 1.5g/l are effective measures.

SPOTTED POD BORER

Maruca vitrata

Pyralidae: Lepidoptera

This pest is found throughout South India on pulses and beans. It webs the Dhaincha leaves

Moth is with dark brown forewings with white club shaped cross band along anterior margin and white hindwings with dark brown border.

The caterpillar with short hairs on black warts webs together the flowers and feeds on them. It also bores into pods at one end and eats up the ripening seeds. Mass excreta can be seen at the entrance of larval burrow.

Foliar spray from flower bud initiation with combination of chlorpyriphos 2.5 ml/l or quinalphos 2 ml/l or novaluron 0.75 ml/l or spinosad 0.75 ml/l or lamda cyhalothrin 1 ml/l in combination with dichlorvos 1 ml /l at wekly intervals is effective

BEAN APHIDS

Aphis craccivora

Aphididae: Hemiptera

Both nymphs and adults suck sap from tender leaves and shoots resulting in twisting of leaves, poor pod development, devitalization of plants and sooty mould. It acts as a vector of Rosette disease in groundnut and broad bean virus in pea.

It is s polyphagous pest. Redgram and other pulses, citrus etc are other host plants.

Spraying with tobacco decoction (1 kg tobacco boiled in 10 lit of water of ½ hour and make up to 30 lit + 100 g soap) and systemic insecticides like dimethoate 2 ml/l or phosphamidon 2 ml/l or malathion 2 ml/l are effective.

REDGRAM COW BUG

Oxyrhachis tarandus

Membracidae: Hemiptera

Nymphs as well as adults suck sap from green stem at all stages of the plantn causing corky tissues and excrete honeydew which attracts ants like Camponotus compressus. Breeding takes place all the year round the limitation being only the availability of food. This species is common all over south India. It is one of the majorpests of redgram.

Spraying dimethoate 2 ml/l, methyl patrathion 2 ml/l or phosphamidon 2 ml/l is effective.

REDGRAM POD BUG

Cavigralla gibbosa, Riptortus linearis, Anoplocnemis phasiana

Coreidae: Hemiptera

Hundreds of nymphs and adults suck sap from the shoots and pods. Shoots fade, pods shrivel and seeds with dark patch loose germination capacity due to the feeding of bugs.

Collection of bugs and their destruction by dipping into kerosinized water and dusting or spraying with carbaryl 10D 10 kg/ac or foliar spray with dimethoate 2 ml/l or monocrotophos 1.5 ml /l are effective.

LEAFHOPPER

Empoasca kerri

Cicadellidae: Hemiptera

Small greenish yellow nymphs and adults suck sap from leaves resulting in severe case, the leaves turn brown, dry and brittle, a condition called “hopper burn”.

Attacked leaflets become cup shaped and yellow at edges.Heavy attack result in the leaflets turning red-brown with subsequent defoliation and stunting.

Collection of bugs and their destruction of infested leaves, seed treatment with carbosulfan @ 30-40g/kg seed, spraying with thiamethoxam 0.4g/l or imidacloprid 0.4 ml/l have been found effective.

GREEN PLANT BUG/STINK BUG

Nezara viridula

Pentatomidae: Hemiptera

It is a polyphagous pest. Nymphs and adults suck sap from tender shoots and developing pods in large numbers, due to that shoots fade. Adults aestivate during April to June and with first rains they mate and oviposit.

Mechanical collection of nymphs and adults and destroying them and foliar spray with carbaryl 3 g/l or endosulfan 2 ml/l is recommended.

GREEN POD BORING CATERPILLAR OR LENTIL POD BORER

Etiella zinckenella

Pyralidae: Lepidoptera

It occurs on redgram, horsegram and other pulses and green manure crop like sunhemp.The larvae feed on floral parts, newly formed pods and seeds in developing pods. Faecal pellets inside damaged pods and small round holes on redgram pods plugged with excreta can be noticed.

Management of gram caterpillar is effective against this pest.

BLUE BUTTERFLIES

Catochrysops cnejus, Lampides boeticus, Catochrysops strabo

Lycaenidae: Lepidoptera

It is seen on redgram, cowpea, lab lab, niger etc. The eggs are laid on flower buds. After hatching the tiny caterpillars enter into unopened flower bud and feed inside. Afterwards they may attack another flower or enter a pod and feed on them developing seeds.

Foliar spray with carbaryl 3 g/l or endosulfan 2 ml/l is effective.

RED GRAM MITE

Aceria cajani

Eriophyidae: Acarina

It infests underside of tender leaves, causing yellowing of leaves and suppression of flowering and fruiting. It transmits pigeonpea sterility mosaic virus. A single eriophyiid mite is sufficient to transmit disease. Disease can be identified from a distance as patches of bushy, pale green plants without flowers or pods. Leaves are small, show a light and dark green mosaic pattern

Destruction of perennial and volunteer pigeonpea and the ratooned growth of harvested plants provide reservoir of mite vectors and pathogens, growing tolerant varieties like ICPL 87119, ICPL 227, Jagruthi, Bahar and foliar spray with dicofol 3 ml/l or wettable sulphur 3g/l in early stages of plant growth will control mite vector

PEA LEAF MINER

Phytomyza atricornis

Agromyzidae: Diptera

Mustard, cauliflower, cabbage, lentil, potato are infested by this pest. Eggs are inserted into the leaf tissue, maggots mine into mesophyll of leaf leading to irregular blotches on leaves,. Pupation is inside leaf mine. Both winter and summer are passed in pupal stage.

`Maggots are parasitized by Braconids, Eulophids. Foliar spray with methyl demeton 2 ml/l or dimethoate 2 ml/l was effective.

PEA STEM FLY

Melanagromyza phaseoli

Agromyzidae: Diptera

It is a major pest of blackgram, greengram and soybean. Incidence is more in rainy season.

Shiny bluish – black fly deposit eggs in punctures made by fly on young leaves. Young plants (less than 40 days) suffer more.

Yellowish maggots bore into nearest vein, reach the stem through petiole, bore down the stem and feed on cortical layers and may extend to tap root resulting in the following symptoms

- Distinct tunnel of stem split open.
- Death of plant or branches.

Pupation is at ground level within the stem. Adult fly exits through a thin semi transparent window.

MANAGEMENT

• Seed treatment with imidacloprid 3 g/kg seed gives protection upto 30 days.

• Foliar spray with acephate 1.5g/l or dimethoate 2 ml/l or monocrotophos 1.6ml/l

PESTS OF TOMATO

SERPENTINE LEAF MINER

Liriomyza trifolii

Agromyzidae: Diptera

It has been introduced into India through chrysanthemum cuttings. It is a pale yellowish fly, measuring 1.5 mm in length. The female fly punctures upper surface of leaf to lay eggs singly. The egg hatches in 4 days.

Minute orange yellow, apodous maggot feeds on chlorophyll mining in between epidermal layers. The symptoms that follow are

- Leaves with serpentine mines
- Drying dropping of leaves in severe cases

Full grown maggot measures 3 mm. Larval duration is about 7 days. Pupation is in soil. Some pupae are found in leaves. Total life cycle takes 3 weeks. Generally it does not cause economic damage.

MANAGEMENT

- v Neem oil 5 ml/l or endosulfan 2 ml/l or carbaryl 3 g/l as foliar sprays are recommended, if situation warrants.

TOMATO FRUIT BORERS

Helicoverpa armigera

Spodoptera litura

Noctuidae: Lepidoptera

The larvae bore into the fruits and make them unfit for consumption and marketing.

- Bored fruits with round (H. armigera)/irregular holes (S. litura)can be readily identified.

Life histories were detailed under the pests of cotton. nSpray application of endosulfan 2 ml/l affords protection.

WHITEFLY

Bemesia tabaci

Aleurodidae: Hemiptera

Both nymphs and adults suck sap from leaves causing chlorotic spots on leaves, yellowing and drying of leaves. It has been reported as a vector of tomato leaf curl disease.

Plucking and burning leaf curl virus affected plants and spraying with systemic insecticides like dimethoate 2 ml/l or methyl demeton 2 ml/l are effective measures.

PESTS OF CHILLIES

CHILLI THRIPS

Scirtothrips dorsalis
Caliothrips indicus
Frankliniella sulphurea

Thripidae: Thysanoptera

S. dorsalis is found in almost all chilly growing areas. It is a polyphagus pest. Besides chilli, it also infests brinjal, cotton, groundnut, castor, bottlegourd, guava, tea and grapevine. It is more common on unirrigated chilli crop than irrigated one.

They are slender, tiny, straw coloured insects with fringed wings.

A female adult inserts 40-48 white, minute eggs into veins.

Both nymphs and adults lacerate the leaf tissues and suck the oozing sap, sometimes even the buds and flowers are attacked. Generally they attack tender leaves and growing shoots. Rarely the older leaves are attacked. Their damage results in

- The infested leaves curling upward, crumbling and shedding
- Infested buds turning brittle with petiole becoming brown and dropping down.
- Affected fruits showing light brown scars.

Pest infestation is severe in dry weather. The damage ranges between 30-50%. One life cycle is completed on an average in 2- 2.5 weeks. There are about 25 generations in a year. Reproduction in thrips is generally sexual, parthenogenesis is also present.

MANAGEMENT

- Seed treatment with imidacloprid @ 3-5 g/kg of seed.
- Foliar spraying with carbaryl 3g/l or phosalone 3ml/l or acephate 1 g/l or fipronil 2 ml/l or spinosad 0.3 ml/l or diafenthiuron 1.2 g/l so as to wet the undersurface of the leaves.
- Application of fipronil 0.3G 8 kg/acre at 15 and 45 days after transplanting.

CHLLI POD BORERS

Spodoptera litura,S. exigua
Helicoverpa armigera; Noctuidae
Utetheisa pulchella; Arctiidae
Lepidoptera

Feeding by S. litura, S. exigua leads to irregular holes on the leaves and fruits. Affected pods turn whitish and dry up. In fruits, seeds are also eaten. Attack of H.armigera leads to round hole on fruits. In addition to these borers, sometimes U. pulchella also feeds on the pericarp leavingthe seed intact. Ladder like marks are seen on chilli pod due to U. pulchella. Their detailed history can be is given under pests of cotton and millets (S. exigua).

MANAGEMENT

1. Deep summer ploughing.
2. Monitoring with pheromone traps @ 4/acre
3. Raising trap crops like castor (S. litura), marigold (H.armigera).
4. Spraying with SNPV/HaNPV at 250LE/acre in the evening.
5. Spraying novuluron 1.0 ml/l or diflubenzuron 1.0 g/l controls just hatched larvae.
6. Foliar spraying of thiodicarb 1.0 g/l or acephate 1.5 g/l or chlorpyriphos 2.5 ml/l or spinosad 0.3ml/l or quinalphos 2 ml/l.
7. Poison baiting with rice bran 5 kg + chlorpyriphos 500 ml or carbaryl 500g + jaggery 500 g with water in the form of small balls in the evening hours.

CHILLI APHIDS

Aphis gossypii, Myzus persicae

Aphididae: Hemiptera

They are polyphagous pests. Cloudy weather is very favorable for multiplication of aphids. Heavy rains cause reduction in their population.

Adults are found in large numbers on the undersurface of leaves and growing shoots of plants.

Both nymphs and adults suck sap and also excrete honeydew on which black sooty mould develops affecting photosynthetic activity thus it causing

- Retardation in growth and fruiting capacity of the plant.
- Sooty mould

Foliar spray with methyl demeton 1 ml/l or acephate 1.5 g/l is effective.

CHILLI MITES

Polyphagotarsonemus latus

Tarsonemus translucens

Tarsonemidae

Tetranychus cinnabarinus

Tetranychidae: Acarina

A minor pest emerged as a major pest in recent past. The infestation starts in the nursery after 40 days of germination. Severe infestation is seen in transplanted crop of 2-3 months old. The tiny white transparent mites are found in large numbers on the undersurface of leaves under fine webs. Both nymphs and adults suck sap and devitalize the plant causing 'Murda' disease of chillies. Infestation results in

- Downward curling of leaves,
- The affected leaves becoming inverted boat shaped,
- The leaves rolling down along the margin with elongation of petioles.
- Affected leaves turning dark green in certain cases.
- Younger leaves at the tip of branch clustering**.**

MANAGEMENT

• Foliar spraying of dicofol 5ml/l or wettable sulphur 3g/l.

• Synthetic pyrethroids not to be used.

• If both thrips and mites are noticed, spraying phosalone 3ml/l or diafenthiuron 1.5 g/l or chlorfenapyr 2 ml/l.

CHILLI BLOSSOM MIDGE

Asphondylia capsici

Cecidomyiidae: Diptera

Fly is dark reddish brown mosquito like midge that lays eggs in flower buds. Maggot is tiny pale orange colored and feeds on the floral parts leading to poor development of fruits. The ovary is distorted into gall like structure of varied shape.

Foliar spray with triazophos 2 ml/l or carbosulfan 2 ml/l followed by chlorpyriphos 2.0 ml/l one week later is found effective.