AESA BASED IPM PACKAGE

PEARL MILLET

Directorate of Plant Protection, Quarantine and Storage
N. H.-IV, Faridabad, Haryana

राष्ट्रीय वनस्पति स्वास्थ्य प्रबंधन संस्थान (रा व स्वा प्र सं)
NIPHM
National Institute of Plant Health Management
Rajendranagar, Hyderabad, Telangana

Department of Agriculture and Cooperation
Ministry of Agriculture
Government of India

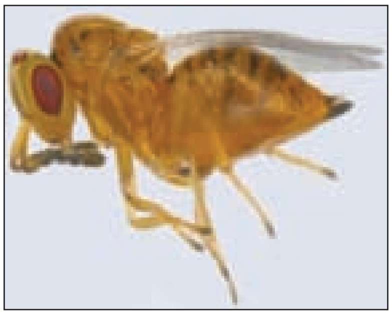
Important Natural Enemies of Pearl Millet Insect Pests

Parasitoids

Trichogramma sp

Chelonus spp.

Cotesia spp.



Aprostocetus spp.

Meterorus spp.

Campoletis spp.

Predators

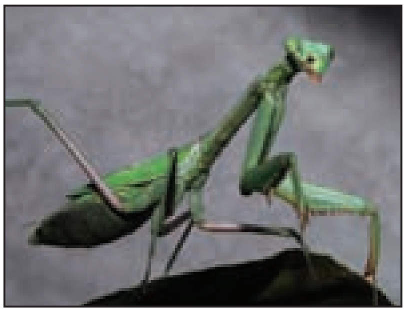
Ground beetle

Hover fly

Ladybird beetle

Red ant

Spider



Preying mantis

The AESA based IPM - Pearl Millet, was compiled by the NIPHM working group under the Chairmanship of Dr. Satyagopal Korlapati, IAS, DG, NIPHM, and guidance of Shri. Utpal Kumar Singh, IAS, JS (PP). The package was developed taking into account the advice of experts listed below on various occasions before finalization.

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Citation Satyagopal, K., S.N. Sushil, P. Jeyakumar, G. Shankar, O.P. Sharma, S.K. Sain, D.R. Boina, N. Lavanya, N.S. Rao, B.S. Sunanda, Ram Asre, R. Murali, K.S. Kapoor, Sanjay Arya, Subhash Kumar, C.S. Patni, H.S. Yadava, B. Gangadhar Naik, S. Deshmukh, S. Gangopadhyay, A. K. Guggari and B.R. Patel. 2014. AESA based IPM package for Pearl Millet. pp 34.

Front cover picture Model AESA chart for Pearl millet

Back cover picture Pearl Millet field

Published by National Institute of Plant Health Management, Rajendranagar, Hyderabad – 500 030

Copies: 1,000; November, 2014

For internal circulation only. Not for sale.

Contact APPA - IPM, Directorate of Plant Protection, Quarantine & Storage, CGO Complex, NH IV, Faridabad, Haryana - 121 001.

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Printed at **Balaji Scan Pvt. Ltd.,**
A.C. Guards, Hyderabad.
Tel : 040-23303424
e-mail: bsplpress@gmail.com
www.balajiscan.com

अपर सचिव
भारत सरकार
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FOREWORD

Intensive agricultural practices relying heavily on chemical pesticides are a major cause of wide spread ecological imbalances resulting in serious problems of insecticide resistance, pest resurgence and pesticide residues. There is a growing awareness world over on the need for promoting environmentally sustainable agriculture practices.

Integrated Pest Management (IPM) is a globally accepted strategy for promoting sustainable agriculture. During last century, IPM relied substantially on economic threshold level and chemical pesticides driven approaches. However, since the late 1990s there is conscious shift to more ecologically sustainable Agro-Eco System Analysis (AESA) based IPM strategies. The AESA based IPM focuses on the relationship among various components of an agro-ecosystem with special focus on pest-defender dynamics, innate abilities of plant to compensate for the damages caused by the pests and the influence of abiotic factors on pest buildup. In addition, Ecological Engineering for pest management - a new paradigm to enhance the natural enemies of pests in an agro-ecosystem is being considered as an important strategy. The ecological approach stresses the need for relying on bio intensive strategies prior to use of chemical pesticides.

Sincere efforts have been made by resource personnel to incorporate ecologically based principles and field proven technologies for guidance of the extension officers to educate, motivate and guide the farmers to adopt AESA based IPM strategies, which are environmentally sustainable. I hope that the AESA based IPM packages will be relied upon by various stakeholders relating to Central and State government functionaries involved in extension and Scientists of SAUs and ICAR institutions in their endeavour to promote environmentally sustainable agriculture practices.

AK Srivastava

Date : 6.3.2014

(Avinash K. Srivastava)

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FOREWORD

IPM as a holistic approach of crop protection based on the integration of multiple strategies viz., cultural, physical, mechanical, biological, botanical and chemical. Over the years IPM underwent several changes, shifting its focus from damage boundary, economic injury to economic threshold. Currently most stake holders rely upon economic threshold levels (ETL) and tend to apply chemical pesticides at the first instance in the event of a pest attack, through Government of India has advocated need based and judicious application of chemicals. This approach is likely to cause adverse effects on agro-ecosystems and increase the cost of agricultural production due to problems of pest resurgence, insecticide resistance and sustainability.

During the late 90s FAO started advocating Agro-Ecosystem Analysis (AESA) based IPM. Experience in different countries have sine show that AESA, which takes into account ecological principles and relies on the balance that is maintained by biotic factors in an ecosystem has also resulted in reduction in cost of production and increase in yields. AESA based IPM also takes into account the need for active participation of farmers and promotes experiential learning and discovery based decision making by farmers. AESA based IPM in conjunction with ecological engineering for pest management promotes bio-intensive strategies as against current chemical intensive approaches, while retaining the option to apply chemical pesticides judiciously as a measure of last resort.

The resource persons of NIPHM and DPPQ&S have made sincere efforts in revising IPM packages for different crops by incorporating agro-ecosystem analysis, ecological engineering, pesticide application techniques and other IPM options with the active cooperation of crop based plant protection scientists working in state Agricultural Universities and ICAR institutions. I hope this IPM package will serve as a ready reference for extension functionaries of Central / State Governments, NGOs and progressive farmers in adopting sustainable plant protection strategies by minimizing the dependence on chemical pesticides.

(Utpal Kumar Singh)

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PREFACE

Need for environmentally sustainable agricultural practices is recognised worldwide in view of the wide spread ecological imbalances caused by highly intensive agricultural systems. In order to address the adverse impacts of chemical pesticides on agro-ecosystems, Integrated Pest Management has evolved further from ETL based approach to Agro-ecosystem Analysis based Integrated Pest Management (IPM).

In AESA based IPM the whole agro-ecosystem, plant health at different stages, built-in-compensation abilities of the plant, pest and defender population dynamics, soil conditions, climatic factors and farmers' past experience are considered. In AESA, informed decisions are taken by farmers after field observation , AESA chart preparation followed by group discussion and decision making. Insect zoo is created to enable the farmer understand predation of pests by Natural Enemies. AESA based PHM also results in reduction of chemical pesticide usage and conserves the agro-ecosystems.

Ecological Engineering for Pest Management, a new paradigm, is gaining acceptance as a strategy for promoting Biointensive Integrated Pest Management. Ecological Engineering for Pest Management relies on cultural practices to effect habitat manipulation and enhance biological control. The strategies focus on pest management both below ground and above ground. There is growing need to integrate AESA based IPM and principles of ecological engineering for pest management.

There is a rising public concern about the potential adverse effects of chemical pesticides on the human health, environment and biodiversity. The intensity of these negative externalities, through cannot be eliminated altogether, can be minimized through development, dissemination and promotion of sustainable biointensive approaches.

Directorate of Plant Protection Quarantine and Storage (DPPQS), has developed IPM package of practices during 2001 and 2002. These packages are currently providing guidance to the Extension Officers in transferring IPM strategies to farmers. These IPM package of practices, have been revised incorporating the principles of AESA based IPM in detail and also the concept of Ecological Engineering for Pest Management. It is hoped that the suggested practices, which aim at enhancing biodiversity, biointensive strategies for pest management and promotion of plant health, will enable the farmers to take informed decisions based on experiential learning and it will also result in use of chemical pesticides only as a last resort & in a safe and judicious manner.

(K. SATYAGOPAL)

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AESA BASED IPM PACKAGE FOR PEARL MILLET

Pearl Millet-Plant description:

Pearl Millet (*Pennisetum glaucum* L.; Family: Poaceae), is an annual grass which is grown widely in Africa and India for its grain which can be used to make flour and other foodstuffs. Pearl millet is an upright bunch grass that tillers from the base and has an extensive root system that provides drought tolerance. Stems are 0.5" – 1" diameter. It is a leafy plant with leaf blades that are 8–40 inches long and 1/2–3 inches wide. The ligule, or junction of leaf blade to leaf sheath, is a fringe of hairs 0.08–0.1 inch long. The sheath has very sparse hairs at the base of the collar and is often hairless. It has slender stem which is divided into distinct nodes. The leaves of the plant are linear or lance-like, possess small teeth and can grow up to 1 m (3.3 ft) in length. The inflorescence of the plant is a spike-like panicle, made up of many smaller spikelets where the grain is produced. Pearl millet can reach 0.5 to 4 m in height depending on the cultivar and is an annual plant, harvested after one growing season. The fruit (or caryopsis) is cylindrical, white or pearl in color, or sometimes yellow or brown, and occasionally purple. Pearl millet is best adapted to sandy or light loams and moist but well-drained soils. It has good tolerance to drought. Production season is generally from late May to September. Pearl millet is a very robust grass which tillers widely and grows in tufts. Pearl millet may also be referred to as brush millet, cat-tail millet or yellow bristle grass and originates from the Sahel zone of Africa.

I. PESTS

A. Pests of National Significance

1. **Insect pests**
   - 1.1 **Cutworm: *Agrotis ipsilon* Hufnagel (Lepidoptera: Noctuidae)**
   - 1.2 **White grub: *Holotrichia consanguinea* Blanch (Coleoptera: Scarabaeidae)**
   - 1.3 **Shoot fly: *Atherigona soccata* Rondani (Diptera: Muscidae)**
   - 1.4 **Stem borer: *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae)**
2. **Disease**
   - 2.1 **Downy mildew: *Sclerospora graminicola* (Sacc.) J. Schröt**
   - 2.2 **Rust: *Puccinia substriata* var. *indica* Ramachar & Cumm.**
   - 2.3 **Blast: *Pyricularia grisea* Sacc. (Hebert) Barr**
3. **Weeds**

   Broad leaf
   - 3.1 **Cock's comb: *Celosia argentea* L. (Amaranthaceae)**
   - 3.2 **Common purselane: *Portulaca oleracea* L. (Portulacaceae)**
   - 3.3 **False amaranth: *Digera arvensis* Forssk (Amaranthaceae)**
   - 3.4 **Horsepurslane: *Trianthema portulacastrum* L. (Aizoaceae)**
   - 3.5 **Pigweed: *Amaranthus viridis* (Hook. F.) (Amaranthaceae)**
   - 3.6 **Swine cress: *Coronopus didymus* L. Sm. (Brassicaceae)**
   - 3.7 **Black nightshade: *Solanum nigrum* L. (Solanaceae)**

   Grasses
   - 3.8 **Rabbit/crow foot grass: *Dactyloctenium aegyptium* Willd (Poaceae)**
   - 3.9 **Goose grass: *Eleusine indica* L. Gaertner (Poaceae)**
   - 3.10 **Barnyard grass: *Echinochloa crusgalli* L. Scop (Poaceae)**
   - 3.11 **Crabgrass: *Digiteria sanguinalis* L. Scop (Poaceae)**
   - 3.12 **Burmuda grass: *Cynodon dactylon* (Poaceae)**

   Sedges
   - 3.13 **Purple nutsedge: *Cyperus rotundus* L. (Cyperaceae)**
   - 3.14 **Flat sedge: *Cyperus iria* L. (Cyperaceae)**

   Parasitic
   - 3. 15 **Witch weed: *Striga asiatica* (L) Kuntze (Orobanchaceae)**

B. Pests of Regional Significance

1. **Insect pests**
   - 1.1 **Grasshopper: *Hieroglyphus* spp. (Orthoptera: Acrididae)**
   - 1.2 **White ant: *Chrotogonus* sp (Isoptera: Termitidae)**
   - 1.3 **Grey weevil: *Myllocerus* sp (Coleoptera: Curculionidae)**
   - 1.4 **Earhead bug: *Calocoris angustatus* Lethiery (Hemiptera: Miridae)**
   - 1.5 **Hairy caterpillar: *Spilosoma obliqua* Walker(Lepidoptera: Arctiidae)**
   - 1.6 **Earhead worm: *Cryptoblabes gnidiella* Milliere (Lepidoptera: Pyralidae)**
   - 1.7 **Blister beetle: *Mylabris pustulata* Gyllenhal (Coleoptera: Meloidae)**
   - 1.8 **Chaffer beetle: *Rhizotrogus majalis* Razoumowsky (Coleoptera: Scarabaeidae)**
2. **Diseases**
   - 2.1 **Ergot: *Claviceps fusiformis* Loveless**
   - 2.2 **Smut: *Moesziomyces parepenicillariae* (Bref.) Vanky**
3. **Nematode**
   - 3.1 **Reniform nematode: *Rotylenchulus reniformis* Linford and Oliver (Tylenchida: Hoplolaimidae)**
4. **Vertebrates**
   - 4.1 **Rodent**
   - 4.2 **Birds**

II. AGRO-ECOSYSTEM ANALYSIS (AESA) BASED INTEGRATED PEST MANAGEMENT (IPM)

A. AESA:

The IPM has been evolving over the decades to address the deleterious impacts of synthetic chemical pesticides on environment ultimately affecting the interests of the farmers. The economic threshold level (ETL) was the basis for several decades but in modern IPM (FAO 2002) emphasis is given to AESA where farmers take decisions based on larger range of field observations. The health of a plant is determined by its environment which includes physical factors (i.e. soil, rain, sunshine hours, wind etc.) and biological factors (i.e. pests, diseases and weeds). All these factors can play a role in the balance which exists between herbivore insects and their natural enemies. Understanding the intricate interactions in an ecosystem can play a critical role in pest management.

Decision making in pest management requires a thorough analysis of the agro-ecosystem. Farmer has to learn how to observe the crop, how to analyze the field situation and how to make proper decisions for their crop management. This process is called the AESA. Participants of AESA will have to make a drawing on a large piece of paper (60 x 80 cm), to include all their observations. The advantage of using a drawing is that it requires the participants/farmers to observe closely and intensively. It is a focal point for the analysis and for the discussions that follow, and the drawing can be kept as a record.

AESA is an approach, which can be gainfully employed by extension functionaries and farmers to analyze the field situations with regards to pests, defenders, soil conditions, plant health and the influence of climatic factors and their relationship for growing a healthy crop. The basic components of AESA are:

- Plant health at different stages
- Built-in compensation abilities of plants
- Pest and defender population dynamics
- Soil conditions
- Climatic factors
- Farmers past experience

Principles of AESA based IPM:

Grow a healthy crop:

- Select a variety resistant/tolerant to major pests
- Select healthy seeds/seedlings/ planting material
- Treat the seeds/seedling/planting material with recommended pesticides especially biopesticides
- Follow proper spacing
- Soil health improvement (mulching and green manuring whenever applicable)
- Nutrient management especially organic manures and biofertilizers based on the soil test results. If the dosage of nitrogenous fertilizers is too high the crop becomes too succulent and therefore susceptible to insects and diseases. If the dosage is too low, the crop growth is retarded. So, the farmers should apply an adequate for best results. The phosphatic fertilizers should not be applied each and every season as the residual phosphate of the previous season will be available for the current season also.
- Proper irrigation

Observe the field regularly (climatic factors, soil and biotic factors):

Farmers should:

- Monitor the field situation at least once a week (soil, water, plants, pests, natural enemies, weather factors etc.)
- Make decisions based on the field situation and Pest: Defender ratio (P: D ratio)
- Take direct action when needed (e.g. collect egg masses, remove infested plants etc.)

Plant compensation ability:

Compensation is defined as the replacement of plant biomass lost to herbivores and has been associated with increased photosynthetic rates and mobilization of stored resources from source organs to sinks (e.g., from roots and remaining leaves to new leaves) during active vegetative growth period. Plant tolerance to herbivory can arise from the interaction of a variety of plant traits and external environmental factors. Several studies have documented such compensation through increased growth and photosynthetic rate.

Understand and conserve defenders:

- Know defenders/natural enemies to understand their role through regular observations of the agro-ecosystem
- Avoid the use of chemical pesticides especially with broad-spectrum activity

Insect zoo:

In field various types of insects are present. Some are beneficial and some may be harmful. Generally farmers are not aware about it. Predators (friends of the farmers) which feed on pests are not easy to observe in crop field. Insect zoo concept can be helpful to enhance farmers' skill to identify beneficial and harmful insects. In this method, unfamiliar/unknown predators are collected in plastic containers with brush from the field and brought to a place for study. Each predator is placed inside a plastic bottle together with parts of the plant and some known insect pests. Insects in the bottle are observed for certain time and determined whether the test insect is a pest (feeds on plant) or a predator (feeds on other insects).

Pest: Defender ratio (P: D ratio):

Identifying the number of pests and beneficial insects helps the farmers to make appropriate pest management decisions. Sweep net, visual counts etc. can be adopted to arrive at the numbers of pests and defenders. The P: D ratio can vary depending on the feeding potential of natural enemy as well as the type of pest. The natural enemies of pearl millet insect pests can be divided into 3 categories 1. parasitoids; 2. predators; and 3. pathogens.

Model Agro-Ecosystem Analysis Chart

Date:
Village:
Farmer:

Decision taken based on the analysis of field situations

Soil conditions :
Weather conditions :
Diseases types and severity :
Weeds types and intensity :
Rodent damage (if any) :
No. of insect pests :
No. of natural enemies :
P: D ratio :

The general rule to be adopted for management decisions relying on the P: D ratio is 2: 1. However, some of the parasitoids and predators will be able to control more than 2 pests. Wherever specific P: D ratios are not found, it is safer to adopt the 2: 1, as P: D ratio. Whenever the P: D ratio is found to be favourable, there is no need for adoption of other management strategies. In cases where the P: D ratio is found to be unfavourable, the farmers can be advised to resort to inundative release of parasitoids/predators depending upon the type of pest. In addition to inundative release of parasitoids and predators, the usage of microbial biopesticides and biochemical biopesticides such as insect growth regulators, botanicals etc. can be relied upon before resorting to synthetic chemical pesticides.

Decision making:

Farmers become experts in crop management:

Farmers have to make timely decisions about the management of their crops. AESA farmers have learned to make these decisions based on observations and analysis viz. abiotic and biotic factors of the crop ecosystem. The past experience of the farmers should also be considered for decision making. However, as field conditions continue to change and new technologies become available, farmers need to continue improving their skills and knowledge.

- Farmers are capable of improving farming practices by experimentation
- Farmers can share their knowledge with other farmers

AESA methodology:

- Go to the field in groups (about 5 farmers per group). Walk across the field and choose 20 plants/ acre randomly. Observe keenly each of these plants and record your observations:
    - Plant: Observe the plant health, crop stage, deficiency symptoms etc.
    - Insect pests: Observe and count insect pests at different places on the plant.
    - Defenders (natural enemies): Observe and count parasitoids and predators.
    - Diseases: Observe leaves and stems and identify any visible disease symptoms and severity.
    - Rats: Count number of plants affected by rats.
    - Weeds: Observe weeds in the field and their intensity.
    - Water: Observe the water situation of the field.
    - Weather: Observe the weather condition.
- While walking in the field, manually collect insects in plastic bags. Use a sweep net to collect additional insects. Collect plant parts with disease symptoms.
- Find a shady place to sit as a group in a small circle for drawing and discussion.
- If needed, kill the insects with some chloroform (if available) on a piece of cotton.
- Each group will first identify the pests, defenders and diseases collected.
- Each group will then analyze the field situation in detail and present their observations and analysis in a drawing (the AESA drawing).
- Each drawing will show a plant representing the field situation. The weather condition, water level, disease symptoms, etc. will be shown in the drawing. Pest insects will be drawn on one side. Defenders (beneficial insects) will be drawn on another side. Write the number next to each insect. Indicate the plant part where the pests and defenders were found. Try to show the interaction between pests and defenders.
- Each group will discuss the situation and make a crop management recommendation.
- The small groups then join each other and a member of each group will now present their analysis in front of all participants.
- The facilitator will facilitate the discussion by asking guiding questions and makes sure that all participants (also shy or illiterate persons) are actively involved in this process.
- Formulate a common conclusion. The whole group should support the decision on what field management is required in the AESA plot.
- Make sure that the required activities (based on the decision) will be carried out.
- Keep the drawing for comparison purpose in the following weeks.

Data recording:

Farmers should record data in a notebook and drawing on a chart:

- Keep records of what has happened help us making an analysis and draw conclusions

Data to be recorded:

- Check the plant growth weekly.
- **Crop situation (e.g. for AESA):** Plant health; pests, diseases, weeds; natural enemies; soil condition; irrigation; weather conditions
- **Input costs:** Seeds; fertilizer; pesticides; labour
- **Harvest:** Yield (Kg/acre); price of produce (Rs./Kg)

Some questions that can be used during the discussion:

- Summarize the present situation of the field.
- What crop management aspect is most important at this moment?
- Is there a big change in crop situation compared to last visit? What kind of change?

- Is there any serious pest or disease outbreak?
- What is the situation of the beneficial insects?
- Is there a balance in the field between pests and defenders?
- Were you able to identify all pests and diseases?
- Do you think the crop is healthy?
- What management practices are needed at this moment?
- When will it be done? Who will do it? Make sure that responsibilities for all activities are being discussed.
- Are you expecting any problems to emerge during the coming week such as congenial weather conditions for pest buildup?
- What are the problems? How can we avoid it? How can we be prepared?
- Summarize the actions to be taken.

Advantages of AESA over ETL:

One of the problems of the ETL is that it is based on parameters that are changing all the time, and that are often not known. The damage or losses caused by a certain density of insects cannot be predicted at all. In ETL the due recognition of the role of natural enemies in decreasing pest population is ignored. Farmers cannot base their decisions on just a simple count of pests. They will have to consider many other aspects of the crop (crop ecology, growth stage, natural enemies, weather condition, etc.) and their own economic and social situation before they can make the right crop management decisions. In ETL based IPM, natural enemies, plant compensation ability and abiotic factors are not considered. In AESA based IPM emphasis is given to natural enemies, plant compensation ability, abiotic factors and P: D ratio.

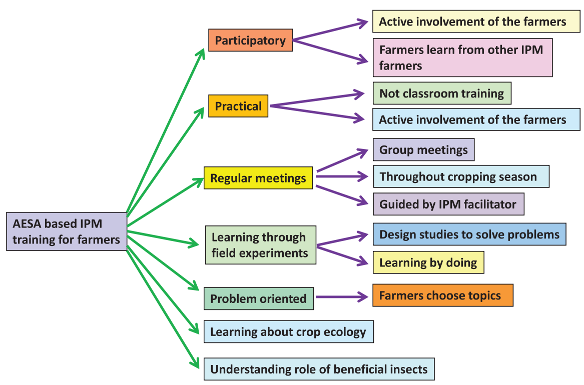
AESA and farmer field school (FFS):

AESA is a season-long training activity that takes place in the farmer field. It is season-long so that it covers all the different developmental stages of the crop and their related management practices. The process is always learner-centered, participatory and relying on an experiential learning approach and therefore it has become an integral part of FFS.

Farmers can learn from AESA:

- Identification of pests and their nature of damage
- Identification of natural enemies
- Management of pests
- Water and nutrient management
- Influence of weather factors on pest buildup
- Role of natural enemies in pest management

FFS to teach AESA based IPM skills:



B. Field scouting:

AESA requires skill. So only the trained farmers can undertake this exercise. However, other farmers also can do field scouting in their own fields at regular intervals to monitor the major pest situation.

Surveillance on pest occurrence at the main field should commence soon after crop establishment and at weekly intervals thereafter. In each field, select five spots randomly. Select five random plants at each spot for recording counts of insects as per procedure finalized for individual insects.

For insect pests:

Shoot fly and stem borer: Count and record the number of both larvae and adults on five randomly selected leaves and symptoms of damage present per plant.

Grasshopper: Count and record the number of nymphs and adults present per plant

Earhead bug: Count and record the number of nymphs and adults present in ear head

White grub, cut worm: Count and record the number of grubs and adults present in ear head

Ear head caterpillar: count and record the number of larva present in ear head.

For diseases:

Whenever scouting, be aware that symptoms of plant disease problems may be caused by any biotic factors such as fungal, bacterial, viral pathogens or abiotic factors such as weather, fertilizers, nutrient deficiencies, pesticides and abiotic soil problems. In many cases, the cause of the symptom is not obvious. Close examination, and laboratory culture and analysis are required for proper diagnosis of the causal agent of disease. Generally fungal diseases cause the obvious symptoms with irregular growth, pattern & colour (except viruses), however abiotic problems cause regular, uniform symptoms. Pathogen presence (signs) on the symptoms can also be observed like fungal growth, bacterial ooze etc. Specific and characteristic symptoms of the important plant diseases are given in description of diseases section.

Root sampling: Always check plants that appear unhealthy. If there are no obvious symptoms on plants, examine plants randomly and look for lesions or rots on roots. Observe the signs of the causal organism (fungal growth or ooze). It is often necessary to wash the roots with water to examine them properly. If the roots are well developed, cut them to examine the roots for internal infections (discolouration & signs). Count the total number of stem damaged/infested/infected due to rot should be counted and incidence should be recorded.

Leaf sampling: Examine all leaves and/or leaflets of each plant for lesions. Leaf diseases cause most damage during the seedling and flowering stages of plant growth. Observe for the symptoms and signs on the infected plant parts. Determine the percent area of leaf infection by counting the number of leaves (leaf area diameter)/ plant infected due to disease and incidence should be recorded.

Stem, flower and ear sampling: Carefully examine the stems, flowers and ear of plants for signs of fungal material diseases or lesions. The stems, flowers and ear should be split or taken apart and examined for discoloration caused by fungi and bacteria. Count then number of plant, pod infected due to disease and incidence should be recorded.

C. Surveillance through pheromone trap catches:

Use Pheromone traps for monitoring of Lepidopteran pests. Install pheromone traps at distance of 50 meter @ 4-5 traps per acre for each insect pest. Use specific lure for each insect pest species and change it after every 20 days. Trapped moths should be removed daily.

D. Light traps:

Set up light traps 1 trap/acre 15 cm above the crop canopy for monitoring and mass trapping of insects. Light traps with exit option for natural enemies of smaller size should be installed and operate around the dusk time (6 pm to 10 pm).

E. Nematode extraction:

Collect 100 to 300 cm^3 (200-300 g) representative soil sample. Mix soil sample and pass through a coarse sieve to remove rocks, roots, etc. Take a 600 cc subsample of soil, pack lightly into a beaker uniformly. Place soil in one of the buckets or pans half filled with water. Mix soil and water by stirring with paddle; allow to stand until water almost stops swirling. Pour all but heavy sediment through 20-mesh sieve into second bucket; discard residue in first bucket; discard material caught on sieve. Stir material in second bucket; allow to stand until water almost stops swirling. Pour all but heavy sediment through 60 mesh sieve to collect cysts into first bucket; discard residue in second bucket. Stir material in first bucket; allow to stand until water almost stops swirling. Pour all but heavy sediment through 325-mesh sieve into second bucket; discard residue in first bucket. Backwash material caught on 325-mesh sieve (which includes small to mid-sized nematodes and silty material) into 250-ml beaker. More than 90% of the live nematodes are recovered in the first 5-8 mm of water drawn from the rubber tubing and the sample is placed in a shallow dish for examination.

III. ECOLOGICAL ENGINEERING FOR PEST MANAGEMENT

Ecological engineering for pest management has recently emerged as a paradigm for considering pest management approaches that rely on the use of cultural techniques to effect habitat manipulation and to enhance biological control. Ecological engineering for pest management is based on informed ecological knowledge rather than high technology approaches such as synthetic pesticides and genetically engineered crops (Gurr et al. 2004 a, b).

Ecological Engineering for Pest Management – Below Ground:

There is a growing realization that the soil borne, seed and seedling borne diseases can be managed with microbial interventions, besides choosing appropriate plant varieties. The following activities increase the beneficial microbial population and enhance soil fertility.

- Crop rotations with leguminous plants which enhance nitrogen content.
- Keep soils covered year-round with living vegetation and/or crop residue.
- Add organic matter in the form of farm yard manure (FYM), vermicompost, crop residue which enhance below ground biodiversity of beneficial microbes and insects.
- Application of balanced dose of nutrients using biofertilizers based on soil test report.
- Application of biofertilizers with special focus on mycorrhiza and plant growth promoting rhizobia (PGPR)
- Application of *Trichoderma harzianum/viride* and *Pseudomonas fluorescens* for treatment of seed/seedling/ planting materials in the nurseries and field application (if commercial products are used, check for label claim. However, biopesticides produced by farmers for own consumption in their fields, registration is not required).

Ecological Engineering for Pest Management – Above Ground:

Natural enemies play a very significant role in control of foliar insect pests. Natural enemy diversity contributes significantly to management of insect pests both below and above ground.

Natural enemies may require:

1. Food in the form of pollen and nectar.
2. Shelter, overwintering sites and moderate microclimate etc.
3. Alternate hosts when primary hosts are not present.

In order to attract natural enemies following activities should be practiced:

- Raise the flowering plants / compatible cash crops along the field border by arranging shorter plants towards main crop and taller plants towards the border to attract natural enemies as well as to avoid immigrating pest population
- Grow flowering plants on the internal bunds inside the field

- Not to uproot weed plants those are growing naturally such as *Tridax procumbens, Ageratum* sp, *Alternanthera* sp etc. which act as nectar source for natural enemies
- Not to apply broad spectrum chemical pesticides, when the P: D ratio is favourable. The plant compensation ability should also be considered before applying chemical pesticides.
- Reduce tillage intensity so that hibernating natural enemies can be saved.
- Select and plant appropriate companion plants which could be trap crops and pest repellent crops. The trap crops and pest repellent crops will also recruit natural enemies as their flowers provide nectar and the plants provide suitable microclimate.

Due to enhancement of biodiversity by the flowering plants, parasitoids and predators (natural enemies) number also will increase due to availability of nectar, pollen and insects etc. The major predators are a wide variety of spiders, ladybird beetles, long horned grasshoppers, lacewing, earwigs, etc.

Plants Suitable for Ecological Engineering for Pest Management

Attractant plants

Cowpea

Carrot

Sunflower

Buckwheat

Alfalfa

Mustard

Cosmos

Anise

Caraway


Dill


Parsely


Marigold

Repellent plants


***Ocimum* spp**


Peppermint

Border plants


Sorghum


Maize

Intercrops


Groundnut


Maize

The flowering plants suggested under Ecological Engineering for pest management strategy are known as attractant plants to the natural enemies of the selected pests. The information is based on published research literature, however, the actual selection of flowering plants could be based on availability, agro-climatic conditions and soil types

Biodiversity of natural enemies observed in Ecological Engineering field at NIPHM

Biodiversity of natural enemies: Parasitoids

Biodiversity of natural enemies: Predators

Biodiversity of natural enemies: Spiders

IV. RESISTANT/ TOLERANT VARIETIES

Disease	Tolerant/ Resistant Variety*
Resistant to downy mildew	*MH 1192, ICMH 451,Pusa 23, MBH 110, PHB 57, WC-C 75, ICTP 8203 and GHB 67*
Resistant and Moderately resistant to Rust	IB 1203, ICML 11 and MH 1192
Tolerant to Smut	WC-C 75, CM 46 and MBH 110

***For detailed and updated information nearest KVK, SAU / ICAR Institute may be contacted**

V. CROP STAGE-WISE IPM

Management	Activity
Pre-sowing*	
	Common cultural practices: • Deep ploughing and soil solarisation to expose pupae and propagules of soil borne pathogens. • Timely sowing should be done. • Field sanitation. • Destroy the alternate host plants • Soil test based application of manures and fertilizers. • Adoption of crop rotation. • Sowing of healthy, disease free and certified seeds • Uproot and burn infected plants early enough to avoid spread of the disease. • Avoid high plant populations • Adopt ecological engineering by growing the attractant, repellent, and trap crops around the field bunds.
Nutrients	• Use well decomposed FYM @ 4t/acre or vermicompost @ 2.0 t/acre treated with *Trichoderma* at the time of last ploughing or at the time of growing. • Apply vermicompost at 1 week before sowing and FYM at 3-4 weeks before sowing. • Do not leave FYM or compost exposed to sunlight as nutrients may lose.
Weeds	• At the time of field preparation, adopt stale seed bed technique. • In Striga affected fields, do not grow pearlmillet or sorghum continuously and follow crop rotation with legumes.
Downy mildew, smut and Nematodes**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15). • For resistant / tolerant varieties consult ICAR Institute / KVK's / SAU's. **Cultural control:** • Use tolerant/resistant varieties e.g. MH 1192, ICMH 451,Pusa 23, MBH 110, PHB 57, WC-C 75, ICTP 8203 and GHB 67 • Eliminate any potentially damaging insect problems. • Plant in a row of 15 inches to 24 inches. Seed may be placed about 6 inches apart within the row. • The seed should be planted shallow, about half inch deep at the rate of 2 Kg/acre. • Maintain good fertility levels, apply adequate organic manures. **Biological control:** • Application of neem cake @ 80 Kg/acre for nematode control. **Chemical control:** • Spray with fungicides metalaxyl 8%+ mancozeb 64% WP@ 800g in 200 l of water/acre for downy mildew. • Seed dressing with fungicides metalaxyl-M 31.8% ES@ 2.0 ml/Kg seed for downy mildew.

Ergot**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15). • For resistant / tolerant varieties consult ICAR Institute / KVK's / SAU's. **Cultural control:** • Dipping the seeds in 10% NaCl salt solution for 10 minute to control the ergot disease. • The crop should be sown as early as possible during June- July with the onset of monsoon. • Use of resistant cultivars is the most cost-effective method for the control of Ergot disease. • Eradicate the weeds like *Cenchrus ciliaris* and *Panicum antidotale* from around pearl millet fields.
Sowing*	
	Common cultural practices: • Use healthy, certified and weed seed free seeds. • Timely sowing should be done. • Line sowing should be done to facilitate inter-culture operations. • Early sowing to avoid the active period of shoot fly population • Removal of diseased crop residues
Nutrients	• Seed treatment should be done with *Azotobacter/Azospirillum* and PSB @ 200 g /acre and VAM inoculum @ 1Kg /acre. • If soil test recommendation is not available follow the blanket recommendation of NPK @ 28:14:14 Kg/ acre for varieties. For hybrids, apply 32 Kg N, 16 Kg P_2O_5 and 16 Kg K_2O per acre. • Apply the recommended N in three splits as 25:50:25 per cent at sowing, 15 and 30 days after sowing and full dose of phosphorus and potassium at sowing. • Under rainfed conditions with low rainfall, the dose of fertilizers should be reduced to 50 percent and applied at the time of sowing.
Weeds	• Plant population should be maintained to its optimum right from beginning to minimize the crop weed competition. • Inter cropping with short duration pulse crops like moong bean should be done to suppress weeds between rows. • Inter cropping with pigeon pea in 2:1 ratio is also recommended for weed suppressing.
Shoot fly**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15) **Cultural control:** • Set up the low cost fish meal traps @ 4/acre till the crop is 30 days old. **Mechanical control:** • Removal of the seedlings with dead hearts and keep the optimum plant stand in the field. • Plough after harvest to remove and destroy the stubbles. **Chemical control:** • Seed treatment with imidacloprid 48% FS 12ml/Kg seed or imidacloprid 70% WS 10 g/Kg seed.
Downy mildew	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15). • For resistant / tolerant varieties consult ICAR Institute / KVK's / SAU's. **Cultural control:** • Roguing and gap filling, deep ploughing and soil solarisation. • Avoidance of monoculture. • Avoidance of low lying fields and water logging. **Biological control:** • The crude extract of *Vinca rosea, Ocimum sanctum, Allium sativum, Datura stramonium, Azadirachta indica* and *Thuja sinensis* can reduce the disease incidence. **Chemical control:** • The systemic fungicide metalaxyl-M 31.8% ES was used for seed treatment 2.0 ml/Kg seed successfully to control downy mildew in pearl millet. • Spray metalaxyl 8%+ mancozeb 64% WP@ 800g/acre in 200 l of water.

* Application of *Trichoderma harzianum/viride* and *Pseudomonas fluorescens* for treatment of seed/seedling/ planting materials in the nurseries and field application (if commercial products are used, check for label claim. However, biopesticides produced by farmers for own consumption in their fields, registration is not required).	
Vegetative stages	
	<u>Common cultural practices:</u> • Collect and destroy crop debris • Provide irrigation at the critical stages of the crop • Avoid water logging • Avoid water stress during flowering stage • Follow judicious use of fertilizers • Sow the lab lab or cowpea as an intercrop (pearl millet: lab lab 4:1). **<u>Common mechanical practices:</u>** • Collect and destroy disease infected and insect infested plant parts. • Collect and destroy eggs and early stage larvae • Handpick the older larvae during early stages • Hand pick the gregarious caterpillars and cocoons which are found on stem/branches and destroy them in kerosene mixed water. • Use light trap @ 1/acre and operate between 6 pm and 10 pm • Install pheromone traps @ 4-5/acre for monitoring adult moths activity (replace the lures with fresh lures after every 2-3 weeks) • Set up bonfire during evening hours at 7-8 pm. **<u>Common biological practices:</u>** • Enhance parasitic activity by avoiding chemical pesticide spray, when 1-2 larval parasitoids are observed in the crops field. • Conserve natural enemies through ecological engineering • Augmentative release of natural enemies.
Nutrients	• Apply remaining 50% dose of N at 15 days after sowing and 25 % N at 30 days after sowing as top dressing with irrigation or immediately after rainfall.
Weeds	• Inter cultivation: Two weeding with one shallow hoeing up to 4-5 weeks after sowing will keep the field free from weeds. • First weeding/ hoeing should be done within three weeks of sowing. • Mulches like straw hay, crop residues etc. can be used in between the rows to suppress the weed growth.
Downy mildew	• As mentioned above in the sowing stage.
Cutworm, stem borer**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15).
Flowering and heading	
Hairy caterpillar**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15). **<u>Cultural control:</u>** • Irrigate once to avoid prolonged mid season drought to prevent pre-harvest infestation. **<u>Mechanical control:</u>** • Dig the trenches of 1 inch depth between the fields & dust the trenches to kill the larvae in pits. **<u>Biological control:</u>** • Spray *Bacillus thuringiensis* @ 400 g/acre.

Ear head bug**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15). **Biological control:** • Spray NSKE 5% or Azadirachtin 1%
Rust**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15). • For resistant / tolerant varieties consult ICAR Institute / KVK's / SAU's. **Biological control:** • Some fungal species controls rust disease such as *Aspergillus globosum, Chaetomium globosum* and *Trichoderma koningii*.
Smut**	• Follow common cultural, mechanical and biological practices (See Page No. 13, 14, 15). • For resistant / tolerant varieties consult ICAR Institute / KVK's / SAU's. **Cultural control:** • Avoid rationing. • Intercropping of mungbean with pearl millet reduces the smut disease.
Birds	**Mechanical control:** • Scare the birds using reflective ribbons, bio-acoustics and automatic mechanical bird scarers. **Biological control:** • Apply NSKE 5% on panicle to save the damage from birds • Spray botanical repellents (neem extracts) to repel the birds from crop fields during milky stage.

Note: The pesticides dosages and spray fluid volumes are based on high volume sprayer. The recommended pesticides are as per CIBRC list updated on 31.10.2014.

** Pests of regional significance

VI. RODENT PEST MANAGEMENT

Rodent management practices:

- Plough the fields to demolish the rodent habitat and maintain weed free fields to reduce alternte source of food and habitat
- Practice burrow smoking by ANGRAU / NIPHM burrow fumigator with natural smoking materials for 2-3 min. for each burrow
- Erect owl perches @ 5-6/acre to promote natural control of rodents
- Poison baiting with zinc phosphide @ 2.0% on community approach. Practice pre-baiting to avoid bait shyness.
- Treat the residual burrows with 0.005% bromadiolone baits

VII. INSECTICIDE RESISTANCE AND ITS MANAGEMENT

Insecticide resistance: Resistance to insecticides may be defined as 'a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species' (IRAC). Cross-resistance occurs when resistance to one insecticide confers resistance to another insecticide, even where the insect has not been exposed to the latter product.

Causes of resistance development: The causes and rate at which insecticide resistance develops depend on several factors, including the initial frequency of resistance alleles present in the population, how rapidly the insects reproduce, the insects' level of resistance, the migration and host range of the insects, the insecticide's persistence and specificity, and the rate, timing and number of applications of insecticide made. For instance, insect pests that survive in large populations and breed quickly are at greater advantage of evolving insecticide, especially when insecticides are misused or over-used.

General strategy for insecticide resistance management: The best strategy to avoid insecticide resistance is prevention and including insecticide resistance management tactics as part of a larger integrated pest management (IPM) approach.

1) Monitor pests: Monitor insect population development in fields to determine if and when control measures are warranted. Monitor and consider natural enemies when making control decisions. After treatment, continue monitoring to assess pest populations and their control.

2) Focus on AESA: Insecticides should be used only as a last resort when all other non-chemical management options are exhausted and P: D ratio is above 2: 1. Apply biopesticides/chemical insecticides judiciously after observing unfavourable P: D ratio and when the pests are in most vulnerable life stage. Use application rates and intervals as per label claim.

3) Ecological engineering for pest management: Flowering plants that attract natural enemies as well as plants that repel pests can be grown as border/intercrop.

4) Take an integrated approach to managing pests: Use as many different control measures as possible viz., cultural, mechanical, physical, biological etc. Select insecticides with care and consider the impact on future pest populations and the environment. Avoid broad-spectrum insecticides when a narrow-spectrum or more specific insecticide will work. More preference should be given to green labeled insecticides.

5) Mix and apply carefully: While applying insecticides care should be taken for proper application of insecticides in terms of dose, volume, timing, coverage, application techniques as per label claim.

6) Alternate different insecticide classes: Avoid the repeated use of the same insecticide, insecticides in the same chemical class, or insecticides in different classes with same mode of action and rotate/alternate insecticide classes and modes of action.

7) Preserve susceptible genes: Preserve susceptible individuals within the target population by providing unsprayed areas within treated fields, adjacent "refuge" fields, or habitat attractions within a treated field that facilitate immigration. These susceptible individuals may outcompete and interbreed with resistant individuals, diluting the resistant genes and therefore the impact of resistance.

VIII. NUTRITIONAL DEFICIENCIES/ DISORDERS

Nitrogen: Little new growth, yellow leaves, this being more pronounced in older leaves and leaf drop. Plants stunted, spindly pale yellow or deep yellow color near the tips and margins progresses towards the base, heads small, seed numbers reduced. **Correction measure:** Apply 8-10 Kg N / acre as top dressing or foliar spray of urea @ 2-3 percent.	
Phosphorous: Small root systems; grain filling inhibited. Growth stunted, spindly, dark green / purple leaves with dark red coloration. Leaf sheaths bend upward with red coloration leaf. Leave appear to be erect and leathery. Roots turn dark brown purple or black. **Correction measure:** Foliar spray of 2% DAP 2-3 sprays at an interval of 15 days.	
Potassium: Deficiency first seen on older leaves. Irregular necrotic patterns intermingled with red pigmentation.Streaked patterns on the interveinal tissue, symptoms at tips and margins move towards the base. **Correction measure:** Foliar spray of KCl @ 1%.	
Sulphur: Deficiency appears first on younger leaves. New growth is pale yellow. **Correction measure:** Foliar spray of CaSO4 @ 2%	

IX. COMMON WEEDS

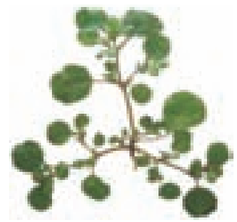
1. Crabgrass: *Digitaria sanguinalis* (L.) Scop. (Poaceae)

2. Barnyard grass: *Echinochloa crus-galli* (L.) Beauv. (Poaceae)

3. Goose grass: *Eleusine indica* (L.) Gaertner (Poaceae)

4. Bermuda grass: *Cynodon dactylon* (L.) Pers. (Poaceae)

5. Rabbit/crow foot grass: *Dactyloctenium aegyptium* L. Willd. (Poaceae)



6. Horse purslane: *Trianthema portulacastrum* L. (Aizoaceae)

7. Swine cress: *Coronopus didymus* (L.) Sm. (Brassicaceae)

8. Cock's comb: *Celosia argentea* L. (Amaranthaceae)

9. Pigweed: *Amaranthus viridis* Hook F. (Amaranthaceae)

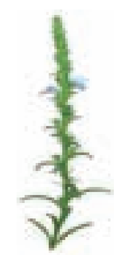
10. False amaranth: *Digera arvensis* (Amaranthaceae)

11. Black nightshade: *Solanum nigrum* L. (Solanaceae)

12.Common purselane: *Portulaca oleracea* L. (Portulacaceae)

13. Purple nutsedge: *Cyperus rotundus* L. (Cyperaceae)

14.Flat sedge: *Cyperus iria* L. (Cyperaceae)



15. Witch weed: *Striga asiatica* L. Kuntze (Orobanchaceae)

X. DESCRIPTION OF INSECT PESTS

1) White grub:

Biology:

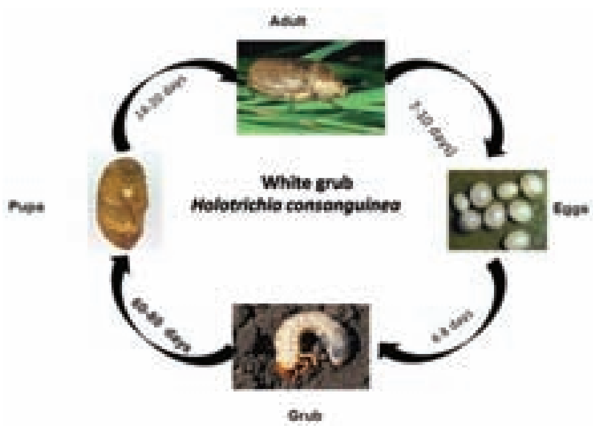
Egg: A female lays on an average of 27 eggs in the soil, which are pear like white enclosed in earthen cells.

Grub: Fleshy 'C' shaped, whitish yellow in colour found close to the base of the clump.

Pupa: Pupae are tan to brown, and occur deeper in the soil in earthen chambers.

Adult: Adult beetles are a rusty-red color just after emerging from the pupal stage, but turn nearly black.

Life cycle:



https://www.google.co.in/search?q=white+grub+life+cycle&espv=210&es_sm=93&source=lnms&tbm=isch&sa

Damage symptoms:

- Yellowing and wilting of leaves.
- Drying of entire crown.
- Affected canes come off easily when pulled.
- Cause extensive damage to roots and base of shoot.

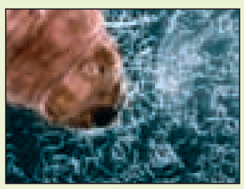
Biological control of white grubs through EPNs:

EPNs seek out and kill all stages of harmful soil-dwelling insects. They can be used to control a broad range of soil-inhabiting insects and above-ground insects in their soil-inhabiting stage of life. The IJs emerge from cadaver, search for root grubs, infect, kill and again multiply and remain in the moist soil. White grubs which are major pests in pearl millet can be managed by using EPNs effectively. EPN can be produced even at farmer level using either *Galleria* or *Corcyra* as a host.

- Entomopathogenic nematodes (EPNs) can be sprayed at the rate of 100 million nematodes per acre, in white grub infested pearl millet fields OR
- EPN infected cadavers of *Galleria/Corcyra* larvae containing live infective juveniles (IJs) are implanted in soil at plant bases at the rate of four cadavers per plant during May/June and/or September for pearl millet white grub control.

Mass multiplication of EPNs

Emergence of EPNs



Infected white grub with EPNs

Natural enemies of white grub:

Parasitoid: *Typhia* spp. (parasitic wasp) etc.

Predators: Ground beetle, ant etc.

2) Cutworm:

Biology:

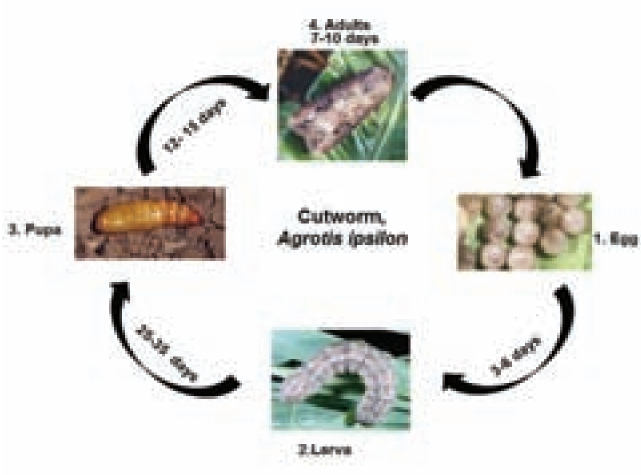
Egg: The egg is white in color initially, but turns brown with age. It measures 0.43 to 0.50 mm high and 0.51 to 0.58 mm wide and is nearly spherical in shape, with a slightly flattened base. The egg bears 35 to 40 ribs that radiate from the apex; the ribs are alternately long and short. The eggs normally are deposited in clusters on foliage. Females may deposit 1200 to 1900 eggs. Duration of the egg stage is three to six days.

Larva: There are five to nine instars, with a total of six to seven instars most common. the larva is rather uniformly colored on the dorsal and lateral surfaces, ranging from light gray or gray-brown to nearly black. The head is brownish with numerous dark spots. Larvae usually remain on the plant until the fourth instar, when they become photo-negative and hide in the soil during the daylight hours. In these latter instars they also tend to severe plants at the soil surface, pulling the plant tissue belowground. Larvae tend to be cannibalistic.

Pupa: The pupa is 17 to 22 mm long and 5 to 6 mm wide and dark brown. Duration of the pupal stage is normally 12 to 15 days. Pupation occurs belowground at a depth of 3 to 12 cm.

Adult: The adult is fairly large in size, with a wingspan of 40 to 55 mm. The forewing, especially the proximal two-thirds, is uniformly dark brown. The distal area is marked with a lighter irregular band, and a small but distinct black dash extends distally from the bean-shaped wing spot. The hind wings are whitish to gray, and the veins marked with darker scales.

Life cycle:



1,3&4https://extension.umd.edu/news/photos/cutworm
2 http://entnemdept.ufl.edu/creatures/veg/black_cutworm.htm

Damage symptoms:

- Cutworms usually feed at night or during overcast days. Newly hatched larvae feed on weeds, and/or young maize plants if present, leaving small irregular holes in the leaves. Such early feeding is of little significance to plants.
- Larger larvae may completely cut through stalks, which can cause plants to wilt and die. Severe stand reductions can result. They sometimes drag cut plants under soil clods or into small holes in the soil to continue their feeding during the daylight hours.
- In other crops like potatoes and root vegetables, damage can take the form of unsightly holes in the subterranean tubers, which may allow the penetration of secondary fungi.
- When numerous, cutworms can destroy as much as 75% of a crop.

Natural enemies of cutworm:

Parasitoids: *Cotesia* sp, *Meterorus* sp, *Campoletis* sp etc.

Predators: Ground beetle, red ant, praying mantis, reduviid bug, ladybird beetle, spider, mirid bug, hover fly etc.

*For the management refer page no 15.

3) Shoot fly:

Biology:

Egg: Eggs are laid generally singly parallel to the midrib on the under surface of the 3rd to 5th leaf. Under high shoot-fly pressure, there may be several eggs on the same leaf. Sometimes, as many as 25 eggs may be laid on the same seedling. They hatch in 2-5 days.

Maggot: Yellow in colour migrate to the dorsal surface of the leaf, enter the space between the leaf sheath and the axis and make a clean cut at the base of the leaf. The larval period lasts for 6 - 10 days.

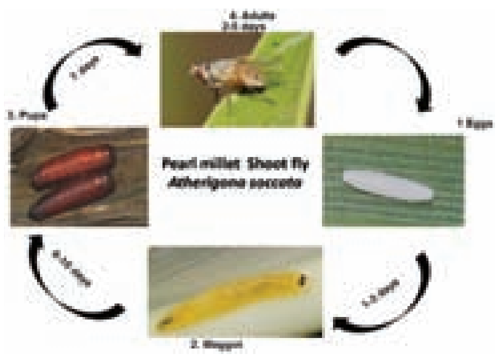
Pupa: Pupation takes place inside the stem and the adults emerge in about a week.

Adult: The adults are dark brown and similar to domestic housefly, but nearly half the size with the males smaller than the females. The adults usually live for 10 to 20 days.

Favourable conditions:

- Shoot fly populations may be recorded throughout the year, and there may be 15 to 16 generations in a year.
- The late sown crops generally suffer greater shoot fly damage because of build up of shoot fly populations on the early sown crops.

Life cycle:



1. http://www.nbaii.res.in/insectpests/images/Atherigona-soccata1.jpg
2. http://www.nbaii.res.in/insectpests/images/Atherigona-soccata2.jpg
3. www.nbaii.res.in/insectpests/images/Atherigona-soccata3.jpg
4. http://www.nbaii.res.in/insectpests/images/Atherigona-soccata4.jpg

Damage symptoms:

- Damage by larvae at the seedling stage (5 to 30 days after seedling emergence) will lead to the typical dead heart symptoms.
- The larva migrates to the upper side of the leaf, and moves along the leaf whorl until it reaches the growing point where the larvae cut the growing point. As a result the central leaf dries up forming a dead heart, which can be pulled out easily and produces a rotting smell.
- Normally the damage occurs 1 to 4 weeks after seedling emergence. Seedlings of 5 to 30 days old are generally susceptible to shoot fly damage.
- Older plants (>30 days after seedling emergence) are not usually damaged by *A. soccata* however, under conditions of high humidity during the rainy season, infestation may occur.
- Under these conditions the infested plants do not produce the typical dead heart symptoms. In this instance, the damaged leaf becomes thin and papery, wrapping around the other leaves. The plants may fail to grow normally.
- Late infestations may also damage the panicle in the formative stage, resulting in rotting or drying up of a portion of the panicle affected by shoot fly damage.

Natural enemies of shoot fly:

Parasitoids: *Trichogramma* spp., *Trichogramma chilonis, Neotrichoporoides* spp. etc.

Predator: Spiders etc.

*For the management refer page no 14.

4) Stem borer:

Biology:

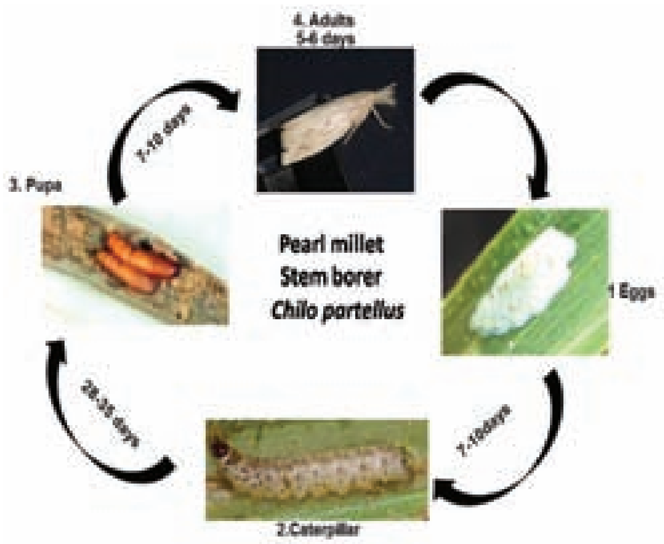
Egg: The eggs are laid on the underside of a leaf near the midrib in 3-5 rows, in groups of 50-100. They are flattened, ovoid, and about 0.8 mm long. Hatching takes place after 7-10 days.

Larva: The young larvae produce characteristic leaf windowing. Sometimes the early stages mine in the leaves, causing yellow streaks. After a few days they bore down inside the funnel. They also may move down outside the stem and then bore into it just above an internode. In older plants the caterpillars sometimes live in the developed heads. In general appearance the caterpillars look like *Busseola fusca* larvae (= Maize Stalk Borer). They are creamy pink with groups of dark spots along the back. The head capsule is brown. When mature they are about 25 mm long. The caterpillars can be distinguished from *B. fusca* and from *Sesamia calamistis* (= Pink Stalk Borer) by the hooks on its prolegs. In *C. partellus* these hooks are arranged in a complete circle. In B. fusca and *S. calamistis* they are arranged in a crescent. The larval period takes 28-35 days.

Pupa: Pupation takes place in a small chamber in the stem. The pupal period takes 7 10 days.

Adult: Adult moths have a wingspan of 20-30 mm. Males are smaller and darker than females. The forewings of males are pale brown. The forewings of the females are much paler and the hind wings are almost white.

Life cycle:



1. http://www.infonet-biovision.org/default/ct/92/pests
2. http://www.nbaii.res.in/insectpests/images/Chilo-partellus6.jpg
3. http://push-pull.net/striga/stemborer.html
4. http://www.nbaii.res.in/insectpests/images/Chilo-partellus15.jpg

Damage symptoms:

- Damage occurs as a series of small holes in lines (pin holes) in younger leaves and/or patches of transparent leaf epidermis (window panes) in older leaves.
- Holes in stem caused by larvae tunnelling into the stem can result in broken stems or drying and eventual death of the growing point of the maize (deadheart).

Natural of enemies of stem borer

Parasitoids: *Cotesia sesamiae*, *Cotesia chilonis* etc.

*For the management refer page no 15.

Natural Enemies of Pearl Millet Insect Pests

Parasitoids

Egg parasitoids

1. *Trichogramma* sp

Egg-larval parasitoid

2. *Chelonus* spp.

Larval parasitoids

3. *Cotesia sesamiae*

4. *Cotesia chilonis*

5. *Aprostocetus* spp.

6. *Campoletis* spp.

Nymphal/larval/adult parasitoids

7. *Cotesia* spp.

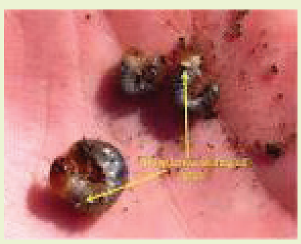
8. *Meterorus* spp.

9. *Campoletis* spp.

1. http://www.nbaii.res.in/Featured_insects/Trichogrammatids.php; 2. http://www.nbaii.res.in/Featured%20insects/chelonus.htm; 3. http://www.sharkeylab.org/cotesia/display_morph.cgi?Species=sesamiae&part=lateralHabitus&Author=Cameron; 4. http://www.nbaii.res.in/Introductions/images/apanteles-chilonis.jpg; 5. http://www.nbaii.res.in/Featured_insects/images/aprostocetus-gala3.jpg; 6. http://www.nbaii.res.in/Featured%20insects/Campoletis.htm; 7. http://www.nbaii.res.in/Featured_insects/images/cotesia-flavipes7.jpg; 8. http://micropics.org.uk/Braconidae/Meteorus/1/meteorus%201.htm; 9. http://www.nbaii.res.in/Featured_insects/images/campoletis-chlorideae4.jpg

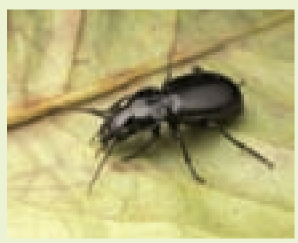
Predators

1. Spider

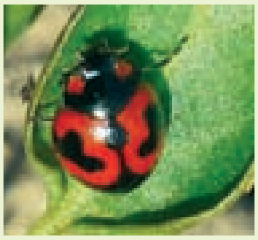


2. Tiny wasp

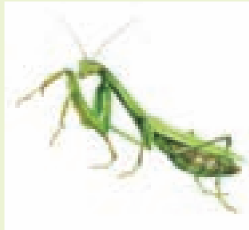
3. Red ant



4. Ground beetle


5. Ladybird beetle


6. Mirid bug


7. Praying mantis


8. Hover fly

2. https://www.google.co.in/search?q=typhia+parasitic+wasp=210&es_sm=93&tbm=isch&biw=1280&bih=699&oq=typhia+parasitic; 3. http://www.couriermail.com.au/news/queensland/queensland-launched-a-war-against-the-fire-ant-invasion-but-12-years-later-they8217re-still-on-the-march/story-fnihsrf2-1226686256021; 4. http://www.mattcolephotography.co.uk/Galleries/insects/Bugs%20&%20Beetles/slides/; 6. http://www.britishbugs.org.uk/heteroptera/Miridae/blepharidopterus_angulatus.html; 7. http://www.kimthompsonartist.com/SingleImages/PrayingMantis.html

XI. DESCRIPTION OF DISEASES

1) Downy mildew:

Disease symptoms:

- The characteristic symptoms of the disease are pale, chlorotic, broad streaks extending from base to tip of leaves.
- At the advancement of disease, the leaf streaks turn brown and the leaves become shredded longitudinally. In severe infection, the downy fungal growth can be seen on the upper as well as lower surface of the leaves.
- The rapid growth of fungal pathogen is favoured by rainy and humid environment. The infected plants fail to form ear but if formed, they are malformed to green leafy structures.
- The complete ear can be transformed into leafy structure.
- The fungal pathogen transformed all floral parts such as glumes, palea, stamens and pistils into green linear leafy structures of variable lengths.
- As the disease advances, the malformed floral structures of ears become brown and dry.

Survival and spread:

- The oospores remain viable for eight months to ten years or more in the soil, which makes primary infection in host plants and present abundantly in diseased leaves fall on the ground.
- The secondary spread of disease starts from sporangia, which are most active in moist environment.

Favourable conditions:

- The atmospheric temperatures between 15-25 °C and relative humidity above 85 per cent.
- Light drizzling accompanied by cool weather is highly favourable

Disease symptoms

http://cropgenebank.sgrp.cgiar.org/images/management/millets_smogs/downy%20mildew.png
http://www.apsnet.org/publications/imageresources/PublishingImages/2011/FI00138.jpg

*For the management refer page no 13, 14.

2) Ergot:

Disease symptoms:

- Sphacelial (conidial) "honeydew" sporulation has been reported on pearl millet (Frederickson and Mantle 1996).
- Cream to pink mucilaginous droplets of "honeydew" ooze out of infected florets on pearl millet panicles and form sclerotia
- Within 10 to 15 days, the droplets dry and harden, and dark brown to black sclerotia develop in place of seeds on the panicle.
- Sclerotia are larger than seed and irregularly shaped, and generally get mixed with the grain during threshing.

Survival and spread:

- The sclerotia take about 30-45 days to germinate and produce air borne spores which spread primary infection to pearl millet crop.
- The secondary spread of the disease is through conidia produced in large numbers in honey dew and disseminated by insects or rain.

Favourable conditions:

- Conditions favoring the disease are RH greater than 80% and 20 to 30°C temperatures.

Disease symptoms

http://cropgenebank.sgrp.cgiar.org/images/management/millets_smogs/ergot.png; http://www.apsnet.org/publications/imageresources/PublishingImages/2007-08/IW000079.jpg

*For the management refer page no 14.

3) Smut:

Disease symptoms:

- Immature, green sori larger than the seed develop on panicles during grain filling stage.
- A single sorus develops per floret.
- As grain matures, sori change in color from bright green to dark brown.
- Sori are filled with dark teliospores.

Survival and spread:

- The primary infection of the disease starts from air borne spores, which produce sporidia on germination that enter in the spikelets and infect ovary.
- Teliospores may remain viable in the soil and sporidia may be produced.

Favourable conditions:

- Optimum environmental conditions for maximum infection include: temperatures of between 25 and 35°C and slightly acidic soils favour the disease development.

Disease symptoms

http://www.infonet-biovision.org/res/res/files/1484.280x185.clip.jpeg; http://cropgenebank.sgrp.cgiar.org/images/management/millets_smogs/smut.png

*For the management refer page no 13.

4) Rust:

Disease symptom:

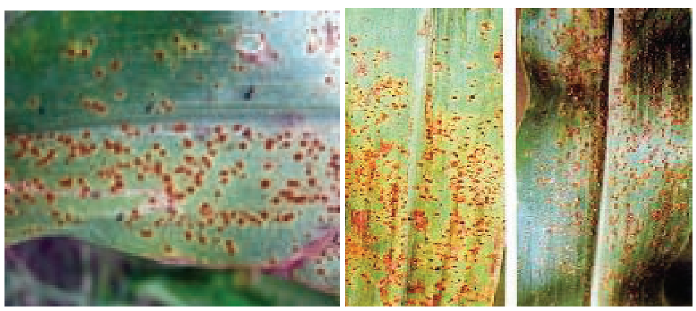
- On pearl millet: Small reddish-brown to reddish orange, round to elliptical uredinia develop mainly on foliage.
- As severity of infection increases, leaf tissue will wilt and become necrotic from the leaf apex to base.
- In infection sites developing late in the season, uredinia are replaced by telia which are black, elliptical, and sub epidermal.

Survival and spread:

- The uredospores survive for a short time in soil and infected debris.
- Presence of alternate host helps in perpetuation of the fungus.

Favourable conditions:

- Low temperature of 10 to 12˚C favour steliospore germination.
- A spell of rainy weather favours the onset of the disease.



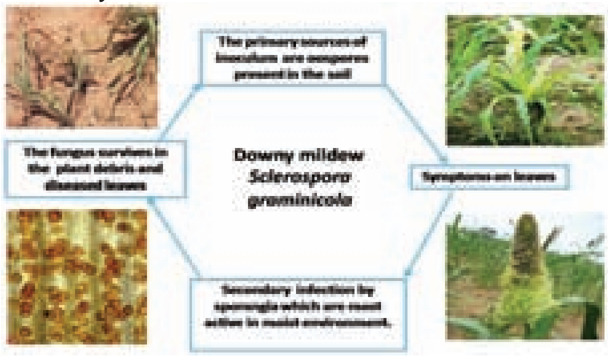
Disease symptom

http://www.apsnet.org/publications/imageresources/PublishingImages/2013/fi00186.jpg; http://www.tifton.uga.edu/fat/rust.jpg

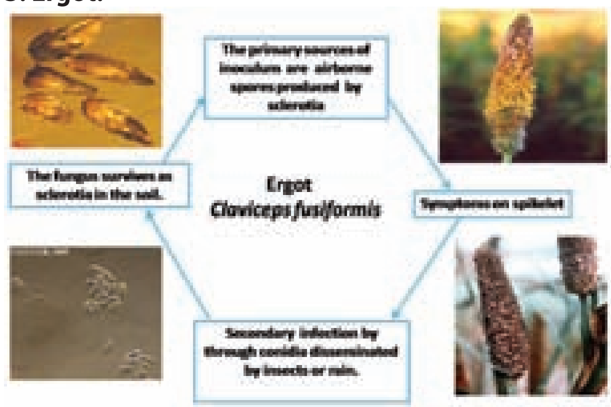
*For the management refer page no 16

Disease cycles:

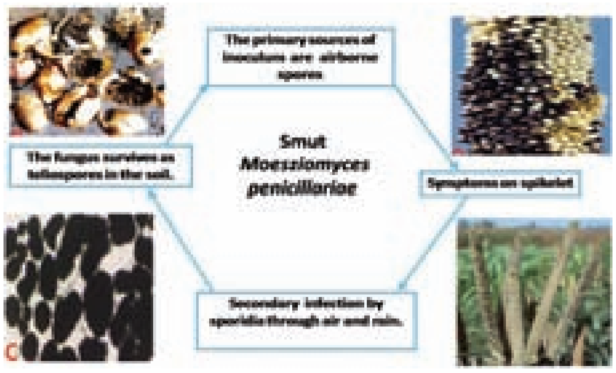
1. Downy mildew:



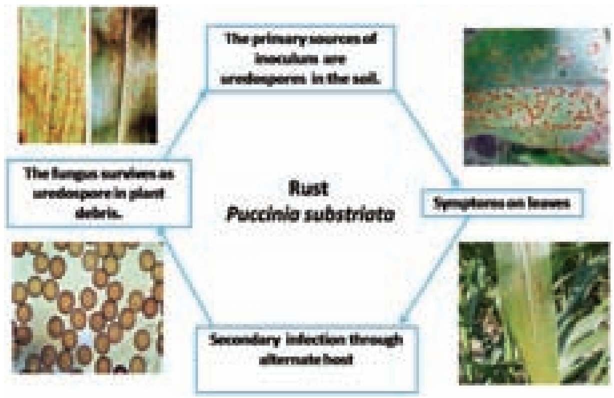
3. Ergot:



2. Smut:



4. Rust:



XII. SAFETY MEASURES

A. At the time of harvest:

Pearl millet varieties produce seeds ready for harvest before the plant is dried down. Although the seeds are not likely to shatter, it is desirable to harvest soon after seed maturity, as plant dry down, allows avoiding unnecessary grain loss to birds. Harvest grain as early as 40 days after flowering. Begin harvesting when seed moisture content drops below 15 percent, but artificial drying to 10-12 percent moisture after harvest is needed to prevent storage molds.

B. During post-harvest storage:

Properly dried grain will store well, but mold will develop on grain that has not been dried properly. Drying after harvest may be difficult because of the small seed size. Since the seed size is smaller than sorghum and corn, it is more difficult to force air through it in a grain drier. Dry the seeds upto 12% moisture content. Avoid keeping the bags directly on the floor and near the walls. Keep the bags over the wooden pallets, so that the absorption of moisture by the seed from the floor and walls is prevented. Keep only 6 to 7 bags in a stack. If the numbers of bags are more, it will excert pressure to the seeds in the basal bags leading to the loss of germination capacity.

XIII. DO'S AND DON'TS IN IPM

S. No.	Do's	Don'ts
1.	Deep ploughing is to be done on bright sunny days during the months of May and June. The field should be kept exposed to sun light at least for 2-3 weeks.	Do not plant or irrigate the field after ploughing, at least for 2-3 weeks, to allow desiccation of bulbs and/or rhizomes of perennial weeds.
2.	Adopt crop rotation.	Avoid monocroping
3.	Grow only recommended varieties.	Do not grow varieties not suitable for the season or the region.
4	Sow early in the season	Avoid late sowing as this may lead to reduced yields and high incidence of white grubs and diseases.
5	Always treat the seeds with approved chemicals/ bio pesticides for the control of seed borne diseases/ pests.	Do not use seeds without seed treatment with biopesticides/ chemicals.
6.	Sow in rows at optimum depths under proper moisture conditions for better establishment.	Do not sow seeds beyond 5-7 cm depth.
7.	Apply only recommended herbicides at recommended dose, proper time, as appropriate spray solution with standard equipment along with flat fan or flat jet nozzles.	Pre-emergent as well as soil incorporated herbicides should not be applied in dry soils. Do not apply herbicides along with irrigation water or by mixing with soil, sand or urea.
8.	Maintain optimum and healthy crop stand which would be capable of competing with weeds at a critical stage of crop weed competition	Crops should not be exposed to moisture deficit stress at their critical growth stages.
9	Use NPK fertilizers as per the soil test recommendation.	Avoid imbalanced use of fertilizers.
10	Use micronutrient mixture after sowing based on soil test recommendations.	Do not apply any micronutrient mixture after sowing without soil test recommendations.
11	Conduct weekly AESA in the morning preferably before 9 a.m. Take decision on management practice based on AESA and P: D ratio only.	Do not take any management decision without considering AESA and P: D ratio
12	Install pheromone traps at appropriate period and distance.	Do not store the pheromone lures at normal room temperature (keep them in refrigerator).
13	Release parasitoids only after noticing adult moth catches in the pheromone trap or as pheromone trap or as per field observation	Do not apply chemical pesticides within seven days of release of parasitoids
14	Apply short persistent pesticides to avoid pesticide residue in the soil and produce.	Do not apply pesticides during preceding 7 days before harvest.
15	Follow the recommended procedure of trap crop technology.	Do not apply long persistent pesticides on trap crop, otherwise it may not attract the pests and natural enemies.

XIV. SAFETY PARAMETERS IN PESTICIDE USAGE

S. No.	Pesticide Classification as per insecticide rulesColour of toxicity triangle	WHO classification of hazard	Symptoms poisoning	First Aid measures Treatment of poisoning	Waiting period from last application to harvest (days)
Insecticides					
1	Imidacloprid Highly toxic 		Harmful if swallowed, absorbed through skin or inhaled. Avoid breathing vapor or spray mist. Causes moderate eye irritation.	**First Aid measures:** Have person sip a glass of water if able to swallow. **Treatment of poisoning** Do not induce vomiting unless told to do so by a doctor, do not give anything by mouth to an unconscious Person. No specific antidote. Treatment is essentially symptomatic.	3 days
Fungicides					
2	Mancozeb Slightly toxic 	Unlikely produce acute hazard	Headache, palpitation, nausea, vomiting, flushed face, irritation of nose,throat, eyes and skin etc.	**Treatment of poisoning:** No specific antidote. Treatment is essentially symptomatic	10 days

XV. BASIC PRECAUTIONS IN PESTICIDE USAGE

A. Purchase

1. Purchase only just required quantity e.g. 100, 250, 500, 1000 g/ml for single application in specified area.
2. **Do not** purchase leaking containers, loose, unsealed or torn bags; **Do not** purchase pesticides without proper/approved labels.
3. While purchasing insist for invoice/bill/cash memo

B. Storage

1. Avoid storage of pesticides in house premises.
2. Keep only in original container with intact seal.
3. **Do not** transfer pesticides to other containers; **Do not** store expose to sunlight or rain water; **Do not** weedicides along with other pesticides
4. Never keep them together with food or feed/fodder.
5. Keep away from reach of children and livestock.

C. Handling

1. Never carry/ transport pesticides along with food materials.
2. Avoid carrying bulk pesticides (dust/granules) on head shoulders or on the back.

D. Precautions for preparing spray solution

1. Use clean water.
2. Always protect your nose, eyes, mouth, ears and hands.
3. Use hand gloves, face mask and cover your head with cap.
4. Use polythene bags as hand gloves, handkerchiefs or piece of clean cloth as mask and a cap or towel to cover the head (Do not use polythene bag contaminated with pesticides).
5. Read the label on the container before preparing spray solution.
6. Prepare the spray solution as per requirement
7. **Do not** mix granules with water; **Do not** eat, drink, smoke or chew while preparing solution
8. Concentrated pesticides must not fall on hands etc while opening sealed container. Do not smell pesticides.
9. Avoid spilling of pesticides while filling the sprayer tank.
10. The operator should protect his bare feet and hands with polythene bags

E. Equipments

1. Select right kind of equipment.
2. **Do not** use leaky and defective equipments
3. Select right kind of nozzles
4. Don't blow/clean clogged nozzle with mouth. Use old tooth brush tied with the sprayer and clean with water.
5. **Do not** use same sprayer for weedicide and insecticide.

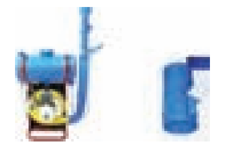
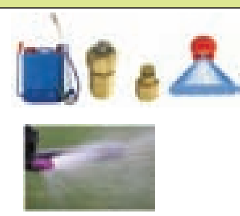
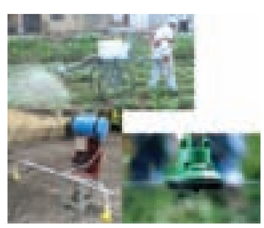
F. Precautions for applying pesticides

1. Apply only at recommended dose and dilution
2. **Do not** apply on hot sunny day or strong windy condition; **Do not** apply just before the rains and after the rains; **Do not** apply against the windy direction
3. Emulsifiable concentrate formulations should not be used for spraying with battery operated ULV sprayer
4. Wash the sprayer and buckets etc with soap water after spraying
5. Containers buckets etc used for mixing pesticides should not be used for domestic purpose
6. Avoid entry of animals and workers in the field immediately after spraying
7. Avoid tank mixing of different pesticides

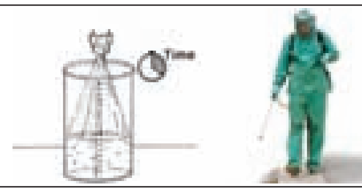
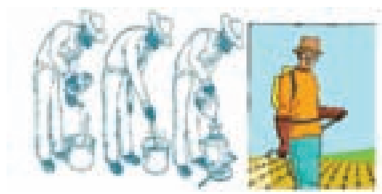
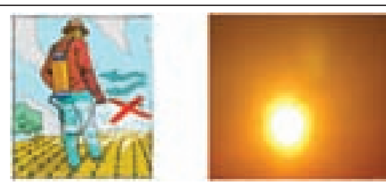
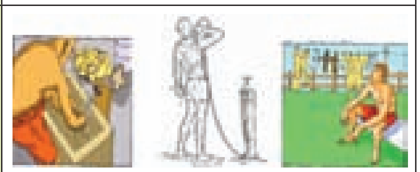
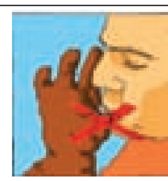
G. Disposal

1. Left over spray solution should not be drained in ponds or water lines etc. throw it in barren isolated area if possible
2. The used/empty containers should be crushed with a stone/stick and buried deep into soil away from water source.
3. Never reuse empty pesticides container for any other purpose.

XVI. PESTICIDE APPLICATION TECHNIQUES

Equipment			
Category A: Stationary, crawling pest/disease			
Vegetative stage i) For crawling and soil borne pests ii) For small sucking leaf borne pests	Insecticides and fungicides	• Lever operated knapsack sprayer (droplets of big size) • Hollow cone nozzle @ 35 to 40 psi • Lever operating speed = 15 to 20 strokes/min *or* • Motorized knapsack sprayer or mist blower (droplets of small size) • Airblast nozzle • Operating speed: 2/3rd throttle	 
Reproductive stage	Insecticides and fungicides	• Lever operated knapsack sprayer (droplets of big size) • Hollow cone nozzle @ 35 to 40 psi • Lever operating speed = 15 to 20 strokes/min	
Category B: Field flying pest/airborne pest			
Vegetative stage Reproductive stage *(Field Pests)*	Insecticides and fungicides	• Motorized knapsack sprayer or mist blower (droplets of small size) • Airblast nozzle • Operating speed: 2/3rd throttle *Or* • Battery operated low volume sprayer (droplets of small size) • Spinning disc nozzle	
Mosquito/ locust and spatial application *(migratory* Pests)	Insecticides and fungicides	• Fogging machine and ENV (exhaust nozzle vehicle) (droplets of very small size) • Hot tube nozzle	
Category C: Weeds			
Post-emergence application	Weedicide	• Lever operated knapsack sprayer (droplets of big size) • Flat fan or floodjet nozzle @ 15 to 20 psi • Lever operating speed = 7 to 10 strokes/min	
Pre-emergence application	Weedicide	• Trolley mounted low volume sprayer (droplets of small size) • Battery operated low volume sprayer (droplets of small size)	

XVII. OPERATIONAL, CALIBRATION AND MAINTENANCE GUIDELINES IN BRIEF

1.	For application rate and dosage see the label and leaflet of the particular pesticide.	
2.	It is advisable to check the output of the sprayer (calibration) before commencement of spraying under guidance of trained person.	
3.	Clean and wash the machines and nozzles and store in dry place after use.	
4.	It is advisable to use protective clothing, face mask and gloves while preparing and applying pesticides. Do not apply pesticides without protective clothing and wash clothes immediately after spray application.	
5.	Do not apply in hot or windy conditions.	
6.	Operator should maintain normal walking speed while undertaking application.	
7.	Do not smoke, chew or eat while undertaking the spraying operation	
8.	Operator should take proper bath with soap after completing spraying	
9.	Do not blow the nozzle with mouth for any blockages. Clean with water and a soft brush.	

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Plants Suitable for Ecological Engineering in Pearl Millet Field

Dill

Sunflower

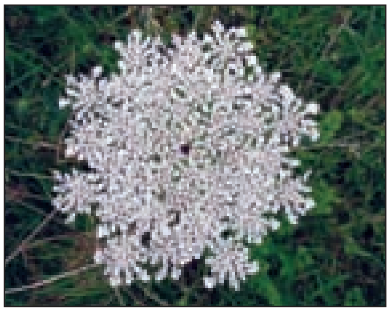
Ocimum spp.

Cosmos

Spearmint

Mustard

Marigold



Carrot

Sorghum

Cowpea

Buckwheat

Maize

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