A

Guide

on

Integrated Production Management of Winter Wheat

Technical Advisory and Innovation Center (TAIC)

Dr. Kauser Iqbal Khan

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Contents

Foreword

The purpose of this guide is to strengthen knowledge and insight in options for Integrated Production Management (IPM) in winter wheat that can lead to sustainable Best Agricultural Practices (BAPs) in Chui Region of Kyrgyzstan.

The main objectives is to strengthening the knowledge of farmers, empowering them with the Best Agricultural Practices, used throughout the world for wheat production and testing and successful adaptation of BAPs among farmers of the region, and as a result get cost effective and sustainable wheat production.

A basic hypothesis of the Sustainable Production is to develop farmer's knowledge of interactions in the wheat agro-ecosystem to be able to make sound management decisions.

To meet the objective TAIC has pioneered Training of Trainers (ToT) and Farmer Field Schools (FFS) in Chui Region of Kyrgyzstan from November 2009.to August 2010.

This Guide is developed by TAIC for facilitators / trainers involved in participatory training of wheat farmers. **Part I** of this guide covers the technical background on the biology and management of winter wheat and **Part II** includes a relevant set of participatory learning exercises.

The technical background information in Part I is derived from information sourced from the CABI Crop Protection Compendium, which is an interactive, multimedia CD-Rom based database of a wide range of science-based information on all aspects of crop protection. Most of the exercises in Part II are existing exercises that have been used by CABI South Asia and others before. The participatory learning exercises in this Guide will be field tested in TAIC's Training of Trainers (ToT) and Farmer Field Schools (FFS) on winter wheat and should be used flexibly and creatively by facilitators / trainers.

All TAIC staff, especially IPM Coordinator Marat Ivakov made their inputs in developing and improving this guide, which will assist them in making better informed choice about integrated wheat production management. Photographic illustrations are included from CABI Crop Protection Compendium, ToT and FFS activities and various other open sources.

Note: All guidelines were discussed in the ToT sessions and added / changed according to local conditions to ensure that facilitation of facilitators / trainers is enhanced.

PART I; WINTER WHEAT INTEGRATED PRODUCTION MANAGEMENT

Winter Wheat Introduction

Morphology

T. aestivum plant is 40-150 cm tall, forming 2-6 seminal roots and many secondary roots, often strongly tillering (up to 40 tillers per plant, depending on cultivar and environment, but normally 2-5). Stem smooth, with 4-7 nodes and internodes, sometimes more; internodes becoming larger from bottom to top. Leaf blades are of 15-40 cm x 1-3 cm, glabrous or pubescent. Spike 5-15 cm long excluding the awns, varying in shape, size and density; awns, when present, up to 16 cm long.

Biology and Ecology

Growth and Phase's development of wheat is influenced by temperature, and the cultivar's vernalization and day length response. After water has been imbibed, germination begins as the endosperm is broken down to provide nutrients to the emerging coleoptile. Optimum germination occurs between 12 and 25°C. The scutellum initially supports early growth and subsequently serves as temporary storage of starch from the endosperm. The seminal roots emerge first. Once the roots start to absorb nutrients and water, the coleoptile emerges 4-6 days after germination. The seminal roots may remain functional for life unless destroyed by diseases or mechanical injury, but they constitute only a small portion of the total root system. The first true leaf of the seedling emerges from the coleoptile. Secondary roots start to develop about 2 weeks after seedling emergence. They arise from the basal node and form the permanent root system, which spreads out and may penetrate as deep as 2 m, but normally no more than 1 m. Leaf and tiller production increase rapidly soon after crop emergence. Cultivars with tall, weak tillers tend to lodge. All spike-bearing tillers eventually flower almost simultaneously. Flowering begins at the middle third of the spike, then rapidly progressing both upward and downward. Most flowers bloom in mid-morning before noon. Wheat is normally self-pollinated: cross pollination is only 1-4%. Pollen is largely shed within the floret. Stigmas remain receptive for 4-13 days. Pollen is viable for up to 30 minutes only. Grains in the centre of the spike and in the proximal florets tend to be larger. Physiological maturity is the stage when the moisture content of the fully formed grain has dropped to 25-35%.

Ecology

Wheat is essentially a temperate-climate crop. It requires 1475-1600 growing degree-days for a complete crop cycle. Optimum temperatures for development are 10-24°C. Relatively low temperatures result in the highest yields. Temperatures above 35°C stop photosynthesis and growth, and at 40°C the crop is killed by the heat. The minimum amount of water required for an acceptable crop is 250 mm in the top 1.5 m of soil. Wheat does not grow well under very warm conditions with high relative humidity, unless irradiation and nutrient availability are very favorable. In addition, wheat diseases are generally encouraged by such climatic conditions. Soils best suited for production are well aerated, well drained, and deep, with 0.5% or more organic matter. Optimum soil pH ranges between 5.5 and 7.5. Wheat is sensitive to soil salinity.

Agronomic aspects

Propagation and Planting

Wheat is propagated by seed. It requires a fine seed-bed that is free of weeds. Heat during critical stages should be avoided. Therefore it is crucial to establish and adhere to an optimum planting calendar, to allow the wheat to flower under the most favorable or coolest environmental conditions and hence to maximize yield. If irrigation is not available, then a compromise has to be made by seeding when soil moisture is optimal. The seed may be dribbled directly into a furrow behind a plough and covered, or machine-planted in rows (spaced at 10-35 cm). Machine drilling uses less seed, promotes uniform germination and stand, and usually gives higher yields. Sowing depth varies from 2-12 cm, with deeper planting required in dry conditions to reach the soil moisture. However, care must be taken not to sow too deep. Seeding rate is commonly 100-150 kg/ha, resulting in 250-300 plants/m^2. The aim is to eventually obtain 400-600 spikes/m^2. It is advisable to use certified seed that has been treated with fungicides against soil- and seed borne diseases.

Husbandry

Uniform crop stand and early vigor discourage weed growth. In this respect tillering allows the crop to compensate for poor stands and variable weather conditions. Tiller production depends on the formation of secondary roots, plant density, available nutrients and climatic conditions. Yield losses due to weeds are caused by early competition in the first 4-5 weeks. Weeds can be controlled by proper crop rotation, pre-seeding irrigation, machine cultivation, or application of chemical herbicides. Irrigation has great potential to increase wheat production. It can be practiced in basins, by furrow, or using overhead sprinklers. Care must be taken not to over-irrigate as wheat is very sensitive to early water logging. The mean nutrient removal per 1 t/ha of grain is 40-43 kg N, 5-8 kg P, 25-35 kg K, 2-4 kg S, 3-4 kg Ca, 3-3.5 kg M, and smaller amounts of micro-nutrients. The exact values depend on the available nutrients and water in the soil, the temperature, and the cultivar. Organic manures and composts may be used. Boron deficiency, results in grain set failure. Soil acidity can be a constraint. Liming might raise the pH, but its economics are unknown

Growth and Developement

Winter wheat production can be improved with good knowledge of growth and development, Seeding date, irrigation scheduling, fertilizer, pesticide, and plant growth regulator application are more effective if accurately timed to crop development. Growth and development are related but separate plant processes. Growth is often described as an increase in size or dry matter, while development involves differentiation into tissues and organs. Plant development is divided into several stages:

- germination and early seedling growth
- tillering and vegetative growth
- elongation and heading
- flowering, and kernel development

Numerical scales have been devised for quantifying the growth stages. Those most commonly used are the Zadoks, Feekes, and Haun growth scales.

The Zadoks system uses a 2-digit code to refer to the principal stages of growth from germination (stage 0) through kernel ripening (stage 9). The second digit subdivides each principal growth stage.

The Feekes scale (1 to 11.4) numerically identifies stages from emergence through ripening.

The Haun scale deals mainly with the pattern of leaf production, in which the length of each emerging leaf is expressed as a fraction of the preceding leaf.

Comparison of Zadoks, Feekes, and Haun growth scales

Growth stage	Scale		
	Zadoks	Feekes	Haun
Planting	00	-	-
Emergence	10	1	0.0
First leaf	11	1	0.0-1.0
Second leaf	12	1	1.1-2.0
Third leaf	13	1	2.1-3.0
Tillering	21-29	2-4	3.1-6.0
Jointing	31	6	6.1-10.0
Flag leaf	37-39	8	8.1-9.0
Boot	40-47	9-10	9.1-10.0
Heading	51-59	10.1-10.5	10.1-11.0
Flowering	61-69	10.5.1-10.5.3	-
Grain formation	71	10.5.4	-
Milk	71-79	11.1	-
Soft dough	85	11.2	-
Hard dough	87	11.3	-
Harvest ripe	92	11.4	-

The planting date is only one of the many management practices that are determined by the growth and development patterns of wheat. The seeding rate, for instance, sets the number of plants per hectare and, along with tillers per plant, kernels per tiller, and weight per kernel, determines the yield of grain. A change to any of these yield components, such as a reduction in the tillering capacity, would change the seeding rate that is needed for maximum production. By knowing how a wheat plant grows and develops, an understanding of why it responds as it does to management and the environment can be gained.

Growth rate

Growth rate is determined by many factors, including genetics, soil type, soil fertility, planting depth, planting date, water availability, and planting density. Temperature, photoperiod, and crop class primarily determine development rate. Thermal time used to describe development rate is most often calculated as growing degree days (GDD). Growing degree days are calculated by adding the maximum and minimum daily temperatures and dividing that number by two to give an average daily temperature. The base temperature, 0 C, minimum for wheat growth, is subtracted from the average temperature. The growing degrees for each day are added together to give accumulated GDD.

GDD = (max. temp. + min. temp.) / 2 - min. temp. for growth

Developmental stage

Developmental stage is more important in timing of management inputs than is calendar time or dry matter accumulation. Physiological processes that determine grain yield occur at fairly well determined growth stages. Correct identification of growth stages is important for making in-season management decisions including irrigation scheduling, in-season fertilizer applications, herbicide and insecticide selection and timing of application, and harvest scheduling. The cereal plant uses water and mineral nutrients from the soil and carbon dioxide from the air to make the products it needs for growth and grain production.

Growth Stages and Management

Nitrogen fertilizer, pesticides, and irrigation must be applied to wheat at certain times to have the most effect. Proper timing for most operations is determined by the growth stage, not by the calendar date. Because growth at any given date can vary from one year to the next, it is important to be able to recognize the different growth stages of wheat.

Growth Stages from Germination through Maturation

The growth and development of winter wheat are divided into stages. Germination leads to seedlings, the first stage of plant growth, followed by tillering, overwintering, jointing, boot, heading, and flowering. Maturation, or development of the grain, is divided into milk, soft dough, hard dough, and physiological maturity, the stage when kernel weight is maximum. Ripening, the last stage occurs as the grain loses moisture until it is ready to harvest.

Germination and Seedling Emergence

Quality seed is essential for establishing a productive stand. Seed should have at least 85 percent germination and should not be shriveled. Large seeds have little, if any, advantage over normal, plump seeds when both are planted at equal volume or weight. A wheat seed begins germination by absorbing water and oxygen. Adequate soil moisture and temperature are needed for this to occur. A firm seedbed assures good contact between the seed and the soil. Inadequate soil moisture is probably the major reason for planting seed deeply. If the soil moisture runs out before the seedlings emerge, as can happen after light rains, survival of the seedlings often depends more on the stage of germination than the length of the dry period. Seedlings from seeds that have germinated for only one or two days can survive desiccation and resume growth when moisture reoccurs, but seedlings that are 4 or 5 days old probably will not tolerate drying. Minimum soil moisture for germination in a silt loam soil is about 8 to 10 percent on a dry weight basis. Seed germination to seminal root emergence requires about 80 growing degree days (GDD. The seminal or seed roots emerge from the seed first. Coleoptile emergence requires 50 GDD, C basis, per 2.5 cm of planting depth after germination. If the coleoptile hasn’t emerged after 150 to 200 GDD, C basis, the field should be examined for crusting and other causes of delayed emergence.

The primary root system supports plant growth until tillering, when the secondary root system becomes the main root system of the plant. The primary roots may persist for the life of the plant and can support some plant growth through the heading stage. The first secondary roots appear at the tillering node about 2.5 cm below the soil line at the two- or three leaf stage. These roots are always produced at about the same distance below the soil's surface, regardless of the depth at which the seed is planted. The secondary root system makes up the major part of the fully developed plant's root system. Root growth may continue at 12.5 mm per day for 60 to 70 days. With no competition, roots may spread 1.2 m horizontally and 1.8 m vertically, with most roots in the top 60 cm of soil. Horizontal root growth is less than 30 cm in wheat fields with normal plant population density. Root development approaches the maximum at about the boot stage. The "boot" represents the swollen flag leaf sheath within which the developing spike is located after being pushed up as the stem has elongated.

As the seedling root system is forming, the coleoptile grows upward and ruptures, allowing the first leaf to begin unfolding as soon as the coleoptile tip breaks the soil surface. Emergence usually occurs 6 to 20 days after sowing, depending on temperature and moisture. Emergence can be later than 20 days after sowing under prolonged cold or dry conditions. Initial formation of leaves and stems occurs at the shoot apex, which is located just below the soil surface.

Seedling Development

The coleoptile ceases elongation when exposed to light. The primary leaf then begins expansion and emerges from the coleoptile. Rate of leaf formation is governed primarily by temperature, and averages 100 GDD, C basis, per leaf. When three leaves are present on the main stem, a tiller forms in the axil of the first leaf. At this time, nodal or adventitious roots form at the base of the main stem in the crown region of the plant. Coleoptile tillers may form from the sub crown internodes region between the seed and crown area of the plant. Moisture deficits reduced average coleoptiles tiller formation. Extremely shallow or deep planting also may prevent formation of coleoptiles tillers. With the development of each leaf after three leaves, primary tillers can form in the axils of the second, third, etc., leaf on the main stem. Primary tillers also can produce secondary tillers after reaching the third leaf stage. As with coleoptile tillers, moisture deficits delayed formation of tillers in the axils of leaves one to three on the main stem. Mixtures of nitrate forms of nitrogen and ammonia favor an increase

Vernalization

Wheat is classified as having either a spring or a winter growth habit. Plants with a winter habit require a period of chilling, or vernalization, to induce the formation of reproductive structures.

Without proper vernalization, winter habit plants either fail to head or head much later than normal. Plants with a spring habit do not require vernalization. To produce heads, germinating winter wheat seeds or seedlings must be exposed to temperatures between 0C and 10 C. The optimum temperature is 3 C. The exposure to cool temperatures must be continuous and not interrupted with warm temperatures. Temperatures above 10 C can stop or reverse the vernalization process. The length of time required for exposure to cool temperatures varies from four to eight weeks.

Overwintering

Decreasing day length and gradually falling temperatures during fall prompt the wheat plant to develop a high level of cold hardiness. Hardiness usually is greatest during early winter and is lost gradually as the season progresses. Most winterkilling occurs during late winter, when warm spells cause the plants to loose hardiness and then are followed by cold fronts that cause the damage. Snow provides excellent protection because it insulates the plants from extreme cold and keeps them from responding to warm spells. The critical plant part is the growing point, which is protected partially by being about 2.5 cm below the soil surface during winter. The entire plant is killed by injury to the growing point, which turns from a white, turgid appearance to a brown, wilted appearance after it is frozen. Leaves often stay green during mild winters, but freezing or “burning” of leaves by cold has little effect on yield.

Winter Hardiness and Cold Tolerance

Winter hardiness is the ability of a plant to survive cold temperatures, desiccation, diseases, insects, water logging, ice encasement, wind abrasion, and other factors under field conditions. Cold tolerance refers only to the ability of a plant to withstand exposure to cold temperatures. Winter damage to wheat is dependent on cold tolerance of the cultivar, temperature level, duration of exposure to temperatures near or below the freezing tolerance of the wheat cultivar, and management. Management factors, particularly planting date, planting depth, seedbed preparation (residue management), and plant nutrition affect level and duration of temperature exposure. Other factors such as soil moisture deficits or excess, plant nutrition, diseases, and insects can affect cold tolerance. Healthy, vigorous plants have a greater ability to withstand winter damage than plants that are stressed.

Early planting and seeding

No-tillage and other practices that conserve surface residue aid survival by reducing soil moisture loss, which reduces plant desiccation, slows cooling of air and soil temperatures near plants, and helps trap snow. Snow cover reduces exposure of wheat plants to lethal temperature. Phosphorus deficiencies and nitrogen excesses reduce winter survival of wheat. Phosphorus may aid recovery in the spring more than increase winter hardiness directly. The soil nitrogen level does not usually affect winter survival unless applied in the seed row at planting time.

Dehardening can occur if water logging occurs or if wheat crown temperatures warm above 9 C Dehardening occurs approximately three times faster than hardening, but frozen and wet soils warm more slowly than air temperatures, giving a buffering effect on rapid dehardening with fluctuating temperatures above 9 C. Prolonged exposure to cold temperatures above the lethal point also reduces hardiness.

Desiccation from wind causing evaporation or plant abrasion adds to the previously described winter stresses. Stubble and snow cover greatly reduce the opportunities for desiccation.

Reproductive Development

Temperature and moisture at planting, and growing degree days after planting, are important variables that influence plant growth and development prior to exposure to cool temperatures for vernalization. Thus, plant size, leaf and tiller number, and general appearance of winter wheat is variable at time of vernalization and subsequent initiation of reproductive development. Formation of spikelet and florets begins at the base of the spike and progresses upward. Once the terminal spikelet has been formed, no further spikelets are possible. Under good conditions, 19 to 20 spikelets will form with an average of three well-developed seeds. Warm temperatures reduce the number of spikelets and florets by speeding up the formation of the terminal spikelet. Late seeding of winter wheat delays the transition from a vegetative to a reproductive phase and thus contributes to reduced yield at this stage of development by reducing potential spikelet and floret numbers. Late seeding also reduces potential tiller numbers. Reduced tiller numbers potentially means fewer heads per plant. The combination of fewer heads per plant and fewer spikelets and florets per head reduces yield potential. Increased seeding rates may partially offset the lack of sufficient tiller numbers in the absence of diseases.

Tillering and Vegetative Growth

Branching is called tillering. Individual branches are called tillers. Two to four primary tillers develop from buds in the crown area of the main stem. Secondary tillers develop from buds in the axils of leaves at the base of the primary tillers. Tertiary tillers may develop from buds in the axils of leaves at the base of the secondary tillers. Each plant has the potential to produce more than 50 tillers. Usually only two to four tillers survive to produce fertile spikes at normal seeding rates and growing conditions. The number of tillers that form is influenced by plant density (more with low plant density), soil moisture and nutrient supply (more with high supply), sowing date (more with early sowing), temperature (more under cooler temperatures), and cultivar. Water stress, nutrient deficiency, low temperatures, weed competition, and pest damage during early development reduce the number of tillers. The emergence of primary tillers is synchronous with the emergence of leaves on the main stem of the plant. The first primary tiller begins developing as leaf 4 of the main stem emerges; the second primary tiller begins developing as leaf 5 emerges. Subsequent primary tillers begin developing when subsequent leaves emerge. Successive tillers develop fewer leaves; flowering and grain development is only slightly delayed on later developing tillers. Before the main stem and tillers begin to elongate, the spikes differentiate.

The main stem and first-formed tillers contribute the most to yield because of higher spikelet and kernel numbers per head. Additionally, kernel weights are usually higher on the main stem and first formed tillers because maturation of the kernels occurs with more favorable temperature and moisture supply. The number of tillers is determined by the seeding rate, soil moisture and fertility, temperature, and variety. A winter wheat plant grown under usual conditions will have three to six tillers. Tillers develop soon after the seedling emerges from the soil and have all the other growth stages of the main stem. Tillering can be encouraged by planting early; fertilizing with nitrogen; and, where possible, irrigating if soil moisture is low. Late planting is particularly disadvantageous because it reduces tillering and must be compensated by higher seeding rates. Tillers are formed only during the fall but make most of their growth in the following spring. Warming temperatures in late winter cause wheat to “green up” and resume growth. Tillers that were initiated in the previous fall grow rapidly and change back from the prostrate form to an upright form as the sheaths, the parts of the leaves that cover the stems, become longer. Nitrogen fertilizer should be top dressed at this time to stimulate growth of the tillers, which will produce most of the grain at harvest. The growing points are still at their protected underground position at this stage, but drought and other stresses may restrict growth of the tillers. Herbicides stop development of the tillers and should not be applied at this stage.

Jointing

The development of nodes and internodes that form the stem of the wheat plant begins when growth of the tillers is complete. This phase marks the change from vegetative growth to reproductive growth and is important for several reasons. Growth of the internodes pushes the growing point above the soil. The elevated position of the growing point along with the gradual loss of winter hardiness also makes the plants increasingly susceptible to late frosts. The growing point is the most susceptible of all plant parts to frost at this stage. The change from vegetative to reproductive growth also is when the maximum number of kernels that will be formed in the head (spike) is determined, causing the yield at harvest to be susceptible to stress at this stage. Jointing does not occur until the plants have been exposed to winter temperatures and begin spring growth.

Exposure to low winter temperatures is necessary to induce jointing in winter wheat; without it, the plants would continue to produce more leaves. With the formation of the spike and subsequent stem extension, tillering ceases. By the time the plant has reached the boot stage, all of the potential heads and sites for spikelet's and florets have been developed.

Heading and Flowering

At the heading stage, the spike emerges from the boot. Within 1 to 7 days after heading, the flowering stage and pollination occur, and the grain begins filling. Wheat is classified as a long-day plant because it will flower only when days are long and nights, the important times, are short. Wheat is a self-pollinated crop. Pollination usually occurs by the time anthers have emerged. Flowering usually begins in the center of the spike and progresses toward the ends and occurs 1 or 2 days earlier on the main stem than on the tillers. Appearance of the yellow anthers outside of the florets marks the completion of flowering. The actual number of kernels that will form in the spike is determined at this stage. These stages of plant development are particularly sensitive to moisture stress, frosts, and high temperatures. Plants that reach these stages during the hottest portion of the year because of late seeding are susceptible to heat and moisture stress and reduction of pollination and fertilization. Reduced pollination and fertilization decreases potential kernel number per head and yield. Photosynthesis often exceeds demand at these stages because stem extension and leaf expansion is complete and kernel fill has not yet begun. Excess carbohydrate can be stored in the peduncle and second internode at this time. This carbon is later used as a source for kernel fill.

Kernel Development, Filling and Yield

Kernel development includes five stages: watery, milky, soft dough, hard dough, and mature. Current photosynthesis from the flag leaf, awns, and youngest leaf blades and sheaths provide 70 to 80 percent or more of the carbohydrates needed for kernel fill under good conditions of soil moisture and moderate temperatures. If soil moisture is inadequate or if temperature and wind combinations cause temporary wilting or water deficits, photosynthesis is reduced. Temperatures above 32 C also reduce photosynthesis. If current photosynthesis cannot supply the kernel demands for carbohydrate, stored carbon can be remobilized from the peduncle, second inter node, lower leaves and stems, and senescing tillers. Stored carbohydrates from the peduncle and second inter node can contribute 10 to 20 percent of the needed carbon for kernel fill under good conditions. Dry matter begins accumulating in the kernel during the milk stage. During early milk stage, a clear fluid can be squeezed from the kernel. During late milk stage, milky fluid can be squeezed from the kernel. Most of the dry matter accumulates during the soft dough stage. Loss of water gives the kernel a doughy or mealy consistency. At the end of the hard dough stage the kernel reaches physiological maturity, water content drops to about 30 percent, and the plant loses most of its green color. The kernel contents can be divided with a thumbnail. At the hard kernel stage the plant is completely yellow and water content of the kernel is 20 to 25 percent. The contents of the kernel are difficult to divide with a thumbnail, but its surface can be dented. When kernel moisture content has dropped to 13 to 14 percent, the grain is harvest ripe. The surface of the kernel cannot be dented with a thumbnail.

The final yield component, kernel weight, is determined during maturation. Yields are high when favorable filling conditions, mild temperatures, and active leave promote growth of large, plump kernels. High temperatures, especially when accompanied by winds, and foliar diseases such as leaf rust cause shriveled kernels, low test weights, and low yields. Grain must be harvested promptly after ripening to save the yield. Hail, lodging, and pre harvest sprouting are ever-present threats to ripe grain.

Yield Components

Wheat yield is the product of plant density, tiller number, number of spikes per plant, number of spikelets per spike, number of kernels per spikelet, and kernel weight. Plant density is determined by seeding rate, germination percentage, and the number of seedlings that emerge and survive. Tiller number per plant depends on plant density, cultivar, sowing date, availability of moisture and nutrients, and temperature. The number of spikelets that can form is determined by when stem elongation is initiated; stress (weed competition, heat, cold, drought, nutrient deficiency, diseases) during this period reduces the number of spikelets that are formed. Florets are initiated during the stem elongation stage. The Wheat plant is not able to produce enough photosynthate to allow development of all florets. The fastest growing florets have first access to the available carbohydrate, nitrogen, and other nutrients and are the most likely to produce mature seed. Good growing conditions during stem elongation favor development of the maximum number of florets. The cells of the endosperm accumulate starch and protein during grain filling. Any stress or damage that reduces photosynthetic output or interferes with the transport of carbohydrate between flowering and hard dough stage will reduce kernel weight.

Wheat Seed

Wheat Varieties

Choosing a variety is one of the most important management decisions made by farmers. Roughly half increase in yield can be achieved due to improved varieties with the remaining half due to improved management. The proper choice results in the most cost-effective means of addressing major disease problems. No one variety has the best traits for all production areas or conditions.

Seed quality

Seed quality is the foundation for obtaining excellent germination and stand establishment. Every effort should be made to obtain the best seed available. Good quality seed is true to variety and relatively free from crop mixture, weeds, and diseases. It has plump kernels of high germination and vigor. Seed size is one of the most important characteristics in determination of wheat seed quality. Large, dense kernels are considered to be of better quality than low test weight kernels. Large seed tends to tiller more than small seed. However, small, dense kernels are better than large, light kernels. Test weight and protein per seed are also important characteristics. The amount of protein, not protein percentage, in the seed is very important to early seedling vigor. Large seed may have a lower protein percentage than small, shriveled seed, but because it is larger it will have more total protein per seed. Buying certified seed is the best way to ensure that one is getting good seed quality with minimal contamination from varietal impurities, weed seed, and other crop mixtures.

Sowing

Seed bed Preparation

Seedbed conditions that promote rapid germination and uniform emergence are desirable for winter wheat production. Seedbed preparation varies depending on residue of the preceding crop, the need for moisture conservation. Soil type and previous cropping pattern dictate the amount of tillage necessary to prepare the seedbed. Regardless of tillage system, wheat requires a seedbed that maximizes contact between the seed and surrounding soil. Good seed-soil contact maximizes rapid seed germination and promotes uniform, rapid emergence. Overworking a seedbed depletes soil moisture and promotes soil crusting. One of the goals of seedbed preparation should be maintaining moderate amounts of residue on the soil surface. A field with a large amount of residue from the previous crop, such as a crop produced on irrigated soil, requires deep plowing or deep tillage to help decompose the residue and to keep the surface soil free of debris. Soil should be plowed or disked as deeply as possible to help break up compaction and reduce the risk of herbicide carryover. Deep plowing, or at least two diskings, may be necessary. Disking and harrowing follow plowing or chiseling to complete seedbed preparation. Soils should not be tilled when wet since this contributes to soil compaction, large clods, and other physical conditions unfavorable for growth.

Maintaining crop residues on the soil surface has the following advantages:

- reduced soil erosion from wind and water
- increased moisture penetration
- increased uniformity of soil moisture across the field

- reduced evaporation from the soil surface
- trapping of snow and less damage from drifting snow
- cooler soil temperatures at seeding time

Seeding Dates

Choosing the correct sowing date can reduce the likelihood of damage by frost and certain diseases, make weeds easier to control, and increase yield. Improper seeding dates, either early or late, have many adverse consequences. Planting too early can cause excessive large plants resulting in depletion of valuable soil moisture for early spring growth, increases the risk of frost injury and also exposes the plants to several potential disease and insect problems. Planting later than optimum often causes limited fall growth, both root and tiller formation and subjects the wheat to wind damage and increased potential for winterkill damage. Optimum seeding dates encourage uniform and high seed germination, strong plants, and a vigorous root system. A good plant density for an irrigated field averages about 270 plants per square meter. Consider replanting if the stand is less than half of that density.

If soil type and weather permit, field preparation should be delayed until fall rains stimulate weed seed germination so that weed seedlings can be destroyed before or during sowing. Sowing should not be delayed too long, Late-sown grain produces fewer tillers and shorter plants; it is also likely to be damaged by barley yellow dwarf virus.

Altering planting dates primarily to control a disease or pest should be considered only if there is no other acceptable method of control of the disease or pest. A good goal would be to have five to six main stem leaves developed prior to winter. A plant of this size should also have two to three developed tillers and would require approximately 1080 to 1260 growing degree days. Planting dates would have to be adjusted based on their average temperatures. Seeding date affects heading date the following spring and consequently the time that grain fill occurs. In general, for every three to four days of delay in seeding date during the normal seeding time, heading date will be delayed by one day. This delay decreases with earlier seeding and increases as seeding date is delayed past the optimum time.

Sowing Date

If soil type and weather permit, field preparation should be delayed until fall rains stimulate weed seed germination so that weed seedlings can be destroyed before or during sowing. Sowing should not be delayed too long,

Replanting is necessary if stand establishment is poor. A good plant density for an irrigated field averages about 270 plants per square meter. Consider replanting if the stand is less than half of that density.

Seeding Rates

Seeding rates vary like seeding dates because of environmental conditions. Winter wheat should be seeded at rates of pure live seed (PLS) per hectare, depending on variety, seed size, soil moisture, and seeding date. This number corresponds to approximately 36 to 66 seeds per square meter. Actual seeding rates on a PLS basis are calculated by dividing the desired seeding rate by the percentage of pure, live seed in a seed lot as determined from standard germination and purity tests.

Seeding rates that are too high result in excessive vegetative growth, which uses valuable soil moisture and reduces grain yields. Seeding rates that are too low tiller more than with higher seeding rates but produce reduced yields and may result in higher weed pressure due to lack of crop competition.

The optimal seeding rate is determined by sowing method and growing conditions. It ranges from about 2.5 million per ha, for rainfed crops to 3.0 to 3.7 million seeds per ha for irrigated crops.

Higher rates are used for broadcast sowing since a smaller proportion of broadcast seed emerges. Higher rates and narrower row spacing are recommended for late sowing to compensate for the fewer tillers that will form and because higher sowing densities tend to shorten the time to flowering. Higher rates are also recommended if poor growing conditions (e.g., competition from weeds) are anticipated. Lower seeding rates can help avoid lodging.

Seeding Depth

Best germination and emergence of winter wheat occurs from seeding depths of 2.5 to 4 cm. Seeding less deep can be done if soil moisture is adequate at the soil surface and good seed-soil contact can be achieved. The main threat from shallow seeding is that the seed-row may become too dry before the seed can germinate and send roots into deeper moist soil. Planting at deeper depths results in reduced stands. Deeper seeding also alters plant morphology and development and results in lower yields. Plants emerging from deeper depths require more water, more time, and face greater risks from soil crusting. Available soil moisture is the single most important factor in determination of proper seeding depth but soil temperature, texture, surface conditions, and variety should also be considered.

Row Spacing and Direction

The type of planting equipment used and consequent row spacing is largely determined by soil moisture, seed-bed conditions, and anticipated precipitation potential. Generally, narrower row widths with proper seed placement and depth give higher yields when moisture is adequate. Striving for narrow rows in moisture-stressed environments is generally not practical.

Drilling Versus Broadcast Seeding

Most sowings on irrigated soils are drilled. The advantages of drilling over broadcasting include a more uniform depth, some reduction (up to 20%) of seeding rate, more uniform emergence, and the ability to place a starter fertilizer (a low-nitrogen, high-phosphorus fertilizer) with the seed. The advantage of broadcast seeding is that it permits large acreages to be sown in less time; the disadvantages are poor soil to seed contact, uneven planting depths (some seed too shallow for proper emergence of permanent root systems, and other seed too deep for germination), and, often, poor plant distribution. Broadcast seeding is successful when soil conditions are optimal, the seedbed is prepared properly, and rainfall or irrigation follows broadcasting and harrowing.

Residue Management

Residue management, through conservation tillage, is an effective tool for reducing soil erosion. The percentage of the soil surface covered with residue is important in determining how much erosion will occur from rainfall runoff. Crop residue shields the soil surface from the rainfall impact, thus reducing the amount of particle detachment. Residue also reduces the amount of crusting, which allows more water to soak into the soil.

Minimum-Till and No-Till

Minimum-till and no-till seedbed preparation can be very beneficial in rainfed cropping systems because the crop residue that remains on the soil surface helps retain moisture and prevent soil erosion. In addition, reduced tillage systems generally have lower input costs than conventional systems. Seedbed preparation usually consists of applying chemical weed control if weeds are present and drilling seed directly through the residue of the previous crop. The amount of disking and harrowing needed to bury surface crop debris, kill emerging weeds, and incorporate seed or fertilizer is limited. Straw and chaff must be thoroughly chopped and spread during harvest of the previous crop in order for sowing to be successful. Also, care must be taken in setting up sowing equipment so that the drill is able to cut through surface residue.

Mulching

Mulch may be used in irrigated production. Fields are prepared, leveled, fertilized, and irrigated approximately 2 to 4 weeks before sowing to allow enough time for the fields to dry sufficiently for mulching and seeding. A mulch layer of dry soil 5 to 7.5 cm thick is created and seed is drilled into the moist soil beneath the mulch layer. This system of mulching can provide excellent weed control.

Irrigation Management

Wheat can develop an extension root system with penetration to 2 meters under favorable conditions. Most of this growth occurs in the spring during the rapid growth period after breaking of dormancy. A normal root extraction pattern is to have about 70 percent of water extraction occur in the upper one-half of the root zone.

After planting and emergence in the fall, water use increases as wheat establishes itself until temperature forces it into dormancy. Water use begins in the spring with rapid water use increase corresponding to the rapid period of growth between breaking from dormancy until heading. Boot to heading may be the critical stage of growth for wheat, although wheat is tolerant of water stress throughout its life cycles. Water use rates drop off rapidly after grain development.

Sowing and Seedling Emergence

Irrigation may be required at the onset of the growing season if residual soil moisture from the previous crop and rainfall are insufficient for germination and establishment. A farmer must decide whether to pre irrigate and then sow the seed into moist soil, to sow the seed and irrigate to germinate the seed, or to sow the seed into dry soil and rely on rainfall for germination. Timely pre irrigation during warm, dry weather provides soil moisture for rapid seedling emergence and growth. However, pre irrigation followed by extensive rainfall can result in inefficient water use, less efficient nitrogen uptake. If extensive rainfall follows pre irrigation, soils may become waterlogged and anaerobic and in turn reduce seedling establishment.

Moisture Stress at Vegetative Growth Stages

Early moisture stress may cause the crop to head about 7 to 10 days prematurely; the shortened growth period can reduce yield. Plants tend to increase tillering under early moisture stress, but many tillers die without producing grain-bearing heads. If severe moisture stress occurs during the initiation of tillers, those tillers never develop and plants may produce only the main stem (i.e., one head per plant). The spike that emerges from each tiller is formed during the tillering stage, and by the time the fifth vegetative leaf is visible on each stem, the potential number of spikelet's that can grow into mature kernels has been determined. Plants at this stage are sensitive to moisture stress. If moisture stress develops after these parts have formed but before development of the parts is complete. As a rule of thumb, the most recently formed tillers, spikelet's, or florets are sacrificed first. Wheat is also sensitive to moisture stress at the boot stage.

Moisture Stress at Reproductive Growth Stages

Moisture stress during pollination results in underdeveloped kernels or sterility. The milk stage of kernel development is not as sensitive as the pollination stage, but severe moisture stress should be avoided. Moisture stress during the soft dough stage may result in smaller or shriveled kernels. Adequate moisture extends the grain development period and results in higher grain yields and kernel weights. The kernels begin to dry by the time plants reach the soft dough stage. The hard dough stage signifies the end of grain filling. Plants reach physiological maturity at the end of the hard dough stage. Accurately anticipating this stage of development is important for determining irrigation cutoff and minimizing irrigation costs without compromising yield.

Recognizing Symptoms of Moisture Stress

Early symptoms of moisture stress include dark blue-green leaf color, wrinkled leaf margins, and slight rolling or cupping of leaves. More severe symptoms include a deep blue-green canopy, dead tissue along leaf margins, obvious leaf rolling, shortened and spindly stems, and small immature heads. By the time symptoms of severe moisture stress are apparent, the adverse effect on production is irreparable. Moisture-stressed plants are more susceptible to common root rot and damage by Russian wheat aphid and green bug. Irrigation before critical growth stages assures that moisture is present when plants reach those critical periods. Checking soil moisture at different depths and different growth stages and knowing crop water needs at critical growth stages are important to avoid yield loss.

Timing the First Irrigation

The first irrigation may have to be applied before or near the time of sowing to ensure timely seed germination and stand establishment. If rainfall is relied upon for germination, the first crop irrigation can be delayed. Timing largely depends on seasonal rainfall patterns and amounts. Once the rainfall season has ended, stored soil moisture will provide the water for crop consumption until the reserve is depleted. How long this reserve will sustain crop growth before irrigation is needed depends on soil texture and root zone depth. The first post emergence irrigation is needed after about 40 to 50 percent of the stored soil moisture in the crop root zone is consumed.

Determining Irrigation Frequency after the First Irrigation

The wheat root system usually is near full development by about 60 to 70 days after germination, and it reaches maximum development at about boot stage. Only one irrigation is normally needed during that period. Once the root zone is fully developed, the interval between irrigations is fairly consistent up to irrigation cutoff.

Lodging

Lodging in winter wheat may cause serious losses in productivity, grain quality, and harvest efficiency. Lodging increases at higher production levels. Winter wheat lodging can be physiological (inadequate straw strength) or due to foot rot. Lodging can be reduced with many management practices.

Losses Due to Lodging

Reductions in winter wheat grain yield and quality due to lodging depend on lodging extent, timing, and severity. The earlier lodging occurs, the greater the potential for damage. Early lodging can trap moisture in the plant canopy that can increase foliar disease. Early lodging also allows weeds more competitive space in the interrupted crop canopy. The greatest losses with early lodging are due to decreased photosynthesis prior to physiological maturity and decreased grain filling. Additional crop loss from both early and later lodging comes from delayed drying and increased losses associated with crop harvest. Harvest losses include the inability to pick up or recover all the grain from the matted wheat. More grain is lost during threshing because more and often wetter plant material is picked up and processed by the combine. When the crop is lodged but physiologically mature, moisture from rain or dew stays on the grain longer and increases the potential for grain sprout, mold, and kernel discoloration.

Lodging Contributing Factors

Lodging occurs when the plant stem is unable to support its own weight. Susceptibility to lodging limits the ability of a variety to utilize or respond to management factors such as fertility and irrigation. Lodging susceptibility can be an important variety selection criterion. Disease-caused lodging creates a mat that is very close to the ground from which the plants cannot straighten. Physiological lodging tends to be more orderly, with plants lodging or leaning in one direction and usually not bending over as near to the ground. The upper stems and heads of lodged wheat can become more upright after physiological lodging if plant stems are not broken. High levels of soil nitrogen and other nutrients can make winter wheat more prone to physiological lodging. Excessive available N early in the season promotes vegetative growth and increases lodging potential. High seeding rates can also increase lodging potential because crowded plants produce more fine-stemmed tillers and taller growth. Improper irrigation timing can cause lodging, especially when plants are past the soft dough stage. Lodging often occurs when sprinkler irrigation or rainfall adds additional weight to the plants and wind then bends the plants over. Severe weather, such as a thunderstorm, can cause lodging even under the best crop management conditions.

Lodging Control

Several crop management practices can reduce lodging of winter wheat:

- Select varieties with better resistance to lodging as long as yield potential and quality are not sacrificed
- Apply nitrogen at recommended rates and intervals to avoid excessive vegetative growth
- Avoid excessive seeding rates that result in weakened stems

- Control diseases by crop rotation

Soil Temperature

Winter wheat undergoes two important physiological changes in the fall. The processes that bring about these changes are known as vernalization and cold acclimation. Vernalization is required before heading will take place the next summer. If seeding takes place after the optimum date, vernalization will be affected and maturity delayed Cold acclimation is necessary before plants can survive the low temperatures of winter. Vernalization and cold acclimation require growth when minimum morning and maximum afternoon soil temperatures are below 7 and 10°C, respectively.

Four to five weeks growth at temperatures higher than those required for vernalization and cold acclimation is necessary to ensure that plants have sufficient energy reserves available for a quick start in the spring. Seeding when maximum afternoon soil temperature is approximately 18°C usually allows sufficient time for this growth and development to take place before freezeup. Seeding later, when temperatures are lower, will result in delayed germination, slow plant emergence and a reduced rate of subsequent plant growth. This usually translates into a higher risk of winterkill, lower yield, and delayed maturity.

Soil Moisture

The minimum soil moisture required for germination of wheat is quite low. In fact, germination has been observed in soils where the moisture level has been less than the permanent wilting point (soil moisture so low that established plants wilt and do not recover under humid conditions at night). It is usually advisable to seed at the optimum date as estimated by soil temperature unless the soil is extremely dry. Under dry conditions it is important to ensure that the seeding operation leaves the seed covered with well-packed soil. Loose soil fill is subject to greater drying, and seeds that are not covered will often fail to germinate even when moisture conditions are favorable.

Freeze Injury to Wheat

Low temperature injury during winter and spring are destructive. Wheat has little resistance to low temperatures after it begins rapid growth in the spring.

Winter Injury

Low temperatures kill winter wheat plants by injuring the crown. The hardening process is the key to a plant's ability to withstand low temperatures. When adequately hardened, crowns can tolerate temperatures down to -48° to -52° C. Plants in the three leaf to four leaf stage with good root systems are in the best position to survive the winter. Plants that develop numerous tillers because of early seeding remain more vulnerable to low temperatures than those seeded later. Larger plants are more subject to desiccation due to cold, dry winds or an open winter with a lack of adequate snow cover. Good stands and dense canopies provide insulation from cold temperatures so the temperatures in the winter canopy can be much higher than the air temperature. Also, moist soil cools off much slower than dry soil. Plants killed by low temperatures normally will fail to green up in the spring and will have a bleached tan color. Typically, these symptoms will be most apparent on exposed ridges. Wheat that has suffered winter injury will often green up in the spring only to decline and eventually die. The crown tissue of plants suffering from winter injury will be soft, brown and mushy. Secondary roots will be rotted off. Healthy plants have firm, pale green crowns and white roots.

When and Where Spring Freeze Injury Occurs

Spring freeze occurs whenever low temperatures coincide with sensitive plant growth stages. Injury can cover large areas or only a few fields or parts of fields. It is often more severe along river bottoms, valleys and depressions in fields where cold air settles. Early maturing wheat is more likely to be injured by freezes than late maturing wheat because of its advanced growth. Susceptibility to freezing temperatures steadily increases as maturity of wheat advances during spring. When growing conditions are favorable and available soil nitrogen is high, wheat may be less sensitive to freeze injury because of its lush growth and high moisture content. Conversely, drought stress and poor canopy subjects the plants to cold and increases the severity of freeze injury. Ample soil moisture, cool temperatures, and high soil fertility slow plant maturity, so injury is less severe than in plants that have had less favorable growing conditions and are at a more advanced growth stage when freezing occurs.

Temperatures Causing Spring Freeze Injury

Winter wheat goes through a complex process of cold hardening during fall that increases its resistance to cold winter temperatures. Its cold hardiness is quickly lost when growth resumes during spring, leaving little resistance to freezing.

Wheat is most sensitive to freeze injury during the reproductive period, which begins with pollination during late boot or heading stages. Temperatures that are only slightly below freezing can severely injure wheat at these stages and greatly reduce yields.

The degree of injury to wheat from spring freezes is influenced by both low temperature and the duration of low temperatures. Prolonged exposure to freezing causes much more injury than brief exposure to the same temperature. The many factors influencing freeze injury to wheat plant growth stage, plant moisture content, and duration of exposure make it difficult to predict the extent of the injury. This is complicated further by differences in elevation and topography among wheat fields.

Symptoms of Spring Freeze Injury

Knowing the symptoms of freeze injury and doing an early injury assessment can improve earlier management decisions. Waiting until harvest to learn that wheat has been damaged by freezing decreases the value of the damaged crop for some uses and limits management choices. Assessment of freeze injury is aided by several characteristic symptoms that develop at each growth stage. Cold temperatures after spring freezes might delay development of injury symptoms, but injury to vital plant parts can be detected by careful examination. It is important to know which plant parts are most vulnerable at each growth stage, where they are located on the plant, and their normal appearance as well as their appearance after injury.

Management of critical stages of winter wheat

Pre-planting decisions:

- Choose well adapted disease resistant varieties
- Plant after the fly free dates in your area to prevent Hessian fly problems
- Fertilize and lime according to soil test recommendations
- Practice crop rotation

Emergence to growth stage 2 (fall of year, prior to dormancy)

Disease: Powdery mildew

Damaging & monitoring stage: all

Sampling method: Sample 5 locations in the field, 1 meter of row

Sampling frequency: Once per season, 5 - 6 weeks after planting

Threshold: If present, scout for pm in spring

Pest; Aphids

Sampling method: Sample 5 locations in the field, 1 meter of row

Threshold: If present, scout for in spring

Notes: Green bug slightly more damaging than other species of aphids

Early spring

Weed: Wild Garlic

Sampling: Examine10 sites 3 m. x 15 m. Count # of garlic plants or clumps

Threshold: 1 clump per 50 sq. m.

Weed: Annual Ryegrass

Sampling; Count the number of plants in 1 sq. meter in 10 sites throughout the field.

Threshold: 10-20 plants per sq. m.

Weed: Winter Annuals

Sampling: Estimate % of ground covered by winter annuals. Rate infestation as follows:

Few<10% ground cover

Light<20% ground cover

Moderate<40% ground cover

Heavy<60% ground cover

Severe>60% ground cover

Green-up to dough stage

Weeds: Wild Onion, Wild Garlic, Canada Thistle, Rough, Blue Grass (RBG)

Sampling method; Map locations of these weeds

Sampling frequency; weekly

Threshold; > few: treat, Canada Thistle - spot treat. RBG - awareness essential due to competitiveness of weed

Pest; Wireworms

Damaging & monitoring stage; Larval

Sampling method; Look for individual tillers turning yellow and dying

Sampling frequency; Weekly from green up to boot stage

Threshold; No threshold for current crop, but serves as indicator for action with next crop

Notes; If > 3% of tillers shows wireworm damage, then the field should be baited before planting wheat again or rotate out of wheat for a period of 3 years

Disease; Powdery Mildew

Sampling method; Sample up to boot stage.5 locations, 1 linear meter of row

Sampling frequency; weekly from green up to boot stage

Threshold; 10% of last fully expanded leaf infected. After boot stage, PM does not warrant treatment

Notes; Using resistant varieties eliminate the need for scouting for this disease

Pest; Aphids

Damaging & monitoring stage; all

Threshold; If present, note for possible treatment at flowering

Pest; Cereal Leaf Beetle

Damaging & monitoring stage; Larval

Sampling method; Sample 5 locations, 1 linear meter.

Sampling frequency; Weekly

Threshold; 1/2 larva per stem or > 25 eggs or small larvae/100 tillers

Six Inch High Plants

Weeds; Zero tolerance weeds: Wild Garlic, Mugwort, Jerusalem Artichoke, Yellow Nutsedge, Quackgrass, Milkweed, Hemp Dogbane, Horsenettle, Canada Thistle

Sampling method; Sample five 1 square meter areas in the field. Count number of weeds. Record plant species. Note zero tolerance weeds. Map perennial weeds.

Sampling frequency; one time evaluation

Threshold; Winter Annuals: 1 weed/square meter; Zero tolerance weeds: ¼ weed/square meter

Notes; Treatment timing is critical due to label restrictions for some herbicides

Boot Stage to Hard Dough

Pest; Aphids

Damaging & monitoring stage; all

Sampling method; Sample 5 locations, 1 linear meter of row from flowering to soft dough

Sampling frequency; weekly

Threshold; 25 aphids/head green bug: 20 aphids/head

Notes; 4 species of aphids affect wheat; green bug more damaging; thus lower thresholds

Pest; Army worm

Damaging & monitoring stage; larval

Sampling method; Sample 5 locations, 3 linear feet of row. Look for leaf feeding. If evident, examine plants and look under debris on soil surface.

Sampling frequency; weekly

Threshold; Small larvae: 6 armyworms per linear row meter OR 12 per square meter. If head clipping is evident, treatment is recommended.

Notes; Armyworms will hide under debris on soil surface. Treatment should be applied when larvae are small; large larvae are difficult to control. If birds are observed feeding in the wheat, investigation for armyworm is warranted.

Pre-heading Stage

Disease; Powdery Mildew

Sampling; Examine 10 plants in 10 sites looking for powdery white mold growth on leaf surfaces. Determine the % of plants infected (incidence) and the % of leaf area infested (severity)

Frequency; Weekly starting at jointing stage

Threshold; 5-10% of upper leaf area infested

Notes; Favorable conditions for powdery mildew development: temperatures 60-75oF, and periods of high relative humidity

Disease; Septoria Leaf & Glume Blotch

Sampling; Examine 10 plants in 10 sites.. Record the # of indicator leaves with 1 or more leaf & glume blotch lesions.

Frequency; Weekly starting at jointing stage

Threshold; 25 of 100 indicator leaves with 1 or more lesions

Pest; Aphids

Damaging & monitoring stage; all

Sampling method; Examine 1 meter. of row in 10 sites throughout the field. Count # of aphids per meter of row; note # of aphid predators & parasitized aphid mummies

Sampling frequency; weekly

Threshold; 450 aphids per linear meter of row

Notes; Aphid feeding causes discoloration on the leaves. Extensive feeding can result in circular yellow to brown spots with dead plants in the center. Natural enemies usually control aphids. The green bug aphid is more destructive than other aphids due to the injection of a toxic substance during feeding.

Pest; Cereal Leaf Beetle

Damaging & monitoring stage; Adult; larval

Sampling method; Examine 10 plants in 10 sites. Record # of affected larvae per stem

Sampling frequency; Weekly from April through June (until hard dough stage)

Threshold; 0.5% beetles per stem and 10-20% defoliation

Notes; Adults & larvae feed on the upper surface of leaves. Adult beetles chew completely through the leaf leaving long skinny holes. The larvae only eat the surface tissue leaving the translucent lower cuticle intact. Larvae cause the most feeding damage and are sometimes heavily parasitized. Once wheat reaches the hard dough stage, beetle feeding has little effect on yield

Heading Stage;

Disease; Powdery Mildew

Sampling; Examine 10 plants in 10 sites to determine the % of plants infected (incidence) and the % of leaf area infested (severity).

Frequency; weekly starting at jointing stage

Threshold; 5-10% of upper leaf area infested

Notes; Favorable conditions for powdery mildew development: temperatures 15-24 C, and periods of high relative humidity.

Disease; Leaf Rust

Sampling; Examine 10 plants in 10 sites to determine the % of plants infected (incidence) and the % of leaf area infested (severity).

Frequency; weekly starting at jointing stage

Threshold; 1-3% of upper leaf area infested

Notes; Favorable conditions for disease development: temperatures 60-85oF, free moisture from showers, dew can be found on the leaves from early evening to late morning.

Disease; Septoria Leaf & Glume Blotch

Sampling; Examine 10 plants in 10 sites

Frequency; weekly starting at jointing stage

Threshold; 25 of 100 indicator leaves with 1 or more lesions

Notes; Septoria development favored by wind driven rain, high relative humidity & temperatures between 20-28 C

Pest; Aphids

Damaging & monitoring stage; all

Sampling method; Examine 10 heads in 10 sites for presence of aphids. Record # of aphids/head. Note # of aphid predators & parasitized aphid mummies

Sampling frequency; Weekly

Threshold; 25 per head

Notes; Feeding on the heads by large numbers of aphids can cause the growing kernels to shrivel.

Pest; Cereal Leaf Beetle

Damaging & monitoring stage; Adult, larval

Sampling method; Examine 10 plants in 10 sites. Record # of larvae per stem

Sampling frequency; Weekly

Threshold; 0.5% beetles per stem and 10-20% defoliation

Notes; Adults & larvae feed on the upper surface of leaves. Adult beetles chew completely through the leaf leaving long skinny holes. The larvae only eat the surface tissue leaving the translucent lower cuticle intact. Larvae cause the most feeding damage & sometimes are heavily parasitized. Once wheat reaches hard dough stage, beetle feeding has little effect on yield.

Pest; Grass Sawfly

Damaging & monitoring stage; larval

Sampling method; Examine 1 linear row meter. in 10 sites throughout the field. Shake the plants & look at the ground between the rows. Count # of larvae. Record # of larvae per ft. & the average size of larvae. Note # of clipped heads.

Sampling frequency; Weekly

Threshold; 1.2 sawfly larvae per linear row meter. If armyworms are present, reduce threshold of both by 1/2

Notes; Sawflies prefer to feed on stems which results in grain head being clipped off. Sawflies are easily distinguished from armyworms by the solid green body, amber head (with brown band on older larvae) and 8 pairs of pro legs. Detection of sawflies when they are still small and easy to control is critical.

Pest; Army worm

Damaging & monitoring stage; larval

Sampling method; Examine 5 linear row meter. in 10 sites throughout the field. Shake the plants & look at the ground between the rows & count # of larvae.

Sampling frequency; Weekly

Threshold; 6 per linear row meter. If sawflies are present, reduce threshold of both by 1/2.

Notes; Small armyworm larvae feed on the leaves of wheat plants, causing little damage. As the wheat matures and starts to dry up, armyworms feed on upper stems and heads and can clip heads. Unlike sawflies, armyworms are striped with only 5 pairs of prolegs. Frass (fecal droppings) may be seen on the soil surface indicating the presence of larval feeding.

Integrated Weed Management in Winter Wheat

Definition of Weed

Technical point of view

Technically speaking weed is a plant which grows out of its proper place i.e maize plant in cotton or barley plant in wheat.

Agronomical point of view

Weeds are those plants which are harmful to the crop plants by sharing for light, moisture, nutrients etc and troublesome in agricultural operations.

Adverse effects of weeds

1. Shelter to insects and diseases
2. Compete with the crop plants for light, moisture and nutrients
3. Troublesome in tilth operations
4. Decrease quality of crop
5. Decrease efficiency of water channel
6. Loss of water by transpiration
7. Render the land unfit for cultivation
8. Increase cost of production

Important weeds of wheat crop

Sr.#	Technical name	English name
Narrow leaf weeds		
1.	*Phalaris minor*	Birds seed grass
2.	*Avena fatua*	Wild oat

Broad leaf weeds		
1.	*Carthamus oxyacantha*	Wild safflower
2.	*Chenopodium album*	Lamb's quarter
3.	*Chenopodium murale*	Fat hen
4.	*Cirsium arvensis*	Creeping thistle
5.	*Cnvolvulus arvensis*	Field bindweed
6.	*Coronopus didymus*	Swine cress
7.	*Cynodon dactylon*	Bermuda grass
8.	*Cyprus rotundus*	Purple nustsedge
9.	*Euphorbia helioscopia*	Sum sperge
10.	*Fumaria indica*	Fumitory
11.	*Lathyrus aphaca*	Crow pea
12.	*Medicago denticulate*	Bur clover
13.	*Melilotus indica*	Sweet clover
14.	*Anagallis arvensis*	Blue pimpernal
15.	*Rumax dentatus*	Broad leaved dock

Solution lies in integrated weed management

Weed management strategies

- Identify weed, life cycle, habitat

Integrated weed management

- *Preventive*
- *Physical*
- *Cultural*
- *Biological*
- *Chemical*

Preventive Weed Control

- prevent the introduction
- plant clean seed-seed laws help w/ noxious weeds
- feed clean feed, cautiously move animals from field to field
- clean equipment – harvest and tillage
- prevent the establishment
- prevent the spread

Cultural Weed Control

It is just practicing good production practices.

- fertility and soil pH adjustment practices
- row spacing and plant density
- dates of planting
- variety or cultivar selection
- crop rotations

Mechanical Weed Control

- Hand pulling
- Hoeing
- Mowing
- Water management
- Smothering
- Artificial temperature
- Burning
- Machine tillage

Factors affecting weed competition:

- Timing of emergence
- Growth form
- Weed density
- Duration of competition
- Physiological basis of competition

List of standardized herbicides for wheat

Sr.#	Name of pesticides	Common name	Dose/acre	Target weeds
1.	Arelon 75 SP	Isoporturon	600 gm	Effective against
	Tolkan 50 SP		800 gm	broad leaf
	Graminon 500 FW		1.5 lit.	weeds and
	Arelon 50 Dispersion		600 gm	grasses
	Kenoran 75 WP		600-700 gm	
	Nocilon 50 WP		800-900 gm	
	Milron 75 WP		500 gm	
2	Doublet 47 EC	Isoproturon + Bromoxynil + MCPA	1 lit.	
3	Panther 52 SC	Isoproturon + Diflufenican	800 ml	
4	Stomp 330 E	Pendimethalin	1.5 lit.	
5	Brominol-M 40 EC	Bromoxynil + MCPA	500 ml	Dicot weeds
	Buctril-M 40 EC		500 ml	
6	Tribunil 70 WP	Methabenzothiouron	700-800 gm	Dicots & grasses
	Tribunil 70 WP		600 gm	
7	Dicuran MA 60 WP	Chlortoluron + MCPA	0.9-1.2 kg	Wild oats
	Agmol Combi 60 WP		1 kg	
8	Dosanex 80 WP	Matoxuron	600 gm	Phalaris minor and wild oats
9	DMA-6	Phenoxy	3 lit.	Broad leaf
10	Flexidor 12.5 EC	Isoxaben	400 ml	weeds
11	Logran Extra 64 WG	Teroutryn + Triasulfuron	100 gm	
12	Pujing 10 EC	Fenoxaprope-ethyl	200 gm	Grassy weed
13	Sencor 70 WP	Metribuzin	100 gm	
14	Puma-S 69 EW	Fenoxaprope- Ethyl	360-440 ml	
15	Topik 50 SP	Clodinafop-Propargyl	100 gm	

Weedicide use options

Time of Application	Target weed group
Pre-emergence	Broad leaf weeds and Narrow leaf weeds
Post-emergence at 1st irrigation	Broad leaf weeds
Post-emergence at 2nd irrigation	Narrow leaf weeds

Selection of Nozzle

Folloings should be taken to account by nozzle selection;

- Type of pest
- Equipment available
- Required angle – crop size
- Application volume
- Area to be covered

Hollow cone nozzle

Insecticides
Fungicides

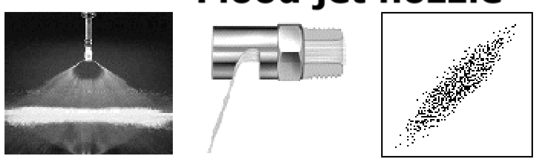
Full cone nozzle

Insecticides
Fungicides

Flat fan nozzle

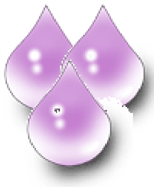
Herbicides

Flood jet nozzle

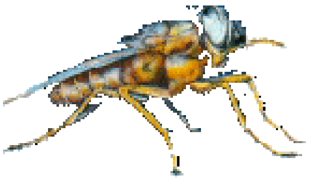


Herbicides

Droplet size



Flying insects



10-50 micron

Insects on surface

30-150 micron

Diseases

30-150 micron

Weeds

100-300 micron

Wild Oat - Avena fatua L

Major hosts

- oats
- barley
- rice
- rye
- wheat
- maize

Minor hosts

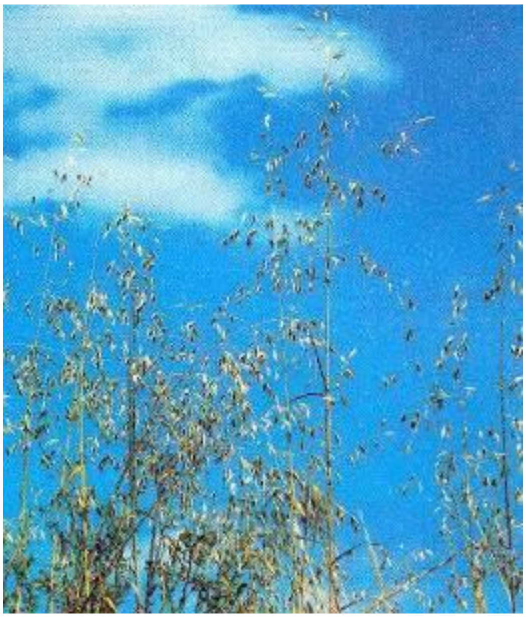
- groundnut
- sugarbeet
- rape

Growth and Crop Competition

Wild Oat forms a large root system with a high uptake of phosphorus and nitrogen. Nitrogen and root competition are therefore very important determinants of yield impact in cereals. The timing of fertilizer application may also result in the promotion of Wild Oat amongst crops. The addition of fertilizer to a wheat crop resulted in increased densities of Wild Oat but vigour decreased. The competition of Wild Oat with winter cereal crops has been assessed. Results indicated that the cereal crops were generally more competitive than the wild oats with the competition beginning at the tillering stage, increasing during growth with the maximum occurring at the shooting and heading stages. For the crops it was intra specific competition that was the most significant whereas for wild oats it was the inter specific competition that was the more significant.

Means of Movement and Dispersal

Natural Dispersal



Wild Oat has relatively large seeds, the majority of which fall close to the parent plant. There are no reports of natural dispersal by wind or water, though this must occur to some extent. Movement by animals is similarly not discussed in the literature.

Agricultural Practices

The dispersal and spread of Wild Oat is closely associated with the cultivation of cereal crops around the world. In a study examining weed dispersal within fields, patches of Wild Oat typically advanced by 1-3 m in a single year with some movement of up to 30 m noted. Movement was in the direction of cultivation and harvesting. Movement over longer distances is most likely the result of importation of contaminated grain.

Pest List

Major host of

- halo blight

Minor host of

- root and foot rot
- nematode, northern root lesion

Wild hosts

- barley yellow dwaf
- European wheat stem sawfly
- rice green leafhopper

Host of

- armyworm, common

Economic impact

Wild Oat is considered to be among the world's worst agricultural weeds and is still increasing in importance. Wild Oat is an intractable weed, because its life cycle is synchronized with the growth of the crop. Wild Oat shows a high competitive ability and is often more competitive than wheat. Shoot biomass and competitiveness are enhanced by ploughing and high levels of fertilization with nitrogen and phosphorus. Competition between cereals and Wild Oat occurs predominantly below ground. Crop yield response depends on time of emergence and density. In cereals, competition starts mainly at the two-node stage and reduces the number of crop tillers. Many damage threshold levels have been estimated for various crops. For cereals the following have been reported: Wild Oat plants/m² caused 14% yield reduction and 5.5% less protein content in wheat; 100 panicles/m² reduced the yield of winter wheat by 34%; 60 plants/m² caused an average yield loss of 0.5 t/ha in about 100 wheat trials; wheat yield loss was below 1% up to 3 plants of Wild Oat /m², reached 2.2% at 5 plants and was 50-60% at 100 plants; Variations in the yield reduction potential of Wild Oat as evidenced above are inevitable and are the result of site to site, climatic and genetic variation. An analysis of the economic benefits of integrated weed management approaches for the control of Wild Oat, reinforced the idea that strategies that directly reduce seed production and seed bank populations yield the greatest economic benefit. The highest long-term benefits will be obtained when Wild Oat is controlled at a density of 2-3 seedlings/m². The continuous and widespread use of herbicides for the control of Wild Oat has frequently resulted in the evolution of herbicide resistance and Wild Oat is listed as the second most herbicide resistance prone weed in the world. Only a few data are available concerning the long-term effect of A. fatua as a host for cereal pests and diseases. Nevertheless, Wild Oat was not pathogenic to wheat.

Physical and Cultural Control

There are some effective non-chemical methods for controlling Wild Oat. These are mainly soil cultivation and crop rotation. The most effective non-chemical control was achieved by the shallowest cultivation possible, carried out as late as possible. Tine cultivation, besides favouring increase of an uncontrolled population, results in a faster population decline than ploughing. Depth of burial and crop rotation influence the seed bank. Under zero tillage the numbers of Wild Oat are generally reduced, but the control of surviving plants with herbicides can be less effective. Summer treatment of soil after cereal harvest (stubble ploughing, summer deep tillage and spring seed-bed preparation), which buries Wild Oat seeds, can create good conditions for weed seed germination and help to markedly reduce weed seed banks. Post-harvest soil cultivation can promote weed seed germination and emerged weeds can be controlled with glyphosate prior to drilling. This treatment combined with a pre or post-emergence herbicide programme resulted in reduced numbers and a decline in Wild Oat over a 4-year period. Straw burning kills many seeds and reduces the dormancy of survivors. In contrast, stubble cultivations have a smaller effect on the germination of Wild Oat. Delayed sowing results in a consistently high degree of Wild Oat control but can also result in significant losses in grain yield and quality. In many cases farmers have had to seek alternative methods in their control of Wild Oat. In cereal crops, reducing the seed bank of weed seeds is the optimum control method. This can be done through changes in the crop sequences. In contrast to these indirect control methods there are only a few non-chemical measures for direct control of Wild

Oat. Mechanical methods are mostly less successful because of the large seed and dense root system. Nevertheless, harrowing or hoeing may break dormancy and therefore increase late emergence. Wild Oat and other grasses are not susceptible to thermal control methods. However, emergence of Wild Oat in wheat can be reduced by flooding. Soil solarisation is used to control A. fatua as well as other weeds and pests. Composting has been found to kill weed seeds. In experiment conducted using feedlot manure containing 12 weed species of which Wild Oat was one, composting reduced the viability drastically within two weeks and killed all seeds within four weeks. Shoot extracts and living tissue extracts from wheat (Triticum aestivum) resulted in a significant decrease in total biomass, pigment, carbohydrate and protein content of Wild Oat. Sorghum water extract reduced the density and biomass of Wild Oat by 22-27%. A natural extract from Parthenuim hysterophorus reduced germination of Wild Oat Wild Oat and inhibited shoot and root growth. Enhanced crop competition can also reduce the growth and yield reduction effect of Wild Oat.

Biological Control

Few papers have been published concerning biological approaches for controlling Wild Oat. They are resultant of fungal infections such as those by Erysiphe graminis f.sp. avenae, Puccinia coronate; P. coronata f.sp. avenae, P. graminis, P. recondita, Pyrenophora, nematodes or hydroxamic acids that have allelopathic effects. Wild Oat is generally susceptible to the same range of parasites as cultivated oats Wild Oat has been confirmed, via virological analysis, to be a natural host plant for the Oat blue dwarf virus.

Chemical Control

Herbicide weed control of Wild Oat has been found to be more effective than cultural control. Good levels of control are given by herbicides belonging to the urea family (e.g. isoproturon or chlorotoluron) and phenoxypropionates (e. g. diclofop-methyl). Many selective herbicides sprayed alone, in mixtures or sequences are known for their high efficacy against Wild Oat. These include the following: atrazine, benzoylprop-ethyl, chlorsulfuron, chlorotoluron, clethodim, clodinafop, cycloxydim, diclofop-methyl, difenzoquat, diflufenican, dimethenamid + trifluralin, fenoxaprop-ethyl, flamprop-isopropyl, fluazifop-P-butyl, fluoroglycofen, flucarbazone sodium, haloxyfop-P-ethoxyethyl, imazamox, imazamethabenz, isoproturon, linuron, linuron + monolinuron + fluazifop-butyl, methabenzthiazuron, oxyfluorfen, pendimethalin, pirifenop-N-butyl, propaquizafop, pyridate, quizalofop-ethyl, rimsulfuron, sethoxydim, sulfometuron, sulfonylaminocarbonyl, triazolinone, terbutryn, tralkoxydim, tri-allate and tria-allate sulfoxide and trifluralin.

Integrated Control

The widespread evolution of resistance to herbicides for the selective control of Wild Oat highlights the need for integrated weed management strategies that do not rely on herbicides alone. In a Russian study by Dudkin, it was concluded that mechanical soil treatments and crop rotations resulted in reduction of Wild Oat by depleting the seed bank. Analysis of the various control strategies for the management of wild oats for economic evaluation has determined that out of all the control strategies examined, the most economically beneficial ones are those which involve the removal of the weed seed and the reduction of seed in the soil seed bank.

Winter wild oat - Avena sterilis L.

Major hosts

- *Triticum spp*

Minor hosts

- *Cereals*
- *Hordeum spp*

Host Range

Winter wild oat is principally a weed of arable crops, particularly cereals

Affected Plant Stages

- Post-harvest
- seedling stage
- vegetative growing stage

Physiology and Phenology

Seeds can lie dormant for up to 5 years under soil, although Sanchez del Arco et al reported that viability in soil of a naturally-occurring infestation for a maximum of 23-24 months. High temperature and soil water stress during seed maturation markedly reduce seed dormancy. Straw burning and cultivation can also lead to reduced dormancy, while plants which survive late applications of benzoylprop-ethyl or flamprop-isopropyl herbicides are also shown to produce less seed of lower viability and reduced dormancy. Smoke stimulates germination in Winter wild oat. Germination temperature ranges from a minimum of 2° C to a maximum of 30°C, with an optimum of 10°. Other authors have reported optimum germination temperatures of 15°C and 25°C. Differences in optima may reflect adaptation to local conditions throughout the wide range of this species. Gibberellic acid and potassium nitrate increase the percentage germination, whereas 2,4-D causes a decrease.

Reproductive Biology

- Reproduction of Winter wild oat is by seed
- Each plant can produce up to 200 seeds

Environmental Requirements

- temperate climates with winter or summer rainfall
- sub-tropical climate with mainly summer rainfall

Pest List

Minor host of

- shootfly

- nematode, northern root lesion

Wild hosts

- stem and bulb nematode
- brown wheat mite

Host of

- stem: oats rust

Cultural Control

Winter wild oat can be controlled by strategic crop rotations, using summer crops to compress Winter wild oat emergence and facilitate easier chemical control. Early cultivation to promote germination flushes of Avena spp., with weed seedlings being destroyed by further cultivation before sowing crop seed. Hand-pulling of established plants can also be used. Increasing the crop sowing rate can be used to reduce weed impact. Control via crop rotation is best achieved by a crop which allows maximum weed emergence followed by total elimination of seed shedding, such as cereals cut green for forage.

Chemical Control

Pre-crop-emergence applications of herbicide may not be effective, since Winter wild oat may establish later than the crop but thereafter exhibit a faster rate of growth. Correct timing and rate of herbicide application is critical to maximize control of partially resistant wild oats. Full rates applied to early growth stages (2-3 leaves) have been shown to be capable of good control. Later applications give poorer control.

Effective compounds

- Atrazine
- Barban
- Chlorfenprop
- Difenzoquat
- EPTC
- Glyphosate
- Linuron
- Metribuzin
    - Metoxuron
    - Monolinuron
    - Imazamethabenz
    - Isoproturon
    - Sulfosulfuron

- Trifluralin
- fluchlorali

Less effective compounds

Effective control by the 'fop' (aryloxyphenoxypropionate) compounds was reported in the 1990s for herbicides such as fluazifop-p, haloxyfop, fenoxaprop and diclofop-methyl but a number of other reports indicate resistance and advise against sole use of fops for controlling Winter wild oat. Of the 'dim' (cyclohexanedione) compounds, cycloxydim gave effective control of Winter wild oat in durum wheat crops.

Integrated Control

Integrated management of Winter wild oat, aimed at minimizing the size of the soil seed bank, is the most economically rational approach to its control. Milling of animal feed before distribution, use of clean seed for planting, avoidance of straw/hay from contaminated areas, and thorough cleaning of machinery after use is likely to prevent the spread of Winter wild oat

Nutrient Management

Adequate nutrients at each stage of development are essential for maximum economic yields of wheat. In general, nitrogen, phosphorus, and potassium are the primary nutrient needs. Climatic and cultural systems must be taken into account when developing a fertilization program.

Determining Nutrient Need

Proper soil sampling is essential to accurately estimate fertility requirements of wheat. Soil fertility conditions often differ both within and among production fields. Nutrient need can be determined by several methods, including, field trials, nutrient removal, plant analysis, past experience, or a combination of these.

Nitrogen

Nitrogen (N) is the plant nutrient most often limiting wheat yields. A soil test for available profile nitrogen is very helpful in evaluating the amount of residual nitrogen. Nitrogen rates are needed to optimize yield of wheat from available stored soil moisture and expected growing season precipitation. Available soil moisture and previous cropping history should be used to estimate potential yield.

Nitrogen recommendation without a soil test

If no soil test information is available, the long term average wheat yield of a field can be used to estimate Nitrogen requirements of wheat crop.

Role of Nitrogen in the Plant

Adequate nitrogen stimulates vegetative growth and increases yield and protein content. Excessive nitrogen increases lodging, delays maturity, increases the severity of some diseases, contributes to groun dwater pollution, and causes rain fed crops to deplete available moisture too early in the season.

Nitrogen Deficiency Symptoms

Symptoms of nitrogen deficiency appear first on older leaves. The older leaves appear pale, with chlorosis beginning at the leaf tip and gradually merging into light green further down the leaf blade, while Younger leaves remain green and appear healthy. As chlorosis spreads to other leaves, older leaves become totally chlorotic, changing from yellow to nearly white. Plants are smaller and produce fewer tillers than plants with adequate nitrogen.

Nitrogen Requirements

The amount of nitrogen required by the crop depends on the type of seed, the previous crop in the rotation, the soil type, and weather conditions and cultural practices during the growing season. More nitrogen is required when wheat follows crops such as vegetable, since more residual nitrogen normally remains after the harvest of vegetables. Excessive winter rains and excess irrigation can cause nitrogen loss from any soil.

Protein content

Protein content can be increased by nitrogen fertilizer. Protein response lags behind yield, with yield receiving the initial benefit. If available nitrogen levels have met the plant's yield requirements, additional nitrogen will be used to increase protein content. If the historical winter wheat grain protein content is less than 12 percent, the crop could probably benefit from additional nitrogen fertilizer if soil moisture is adequate for normal yields. Excess nitrogen applied early in the season can lead to lodging problems or excess nitrate leaching in some areas and should be approached with caution on fields with a history of lodging.

Phosphorus

Phosphorus is critical to wheat growth. Wheat plants do not tiller well under severe phosphorus deficiency and often are more subject to winterkill. Wheat will respond to P fertilizer application if P levels are below critical levels. Some of the most effective methods of P application are to drill the fertilizer with the seed, or below seed depth. This allows the plant to continue to use phosphorus even when the surface is dry. Another alternative would be to apply both nitrogen and phosphorus fertilizer before planting.

Role of Phosphorus in the Plant

Phosphorus plays a role in the transfer and storage of energy within plant cells. Phosphorus nutrition is particularly important for seedling vigor, root development, and early season growth. Normal root and shoot growth and the rate of photosynthesis are governed by phosphorus status. Phosphorus also has a regulating role in tillering; leaf expansion, leaf size, and the rate of assimilate production per leaf area.

Phosphorus Deficiency Symptoms

Early symptoms of phosphorus deficiency include slow growth and vigor, lack of tillering, and sometimes a slight purpling of plants. Leaves become dull dark green. As in nitrogen deficiency, symptoms appear first on older leaves and advance to younger leaves as phosphorus deficiency becomes more severe. Deficient plants usually mature later than normal plants.

Phosphorus Requirements and Rates

If a soil test indicates phosphorus deficiency, apply 33.6 to 44.8 kg/ha of P_2O_5 drilled with seed for irrigated crops, and 22.4 to 33.6 kg/ha of P_2O_5 for dry land crops.

Potassium

Potassium is essential for plant growth and development. It activates enzymes needed for growth and is necessary for the formation and transfer of starches, sugars, and oils; the absorption of nutrients; and the efficient use of water. It enables plants to grow strong roots and resist drought, winterkill, and root diseases. It also helps develop strong stems and decreases lodging. The potassium (K) fertilizer requirement of cereals is relatively low.

Potassium Deficiency Symptoms

Potassium deficiency symptoms generally appear on the older leaves first although growth of the whole plant can be affected. All leaves may have an unthrifty, spindly appearance. During the early states of deficiency, the leaf tips and margins are chlorotic. Necrosis appears on leaves under severe deficiency as speckling along the length of the leaf and spreads quickly to the tip and margins. Complete death of older leaves is common, and plants appear to have dried prematurely, as with drought stress.

Potassium Requirements

Plants need as much potassium as nitrogen during rapid growth periods. Potassium sufficiency in wheat depends on the stage of growth.

Sulphur

Sulfur is required in protein formation. Sulfur (S) deficiency appears as a general yellowing of the plant early in the season and looks much like N deficiency.

Sulfur is an important factor in wheat bread making quality (protein level, loaf volume, and loaf texture). Nitrogen and sulfur requirements are closely linked since both are required for protein synthesis. Sulfur deficiency reduces the number of grains per spike; the number of tillers and grain weight are less affected unless the deficiency is severe

Sulfur Deficiency Symptoms

Symptoms of sulfur deficiency are similar to those of nitrogen deficiency except that the whole plant is pale, with greater chlorosis of young leaves. Sulfur-deficient plants become spindly and develop a pale yellow color.

Sulfur Requirements and Rates

Sulfur deficiency most often occurs on gravelly or sandy soils. It is more common during winter to early spring periods when soils are cool and wet or waterlogged. Sulfur enters the plant through the roots in the form of sulfate. Wheat has a lower sulfur requirement, 11.2 to 33.6 kg/ha, than many other crops, but an adequate level of sulfur is necessary for satisfactory crop growth and for optimal levels of S-containing amino acids in grain. Sulfur deficiency symptoms disappear in most instances as soil temperatures warm, moisture levels drop below saturation, and plant growth progresses.

Micronutrients

Yield responses to iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B) are rarely observed on cereals. Therefore, micronutrient applications are not recommended except where deficiencies are documented with soil and plant tissue tests.

Zinc

Role of Zinc in the Plant

Zinc is an essential micronutrient for crop growth. It is needed for the production of auxins, growth-promoting substances that control the growth of shoots. A critical level of zinc is required in the soil for roots to grow or function effectively.

Zinc Deficiency Symptoms

Zinc deficiency is probably the most widespread micronutrient deficiency in Wheat. It can occur in cold and warm climates, acid and alkaline soils, and heavy and light soils. In general, stems and leaves of deficient plants fail to develop to normal size, and some of the tissues between leaf veins contain so little chlorophyll that they turn yellow. The first symptoms of zinc deficiency normally appear on middle aged leaves. Initial symptoms include a change in leaf color from healthy green to muddy grey green in the central portion of the blade. Leaves appear drought-stressed, and necrotic areas, beginning as small spots, develop and extend to the leaf margins. Leaves may take on an oily appearance, and the necrotic areas may become large and surrounded by mottled yellow green areas. Zinc-deficient leaves eventually collapse in the middle regions. Severe zinc deficiency can result in stunted, chlorotic plants with many collapsed leaves due to necrosis in the center of the leaves.

Zinc Requirements

Zinc deficiency arises from a low content of zinc in soil, unavailability of zinc in high-pH soil, or management practices that depress the availability of zinc.

Magnesium

Young leaves are pale (in contrast to old leaves, which remain dark) and soon become chlorotic and remain unopened, resulting in a twisted appearance similar to that of drought-stressed plants. If the deficiency is severe, the entire length of the leaf remains folded or rolled. Chlorosis of new leaves becomes mottled and finally necrotic; older leaves may develop a mottled chlorosis and in some cases a reddish coloration along the margins.

Iron

Symptoms of iron deficiency are similar to those of magnesium deficiency in that new leaves are affected first and become chlorotic. Iron deficiency differs in that there is a more marked contrast between the green of old leaves and the chlorosis of new growth. Also, leaves show longitudinal interveinal chlorosis, resulting in a pattern of alternate green and yellow striping. Under severe deficiency new growth appears completely devoid of chlorophyll and turns white.

Manganese

Symptoms appear first in new leaves, which become pale and limp in contrast to old leaves. Light gray flecking and striping then appear at the base of the newest fully opened leaf, and, under severe deficiency, flecking and striping appears over the entire length of the leaf.

Copper

Initial symptoms are a general wilting of the plant at early tillering. Plants are light green in color. Withertip, a sudden dying and withering (curling) of the tip end of the blade, appears on young leaves and may extend up to half the length of the leaf. The base of the blade can remain green.

Nutrient Toxicities

Aluminum

Aluminum toxicity may occur on soils with low PH. Retarded root growth is the most characteristic symptom. Plants also have reduced growth above ground and appear unthrifty with thinner than normal leaves. Yellowing occurs along the margin near the tip of the oldest leaf. Brown lesions form in chlorotic regions and work in from the margins, resulting in the formation of indentations. Old leaves become drought-stressed and withered and collapse in the center.

Boron

Initial symptoms, a mottled chlorosis just behind the tip of the oldest leaf and along the margin, are indistinguishable from those of phosphorus toxicity. Eventually, the chlorosis associated with boron toxicity is less yellow.

Manganese

Symptoms appear first on oldest leaves and progress to younger leaves and include chlorosis with little necrosis, chlorosis progressing to necrosis, and in some cases, reddening combined with necrosis and chlorosis. Symptoms first appear on the oldest leaf tips and progress along the leaf with the leaf margins being more affected. A brown blotch or gray flecks of necrotic tissue can appear over the entire leaf.

Integrated Pest Management of Winter Wheat

Integrated pest management (IPM) involves coordinating crop management practices with pest management techniques to achieve economical and sustainable control of pest problems. The goal of an IPM program is to protect the crop from economic damage while interfering as little as possible with the long-term viability of the production system. The most reliable way to do this is to anticipate pest problems and prevent them whenever possible. When pesticides are needed, materials and application methods that are effective, economical, and have a minimum of harmful side effects should be used. Key management methods include

- clean and/or certified seed
- resistant cultivars and crop rotation
- field sanitation and residue management
- proper cultural practices (timing and amounts of irrigation, fertilization

Several diseases and weed seeds can contaminate Wheat seed. Sowing clean seed, or seed certified as free from seed borne diseases and weeds, reduces the likelihood of introducing diseases or weeds into a field. Growing pest-resistant Wheat cultivars can provide economical, long-term protection from some diseases and pests. Many cultural practices have significant impacts on pest management. Infestations of many pests, particularly weeds, result from contaminated seed, soil, water, or machinery. Precautions for preventing the introduction of pests include using high-quality seed, avoiding irrigation water that may contain weed seeds or pest organisms such as nematodes, cleaning equipment before moving it from infested fields, denying livestock access to fields after they have grazed in weedy areas, and destroying stands of problem weeds along field borders before they produce seed that can infest the cultivated area. Practices that produce the most vigorous, competitive stands possible make control of weed pests easier and reduce the susceptibility of crops to disease and insect pests. Important considerations are crop residues, cropping patterns, leveling of irrigated fields to assure uniform water distribution and drainage to avoid flooding, sowing dates, and fertilization.

Crop rotation and fallow periods between crops are effective pest management practices. The most useful rotations for Wheat crops are broadleaf crops because these crops are generally not hosts for most Wheat pathogens and insects.

Wheat thrips - Haplothrips tritici Kurd - Трипс пшеничный

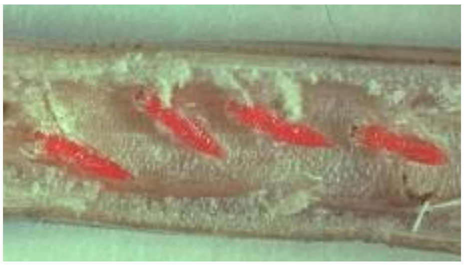
IDENTIFICATION

EGG

- Elliptical; 0.3 mm long
- Laid in irregular masses
- Usually under the lower part of the wheat ear, between the stem of the small ear and the axle of the ear
- Between 74-1008 eggs are laid
- An average of 316 eggs per ear

NYMPH

- Similar in shape to the adult but wingless
- Body mainly brilliant red, with antennae, head, legs and tip of abdomen black



PSEUDO-PUPA

- body red, wing pads as well as the parts that were black in the nymph being white

ADULT

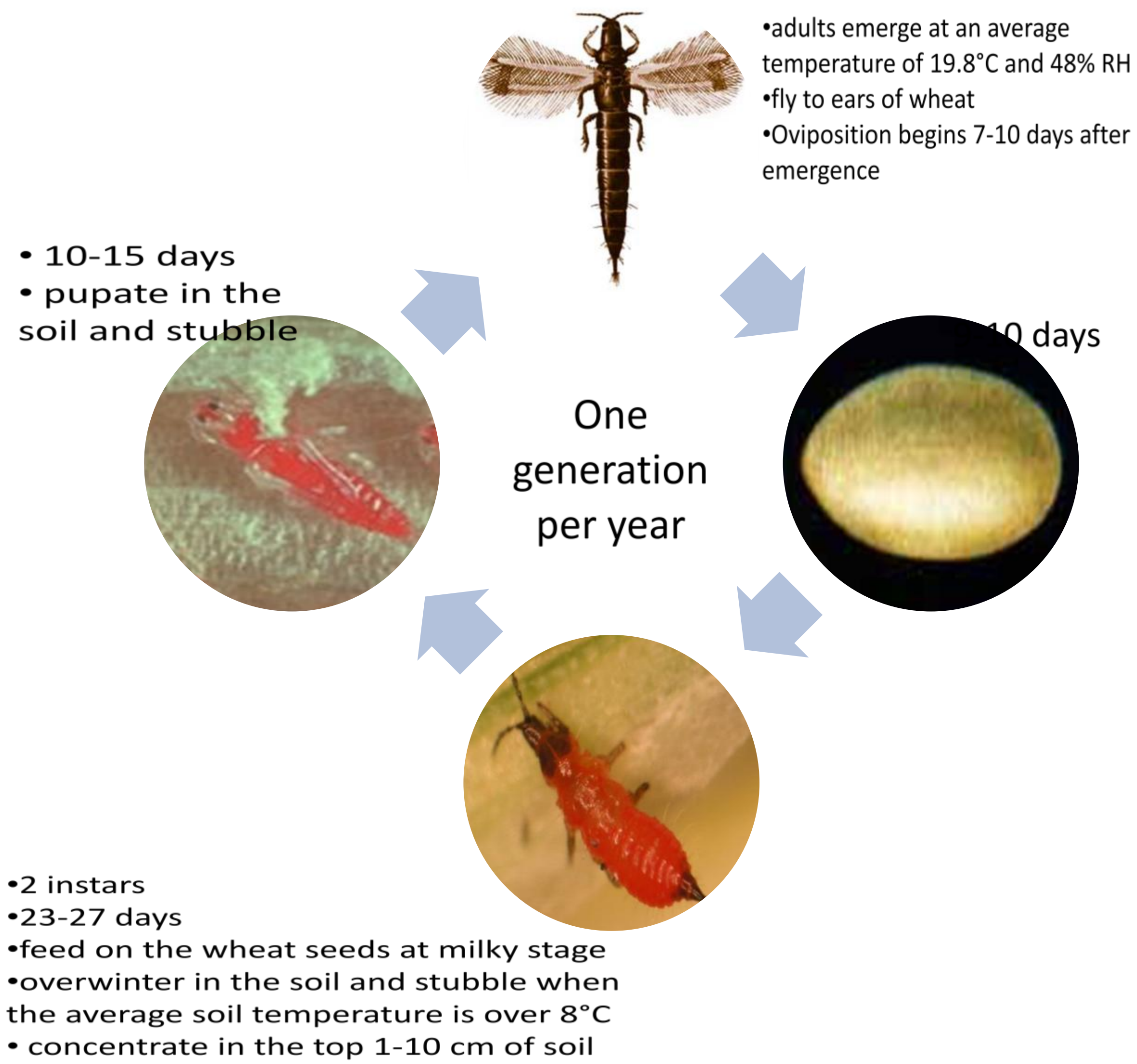
Female

- body 1.5 mm long and black
- antennae black and 8-segmented
- wings translucent, veinless, with a comb of setae on the margins
- 10th abdominal segment tube-shaped

Male

- smaller with abdomen spindly and tapered interiorly
- body mainly brilliant red, with antennae, head, legs and tip of abdomen black

LIFE CYCLE


•adults emerge at an average temperature of 19.8°C and 48% RH
•fly to ears of wheat
•Oviposition begins 7-10 days after emergence
0 days
One generation per year
• 10-15 days
• pupate in the soil and stubble
•2 instars
•23-27 days
•feed on the wheat seeds at milky stage
•overwinter in the soil and stubble when the average soil temperature is over 8°C
• concentrate in the top 1-10 cm of soil

Major hosts

- oats
- barley
- rye

Minor hosts

- Sunflower

Affected Plant Stages

- Flowering stage
- fruiting stage
- vegetative growing stage

Affected Plant Parts

- Fruits/pods
- Inflorescence
- Leaves
- Seeds

Damage

Damage Symptoms

- feed on the ovaries of tender wheat leads to distortions, degenerations, grains sometimes aborting
- bite on hard wheat cause the formation of flecks on the grains
- moves into the furrow of the grain and attacks the pericarp which turn brown and cannot be removed during processing
- feeding cause streaks on leaves
- affect yield (5.6 to 31.6%) as well as the baking quality of flour

Biology and Ecology

- adults emerge in April and fly in search of wheat
- females lay eggs in the ears which are still enclosed in a sheath
- fully developed nymphs leave the ear, penetrate the soil to a depth of 30-35 cm and enter a state of diapause in early July
- they spend the summer in the soil
- reappear in early October to spend the winter under thatch
- pupation starts in the middle of March
- they show great resistance to cold

Detection and Inspection Methods

Ear-forming stage

- under the leaves of wheat

Initial heading stage

- the ear bracts of wheat
- open the ear bracts to detect the eggs
- detect the feeding nymphs in the ear of wheat on the grain with the brown spot at the milky-ripeness stage

After harvesting

- the stubble and soil

Sticky Traps

- blue sticky cards are used for trapping thrips
- Sticky traps should be placed 2 to 5 cm above the crop canopy so that the bottoms of the traps are just above the crop
- three or six traps per 1000 square meter

Cultural Control

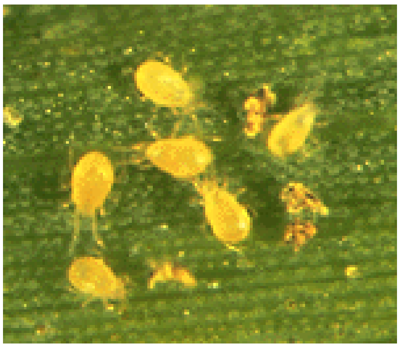
- deep ploughing (to a depth of about 25 cm) after spring wheat harvest or after one shallow ploughing, is an effective method of controlling the population of Wheat thrips nymphs overwintering in the soil and may reduced numbers by 83.9-92.7%
- crop rotation decrease the abundance of wheat thrips 2-4 times than in monocultures
- Balance use of fertilizers i.e. nitrogen or a mixture of nitrogen, phosphorus and potassium lowers densities of Wheat thrips

Predators

- Dolichosoma attacking nymphs
- Malachius attacking nymphs

Biological Control

- Paratinus femoralis predates Wheat thrips in wheat stubble in autumn. The larvae enter the stalks of the stubble and feed on the thrips nymphs
- predatory mites, lady beetles, pirate bugs (Orius) and soil dwelling mites are effective bio-control agents





Chemical Control

• Metaphos (Fenthion) • Parathion-methyl • Fenvalerate • Esfenvalerate • Imidacloprid	• at grain formation • never later than milky grain stage • applied between wheat germination and heading • application of esfenvalerate at grain swelling can give 92% control

.

Sunn pest - Eurygaster integriceps Puton - Клоп вредная черепашка

identification

Eggs

- spherical, slightly ovoid and 1 mm in diameter
- deposit in batches of 14, in two rows, each with seven eggs because of seven ovarial tubes
- by the end of oviposition, fewer eggs may occur in each batch, as a result of ageing
- In less than 1 hour, the nymphs emerge from the egg batch in groups

Development includes five instars

- On oviposition, the eggs are light-green, nearly translucent, with white spots
- In the second instar, the colour darkens
- In the third instar the light-green colour reappears and a dark disk is visible on the superior calotte

- In the fourth instar, an apical anchor-shaped, pink-orange design appears
- In the fifth instar, the egg becomes pink, the design is marked, and a black triangular spot appears above it
- parasitoids Eggs are dark colour and maintain this colour

Nymph

has five nymphal instars

- first instar, nearly spherical, 1.5 mm in diameter and light green in colour, becoming nearly black within a few hours

- second instar, the body length increases (2.2 x 1.5 mm). The head, pronotum, sides and centre of the abdominal segment are black, and the other parts are light in colour
- third instar, the body shape b ecomes ovate (3.5-4.5 x 2.5 mm). The head and thorax are black and the abdomen is light
- fourth instar is 5-6 mm long, 3.4-4.5 mm wide and uniformly brown-yellow
- Fifth instar is almost the size of the adult i.e. 8-10 mm long and 6-6.5 mm wide

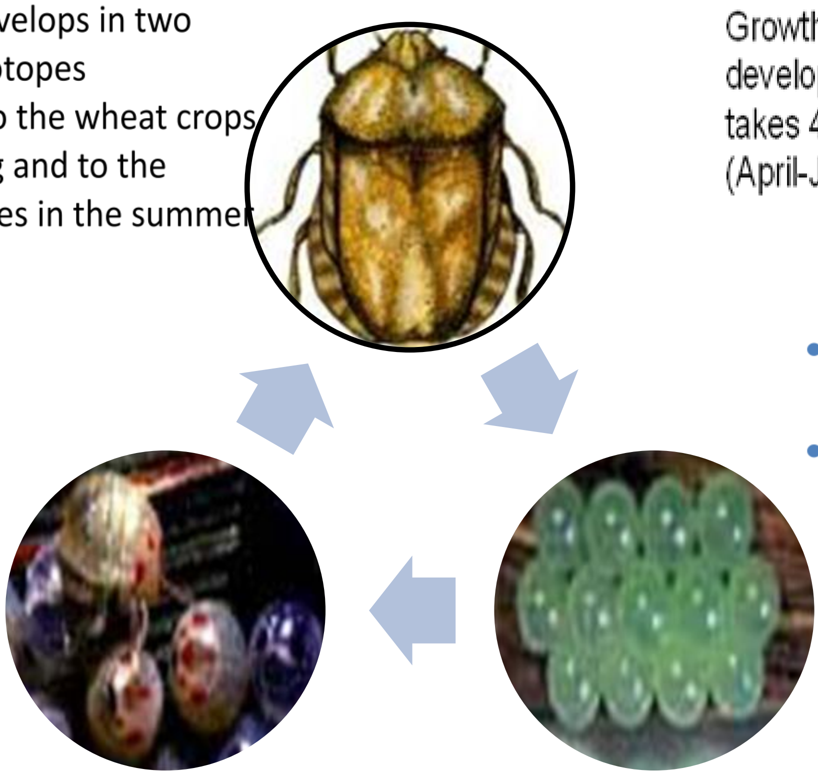
Adults

- ovate body of 11.5-12.3 mm long
- head is triangular in shape and bent from the thorax.
- Colour varies from grey-yellowish or grey-brown to black
- from the side, the body shows a dorsal convex feature and ventrally it is nearly flat
- diapause occurs in the adult stage
- The insects fly to the wheat crops in the spring and to the diapause sites in the summer

Life Cycle

- life cycle develops in two different biotopes
- insects fly to the wheat crops in the spring and to the diapause sites in the summer

Growth and development in wheat takes 4 months (April-July)



- Hatching within 1 hour
- 30-60 eggs per female

- 5 nymphal instars with 3.6, 4.2, 3.7, 5.8 and 10 days, respectively
- strongly influenced by climatic factors

Biology and Ecology

- mating begins in the overwintering sites, but mainly occurs in wheat from the end of March until the beginning of May
- oviposition takes place from April to early June
- growth and development of nymphs occurs during May and June
- emergence of new adults starts in mid-June and continues until the end of July
- growth and development in wheat takes 4 months (April-July)
- diapause represents two-thirds of the life cycle (to cope with high temperatures in summer and low temperatures in winter)
- migration from diapausing sites to wheat fields occurs in April, when the average daily temperature exceeds 10°C and maximum values are above 15°C

Major hosts:

- oats
- ry
- sorghum

Minor hosts:

- barley



Wild hosts:

- wheatgrass
- brome grass
- sunn hemp
- rye grass
- meadow grass



Damage

Affected Plant Stages

- Flowering
- Fruiting
- vegetative growing
- post-harvest stage

Affected Plant Parts

- Inflorescence
- Leaves
- Seeds
- stems and
- whole plant

Symptoms by affected plant part

- Inflorescence: abnormal colour; abnormal forms
- Leaves: yellowed or dead
- Seeds: discolorations; empty grains; shriveled
- Stems: internal discoloration; dead heart
- Whole plant: dead heart; plant dead; dieback

Seedborne Aspects

- reduces the quantity and quality of the grain and impairs germination

Symptoms

- attacks wheat from April until harvest
- adults feed on vegetative plant organs at the end of March or in early April
- nymphs and young adults feed only on the grain within the ear
- in the spring, the leaves and stem base are attacked, whose upper portion became yellow and dry
- after stalk shooting, attack the stalk and lower leaves

- in advanced vegetative phase, damage occur above the last internode
- at ear formation, causing yellowing, drying boot and ear abortion
- appearance of attacked ears is white, sterile and have rigid, diffuse awns
- after flowering, nymphs feed exclusively on the growing grains
- at early grain formation, their attack result in grain shriveling
- at advanced grain ripening, the site of attack is marked by a black point in the centre of a discoloured spot, with yellow-whitish marks
- after harvesting, feed in ears that have fallen on the ground

Detection and Inspection Methods

- use a metric 50/50 cm frame or an entomological sweeping net for sampling
- analyze 20-40 surfaces on the plants and on the surface of the soil
- calculate average density per square metre
- insects on the soil surface are not recorded

At the end of the spring migration

- to determine the number of overwintering adults

At the end of May or in early June

- to determine the numbers of nymphs of the new generation
- similar inspections to estimate the degree of parasitization

Integrated Pest Management

Biological Control

Pathogens

- Bacillus thuringiensis galleriae attacking nymphs, adults
- Bacillus thuringiensis thuringiensis attack nymphs, adults

Parasitoids

Use oophagous parasitoids

Augmentative releases of

- *Telenomus heydeni*
- *Trissolcus basalis*
- *Trissolcus bennisi*
- *Trissolcus gorfii*
- *Trissolcus histani*
- *Trissolcus nigribasalis*

Predators

attacking nymphs, adults

1. *Chrysoperla carnea*


2. *Calosoma investigator*

3. *Harpalus rufipes*

4. *Pterostichus spp*

5. *Merops apiaster*


Cultural Control

- Cultural practices can protect wheat to a small extent
- A well tillered crop, uniform, advanced in vegetation as a result of sowing at the optimum time, in a fertile, well worked soil is in the best position to withstand attack
- Early harvesting can confine the attack and reduce feeding conditions leading to higher mortality during diapause
- good cultural methods cannot prevent intensive outbreaks

Chemical Control

- Chemical control is the only efficient method
- The use of chemical control is based on an accurate estimation of the pest population in a certain area
- applying pesticide to those surfaces exceeding the economic damage threshold
- Elements of the life cycle, such as the developmental stage and pest density, are used to determine the best time for applying treatment

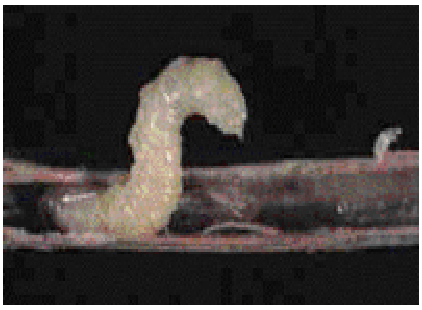
Wheat stem sawfly (Cephus cinctus Norton - Хлебный пилильщик

Identifcation

EGGS

- Eggs are round, white
- about 1-1.5 mm in diameter

LARVAE



- Larvae are white, segmented and legless
- Tan head capsules
- ca 14 mm in length

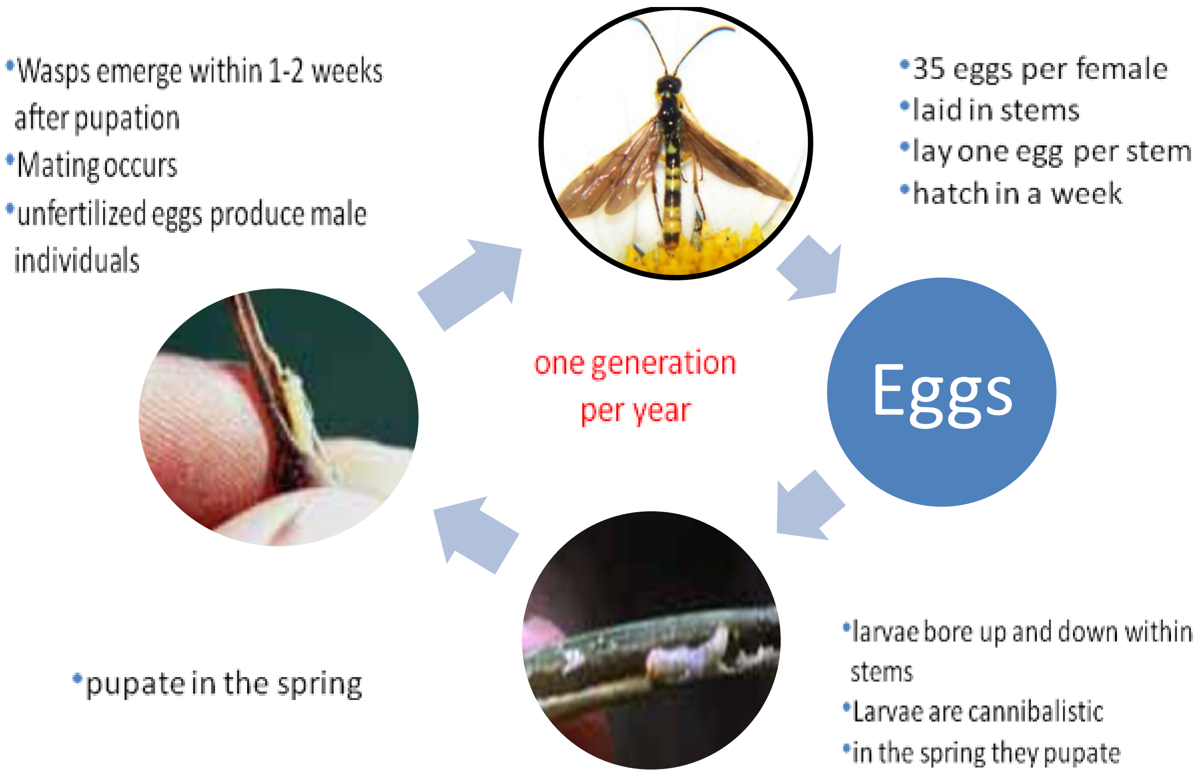
PUPAE

- new pupae are white
- darkened before adult emergence

ADULT

- Adults have shiny black bodies with prominent bright-yellow bands
- body length 7-12 mm
- saw-like ovipositor (hence the name 'sawfly')

Life cycle



Major hosts

- grasses
- wheat

Minor hosts

- barley

Wild hosts

- wheatgrass
- wildrye
- timothy

Damage

Affected Plant Stages

- Flowering stage
- fruiting stage
- vegetative growing stage

Affected Plant Parts

Stems

- internal feeding
- lodging
- broken stems

Damage symptoms

- lodging of mature plants
- broken stems are filled with frass and ends of stems are clean ly cut
- darkened spots are usually visible on stems below nodes as a result of accumulation of carbohydrates that are unable to pass through stems to developing heads

Biology and Ecology

- larvae overwinter underground in stems
- they bore down to the stem crown (where the roots branch out from the stem)
- crown is several centimeters underground
- pupation occurs in early June
- Wasps emerge within 1-2 weeks after pupation
- Adult emergence coincides with the emergence of heads in wild grasses
- mating occurs unfertilized eggs produce male individuals
- wasps disperse short distances to find suitable host plants
- infestation levels are higher in field borders
- Each female produces an average of 35 eggs
- Females have a saw-like ovipositor (hence the name 'sawfly')
- eggs are laid in stems. A female will lay only one egg per stem, but the same stem may receive eggs from subsequent wasps
- Eggs hatch in a week, and larvae bore up and down within stems
- Mature larvae cut a notch around the inside circumference of lower stems
- Weakened stems usually break or lodge before harvest. Larvae remain in the lower stem portion, or stub, which is lined with a thin hibernaculum. The upper end of the stub is filled with a soft plug through which the emerging wasp escapes
- There is one generation per year (univoltine)

Parasitoids

- *Bracon cephi* attacking larvae
- *Bracon lissogaster* attacking larvae
- *Eupelmus allynii* attacking larvae
- *Eurytoma atripes* attacking larvae
- *Eurytoma parva* attacking larvae
- *Macroneura vesicularis* attacking larvae
- *Merisus febriculosus* attacking larvae
- *Pediobius eubius* attacking larvae

Detection and Inspection Methods

- wasps are weak fliers
- sweep nets are thus effective for sampling
- oviposition scars on the plant are nearly undetectable

- Stems should be cut open to reveal eggs and larvae
- Infested stems contain frass and chewed plant material
- Larvae can be found in lower stem stubs in the field after harvest

Cultural Practices

- tillage in the autumn is effective if infested stubble is pushed to the soil surface
- larval mortality in exposed stubs results from freezing and/or desiccation
- damage is greatest in field borders; therefore establishment of trap strips is a control option
- strips of wheat are planted in the borders of old infested stubble and the current crop field
- strips are destroyed after wasps have laid their eggs and any larvae are killed in the process

Insecticides

- Wasps are easily killed with properly timed application of insecticides
- They are not insecticide resistant, and can be killed during flights by application of most insecticides registered for use in wheat

Biological Control

- Native parasitoids occurs

Parasitoids

1. *Bracon cephi*

2. *Bracon lissogaster*

3. *Eurytoma sp*

4. *Pediobius eubius*

Russian wheat aphid - Diuraphis noxia (Kurdjumov) - тля

Identification

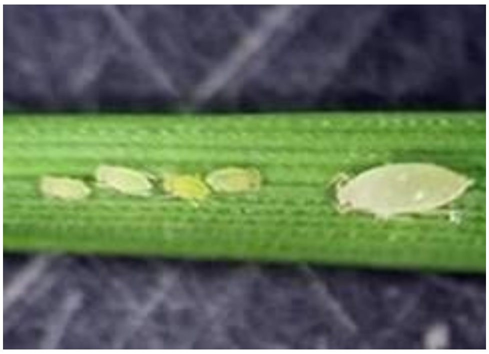
Adults

- small (1.6-2.1 mm long), spindle-shaped, and lime green in color
- shortened antennae and reduced cornicles at the end of the abdomen
- double cauda” from the side view
- females reproduce asexually all year lo ng and give birth to live young for 60-80 days
- head and thorax of winged adults are also dark
- several generations of winged forms every year

Nymph

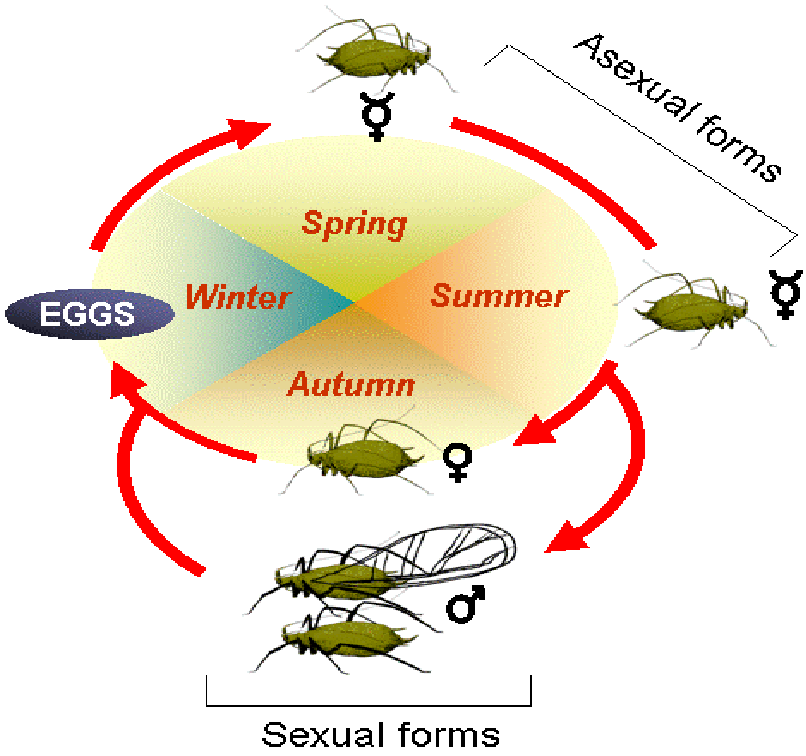
- Similar in shape and colour but smaller in size

Sexual Generation

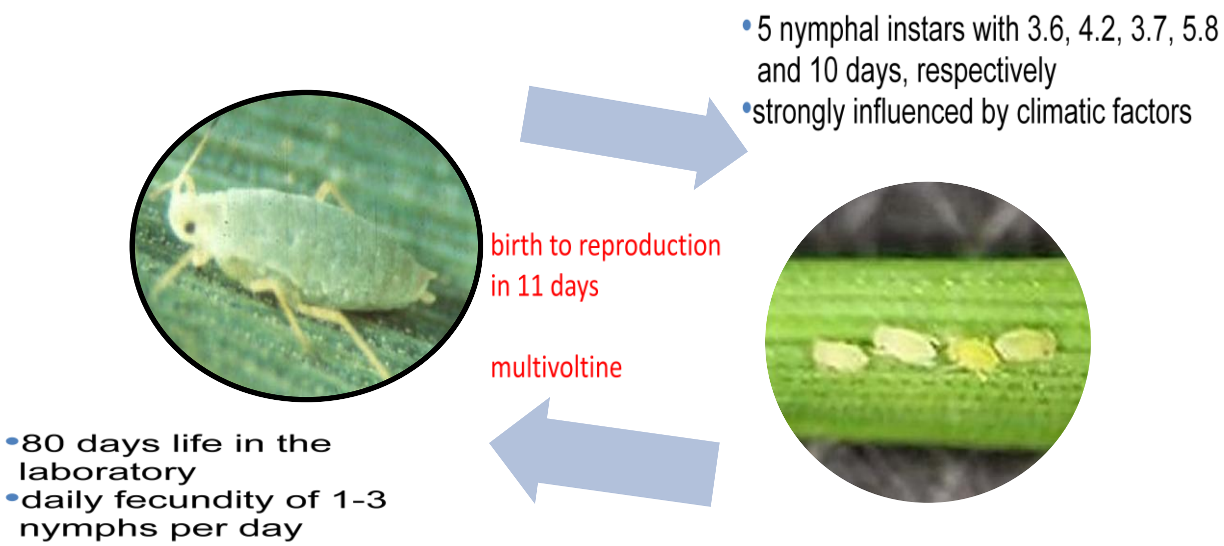


- in Eurasia, some populations have both sexual and asexual generations (i.e. are holocyclic) with sexual forms
- lay eggs in the fall
- aphids overwinter as eggs

Life cycle



Asexual forms
Spring
Winter
Summer
Autumn
EGGS
Sexual forms



• 5 nymphal instars with 3.6, 4.2, 3.7, 5.8 and 10 days, respectively
• strongly influenced by climatic factors
birth to reproduction in 11 days
multivoltine
• 80 days life in the laboratory
• daily fecundity of 1-3 nymphs per day

Biology and Ecology

- Russian wheat aphid is multivoltine with a development time from birth to reproduction of 11 days at 20°C
- Russian wheat aphids seem to be more cold-tolerant than other grain aphids
- survive exposure to -13oF
- temperatures greatly influence developmental rates, with optimal growth (86oF) generating adults in 7-10 days
- Plant growth stage, temperature, and their interaction affect Russian wheat aphids life span and reproduction
- Reproduction is greatest at 18-21°C on wheat in growth stages from jointing to heading
- quick freezes and extended periods of snow cover are detrimental to winter survival
- within a field, survival can be high on the south-facing sides of furrows receiving greater solar insolation
- precipitation and/or humidity may directly or indirectly reduce survival or reproduction of Russian wheat aphid
- peak aphid movement is in July, where they move from summer grain
- begin to infest maturing winter wheat and wheatgrasses
- volunteer wheat and barely provide refuge between summer and fall crop emergence

Major hosts

- barley
- wheat
- durum wheat

Minor hosts

- oats
- rye

Wild hosts

- grasses

Damage

Affected Plant Stages

- Flowering
- Fruiting
- vegetative growing

Affected Plant Parts

- Spike
- Leaves
- stems and
- whole plant

Symptoms by affected plant part

- Inflorescence: abnormal colour
- Leaves: lesions; abnormal colour; abnormal forms
- While feeding, these aphids can transmit a toxin that causes discoloration and distortion of the plant
- Heavily infested leaves will have longitudinal white, purple or yellow streaks

- aphid feeding can prevent normal unrolling of leaves
- plant and head stunting
- bleached heads with poorly formed grain
- In some cases, grain heads never properly emerge because the awns trap the flag leaf

Detection and Inspection Methods

- easily detected in cereal crops by visual examination of plants

Characteristic symptoms

- white to purple streaked and rolled leaves
- heavily infested plants are stunted
- fish-hook shaped seed heads due to trapped by rolled flag leaves

Detection

- suction traps [nymphs and apterous adults]
- Sweep net [apterous and alate adults]
- yellow pan traps [alate adults]
- sticky traps [alate adults]

Integrated Pest Management

Pathogens

- Aphid lethal paralysis virus attacking nymphs, adults
- Beauveria bassiana attacking nymphs, adults

Biological Control

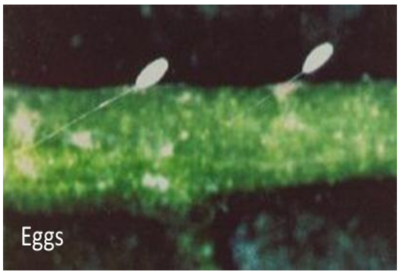
A wide variety of predators and parasitoids attack cereal aphids

Parasitoids

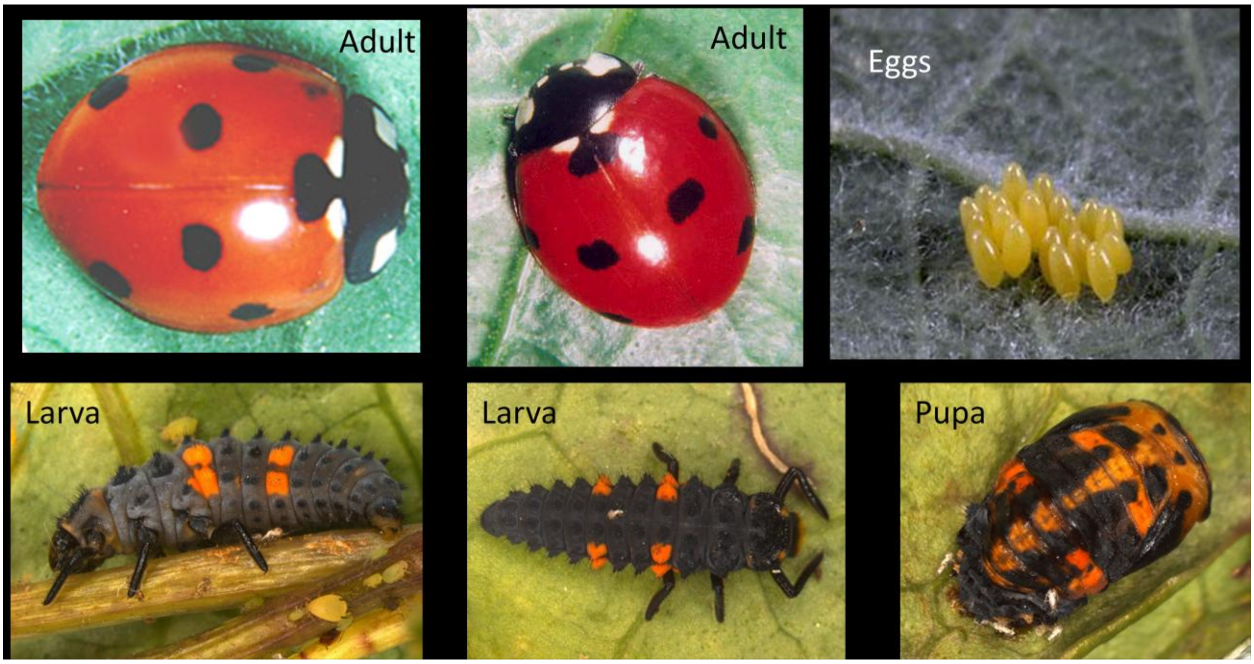
- *Aphidius ervi*
- *Aphidius picipes*
- *Aphidius uzbekistanicus*
- *Diaeretiella rapae*
- *Aphelinus toxopteraphidis*

Predators

- *Chrysoperla carnea*



- *Coccinella septempunctata*



- *Coccinula quatuordecimpustulata*

- *Hippodamia tredecimpunctata*

- *Scymnus nigrinus*

- *Orius majusculus*

- *Aphidoletes aphidimyza*

- *Episyrphus balteatus*

- *Eupeodes corollae*

Cultural Control

- Cultural controls include planting date, planting density, furrow orientation (north to south) irrigation, fertilization, grazing, manipulation of crop residue, and alternative host plants.
- Plant spring grains early and fall grains late to deter winged Russian wheat aphids from starting colonies.
- Remove volunteer grain and wheat grasses to eliminate refuge between spring and fall crops.
- Keep small grain fields healthy by reducing drought stress. As Russian wheat aphids tend to thrive in stressed fields
- Test soil regularly and fertilize as needed
- Select certified varieties that are well-suited for the growing area

Chemical Control

Chemical control is the only efficient method, applying pesticide to those surfaces exceeding the economic damage threshold. Imidacloprid is effective as a seed treatment for wheat. It is an environmentally safer approach than aerial or in-furrow applications of broader spectrum insecticides. The use of chemical control is based on an accurate estimation of the pest population in a certain area

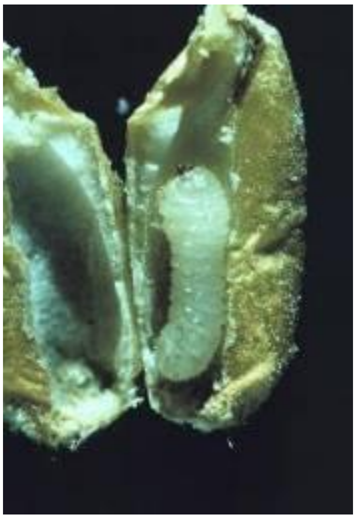
Lesser grain borer - Rhyzopertha dominica (Fabricius) - Зерновой точильщик

Identification

Eggs

- white when first laid
- rose to brown before hatching
- ovoid in shape, 0.6 mm in length, 0.2 mm in diameter

Larvae



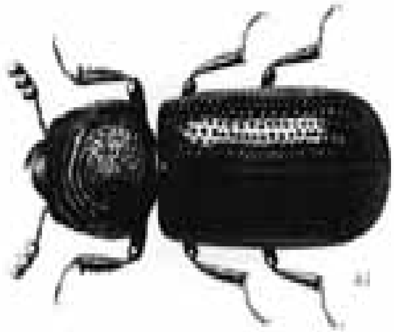
- four larval instars
- lengths of the larvae are 0.78, 1.08, 2.04 and 3.07 mm
- scarabaei form, the first two instars are not recurved, the third and fourth instars have the head and thorax recurved towards the abdomen

Pupae

- pupae are 3.91 mm in length

Adults

- adults 2-3 mm long
- reddish-brown and cylindrical
- elytra parallel-sided
- head not visible from above
- pronotum has rasp-like teeth at the front



Life Cycle

- remain inside the kernel for a few days after eclosion
- Oviposition 15 days after emergence and last up to 4 months
- long-lived up to 240 days

- up to 500 eggs/ female
- egg hatch in 6-14 days
- eggs laid signally of in batches into lose grains

Optimum development time

25 days at 34°C, 70% R.H

- young larva feed on floor
- then bore into grains
- four larval instars
- 27 - 31 days at 28°C

- pupates within the feeding cavity inside the grain kernel
- 8 days at 25°C

Habitat & hosts

Habitat

- cereal stores
- food and animal feed processing facilities

Major hosts

- oats
- barley
- millets
- sorghum
- maize
- dried stored products

Minor Hosts

- chilli
- coriander)
- beans
- Wheat flour
- ginger

Damage

Affected Plant Stages

- Post-harvest

Affected Plant Parts

- Seeds

Biology and Ecology

- lowest temperature at which Lesser grain borer can complete development is 20°C
- at this temperature, the development from egg to adult takes 90 days
- The fastest rate of development occurs at 34°C; at this temperature the egg takes 2 days, the larvae 17 days, and the pupae 3 days to complete development
- Lesser grain borer a is unable to complete development between 38 and 40°C
- Adults live for 4-8 months
- Under optimal conditions of 34°C and 14% grain moisture content, there is a 20-fold increase in the population after 4 weeks
- successfully infest grain at 9% moisture content
- higher fecundity, a faster rate of development, and lower mortality on grain of higher moisture content
- adult males produce an aggregation pheromone in the frass that attracts both male and female adults
- adults are good flyers, and can be trapped in pheromone-baited flight traps placed several kilometers from grain stores
- Adults can bore into intact kernels

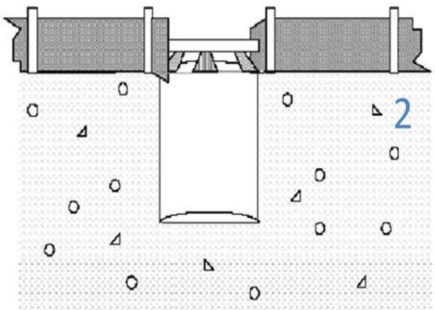
Impact

- the larvae and adults consume the seed
- three types of costs associated with infestations
    - loss in quantity of seed stored
    - loss in quality of seed stored and
    - the cost to prevent or control infestations
- Fumigation with aluminum phosphide, the most common method of control, will also control all stored-product insects in the grain bulk
- If wheat has 32 insect damaged kernels/100 g or more, the lot is downgraded to the lowest grade

Detection and Inspection Methods

1. Sieve: 200-1000 g sample of the grain & look for adult
2. Berlese funnel extractions: extract adults and larvae from inside the seed
3. probe pitfall traps: inspect periodically for 2-7 days. But ineffective at temperatures below 10°C, when the insects stop moving
4. Pheromone-baited flight traps: highly sensitive tool for the detection

5. ELISA test which detects the presence of the insect muscle protein, myosin, can also be used



Physical Control

- **Reducing temperatures** to below 34°C reduces the rate at which the population of Lesser grain borer increases, and it cannot complete its life cycle at temperatures below 20°C
- All insects are controlled in 3-10 weeks at 9°C, and in 3-4 weeks at 4°C
- **Increasing grain temperature** to above 34°C also reduces the rate at which the population of Lesser grain borer increases
- Lesser grain borer can be controlled by heating the grain to 65°C in 4 minutes, and rapidly cooling it to below 30°C
- **Reducing grain moisture content** also reduces insect populations, by reducing the number of eggs produced and the survival of offspring and adults
- Lesser grain borer at 34°C produces109 adults per female per generation at 14% moisture content, 10 adults at 10%, 0.3 adults at 9%, and none at 8% moisture content
- **Addition of inert dusts** to the grain can reduce insect numbers by absorbing cuticular waxes and causing the insects to die from desiccation
- **Inert dusts forms:** including ash, lime, clay, diatomaceous earth and silica aerogel
- diatomaceous earth concentrations between 500 and 1000 p.p.m. are required to control populations
- **The manipulation of gases** (nitrogen, oxygen and carbon dioxide) within storage structures
- high carbon dioxide and low oxygen. For control, oxygen levels must be maintained below 1% for 20 days; or carbon dioxide levels maintained at 80% for 9 days, 60% for 11 days or 40% for 17 days
- or carbon dioxide levels initially above 70% must decline over at least 15 days to not less than 35%

- Control is achieved faster at high temperatures
- **Controlled atmospheres** are more effective in drier grain. Structures should be sealed, joints caulked, and plastic placed over doors, windows and openings before the addition of gases
- **Placing grain in airtight structures.** These can range from well-sealed barrels holding several kilograms to 100-t capacity metal bins.
- structures should be pressure-tested to confirm air-tightness
- good sanitation
- removing spilt grain around storage facilities

Biological Control

The use of natural enemies to control Lesser grain borer and other stored grain insects has been limited.

Chemical Control

- resistance to insecticides is also a growing problem, especially with residual insecticides such as malathion, chlorpyrifos-methyl and pirimiphos-methyl, but also with fumigants
- Insect growth regulators have low toxicity to mammals, but take longer to control insect populations and are more expensive than other insecticides
- sprayed or dusted directly onto the grain, and protect grain from 2 weeks to over a year
- After treatment with an insecticide, grain often must be held for a certain period of time before it can be processed or used as animal feed
- phosphine and methyl bromide, to control insect infestations in stored commodities
- Phosphine is usually applied to the grain as aluminium phosphide pellets or tablets
- Methyl bromide is used mainly for empty structures and is delivered as a gas

Spring green aphid - Schizaphis graminum Rondani - Зерновая тля

Identification

Eggs

- overwintering eggs are broadly elliptical
- Approx. 0.75 mm in length and 0.38 mm broad
- at oviposition: pale yellow-green
- fertile eggs: dark green
- finally: shiny black

Nymphs

- first-instar nymph: dark green to pale green and about 0.7 mm
- second-third instar: pruinose form
- less true of fourth-instar nymphs which will give rise to alate adults

Adults

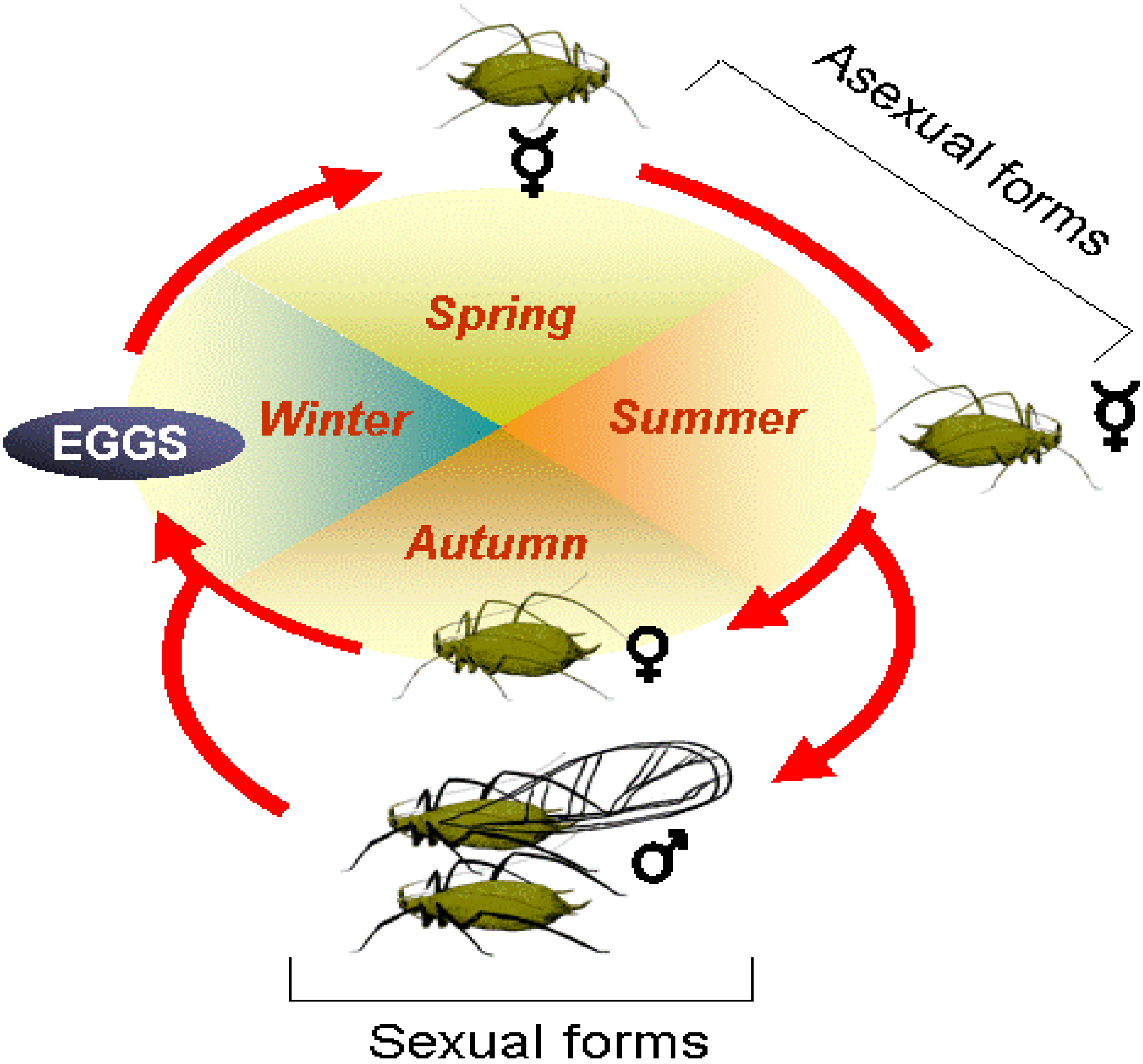
Wingless females

- 1.5-2.0 mm in length
- typically a dark green stripe on a pale green back
- tips of legs, tips of cornicles, and most of antennae are black

Winged form

- body green and olive-tan
- Darker green stripe on back

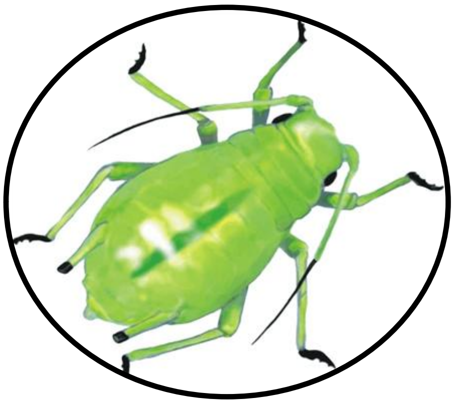
Life Cycle



Asexual forms
Spring
Winter
Summer
Autumn
EGGS
Sexual forms

Life Cycle

- 3 nymphal instars
- strongly influenced by climatic factors



- females give birth to live young within 7 days of their own birth at 25°C
- produce1-3 nymphs per day for the next 20-30 days

Biology and Ecology

- holocyclic
  - reproduces sexually overwinter
  - persists as entirely parthenogenetic winged and wingless females wherever winter conditions permit
- nymph birth rates vary with temperatures between 10 and 30°C
- mostly die at temperatures below -20 or above 40°C
- winged forms are most common on crowded or stressed plants
- Dispersal is greatly enhanced by prevailing winds

Hosts

Major hosts

- oats
- maize

Minor hosts

- large crabgrass

Damage

Affected Plant Stages

- flowering stage
- seedling stage and
- vegetative growing stage

Affected Plant Parts

- leaves
- ears / spikes

Damage

Symptoms by affected plant part

- Leaves
- lesions
- abnormal colors
- abnormal leaf fall
- honeydew or sooty mould

Detection and Economic Threshold

Detection

- suction traps [nymphs and apterous adults]
- Sweep net [apterous and alate adults]

- yellow pan traps [alate adults]
- sticky traps [alate adults]

Economic thresholds

- number of greenbugs per leaf, plant, or specified length of plant row at a given growth stage

Cultural Control

- the reflectance from previous cropping residue appears to be a deterrent to aphid infestations
- losses from aphid damage are stressed by drought and soil fertility stress
- populations will flourish with abundant moisture and soil fertility

Biological Control

- the long list of natural enemies gives an indication of the importance of these agents
- augmentation of parasitoids and predators has little value because of the rapid build-up potential of greenbugs on large areas of susceptible host material

Pathogens

- *Beauveria bassiana* attacking larvae, nymphs, pupae, adults
- *Conidiobolus obscurus* attacking nymphs, adults

Parasitoids

- Aphelinus toxopteraphidis attacking nymphs, adults
- Aphidius ervi attacking nymphs, adults

Predators

- *Aphidoletes aphidimyza* attacking eggs, nymphs, adults

Chemical Control

- cholinesterase found in greenbugs
- resistant to carbofuran, chlorpyrifos, disulfoton, dimethoate, and fenvalerate

Lesser grain weevil - Sitophilus oryzae (Linnaeus) - Амбарный долгоносик

Identification

Egg

Opaque, shining white, ovoid to pear-shaped in form, widest below middle, bottom broadly rounded, Length 0.65 to0.70 mm, width 0.28 to 0.29 mm

Larva

Cream colored body and dark head capsule. Mature larva 2.5 to 3 mm. in length. Head light brown in color, anterior margin and mandibles much darker. There are four instars

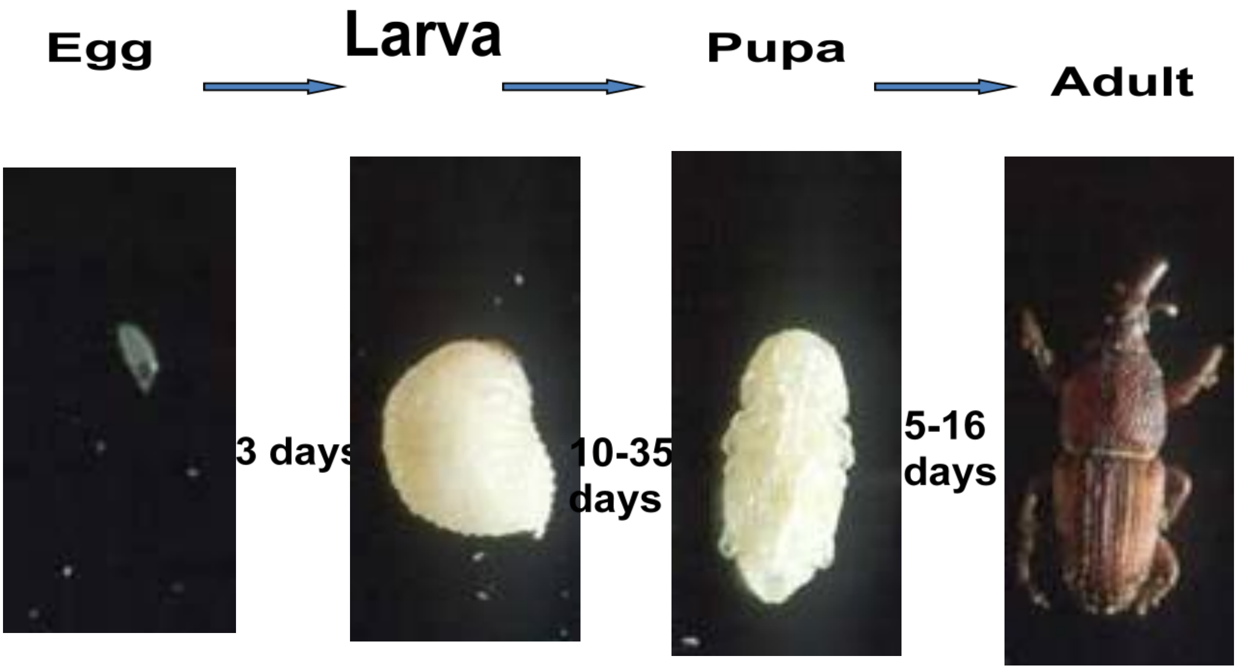
Pupa

White, found inside the grain

Adult

Body length 2.3 - 3.5 mm, reddish-brown to black in color with four reddish or paler spots on the corners of the elytra; prothorax is strongly pitted with round or irregularly shaped pits and the elytra have rows of pits within longitudinal grooves. Thorax longer than wide

Life cycle



Adults live for 7-8 months and may survive for 2 years

Major hosts

- sorghum
- wheat
- maize
- dried stored products

Minor hosts

- barley
- rye

Damage

Affected Plant Stages

- Post-harvest

Affected Plant Parts

- Seeds

Damage Symptoms

- The eggs, larvae and pupae are not normally seen because they develop inside intact grains
- The larvae chew large, irregular holes in the germ and endosperm of the kernel
- Adult emergence holes (about 1.5 mm diameter) with irregular edges are apparent some weeks after the initial attack
- In a heavy infestation, the only part of a grain that remains is the shell of the kernel perforated by adult feeding and emergence holes

Symptoms by affected plant part

- Seeds: internal feeding

Detection and Inspection Methods

- Flight traps will collect S. zeamais, but seldom S. oryzae (which rarely flies)
- A male aggregation pheromone attracts both sexes in Lesser grain weevil

These weevils almost completely destroying grain in elevators, bins, ships, and anywhere else where physical conditions for growth are favorable and the grain is left undisturbed for some time. Attack is evidenced by surface heating of the grain, by dampness sometimes to the extent that germination occurs and by the presence of numerou s adults.

Adults may also feed on flour, semolina. and other milled cereals. These are probably migratory, and will not lay eggs, since larvae need whole kernels in which to develop. Hard caked flour may, however, encourage egg laying. Adult weevils found wandering about in a house may cause anxiety for the safety of timber and furnishings, but in this respect they are harmless, and will quickly die. The source of infestation is usually a packet of cereal in the food cupboard.

Biology and Ecology

- The adults are long-lived (several months to one year)
- Eggs are laid throughout most of the adult life, although 50% may be laid in the first 4-5 weeks
- Each female may lay up to 150 eggs
- The eggs are laid individually in small cavities chewed into cereal grains by the female
- Each cavity is sealed, thus protecting the egg, by a waxy secretion (usually referred to as an 'egg-plug') produced by the female
- The incubation period of the egg is about 6 days at 25°C
- Eggs are laid at temperatures between 15 and 35°C (with an optimum around 25°C) and at grain moisture contents over 10%; however, rates of oviposition are very low below 20°C or above 32°C, and below about 12% moisture content
- Upon hatching, the larva begins to feed inside the grain, excavating a tunnel as it develops
- There are four larval instars: in wheat at 25°C and 70% RH, pupation occurs after about 25 days, although development periods are extremely protracted at low temperatures (e.g. 98 days at 18°C and 70% RH)
- Pupation takes place within the grain; the newly developed adult chews its way out, leaving a large, characteristic emergence hole
- Total development periods range from about 35 days under optimal conditions to over 110 days in unfavourable conditions

Impact

- Lesser grain weevil is universally regarded as one of the most destructive primary pests of stored cereals such as wheat
- It can attack cereal plants in the fields. Voracious feeding on whole grains by this insect results in weight loss, fungal growth, quality loss through an increase in free fatty acids and it can even completely destroy stored grain in all types of storage
- Invasion by this primary pest may cause grain heating and may facilitate the establishment of fungal colonies, secondary insect pests, and mite pests

Cultural Control

- Good store hygiene plays an important role in limiting infestation by Lesser grain weevil
- The removal of infested residues from last season's harvest is essential

Modified Atmospheres

- Raised levels of carbon dioxide are known to be toxic to many insect species, but Lesser grain weevil has shown to be one of the more tolerant species to this treatment

Biological Control

- Biological control has not been practised against these species
- There may be some potential for the development of pest management strategies that favour the action of natural parasites

Bio-Control Agents

Pathogens

- *Bacillus thuringiensis thuringiensis*
- *Beauveria bassiana*
- *Microsporidium sitophili*

Parasitoids

- *Anisopteromalus calandrae*
- *Cerocephala dinoderi*
- *Cerocephala oryzae*
- *Theocolax elegans*

Predators

- *Acaropsellina docta*
- *Carcinops troglodytes*
- *Tenebroides mauritanicus*

Chemical Control

- low susceptibility to synthetic pyrethroids
- readily killed by organophosphorous compounds such as Fenitrothion and Pirimiphos-methyl
- Grain stocks may be fumigated with Phosphine or Methyl bromide to eliminate existing infestation, but these treatments provide no protection against re-infestation
- pupal stage have a lower natural susceptibility to the fumigant Phosphine and to carbon dioxide used in controlled atmosphere storage

Botanical extracts

- *Ocimum basilicum*
- *Capsicum frutescens*
- *Piper guineense*
- *Tetrapleura tetraptera*
- *Neorautanenia mitis*
- *Ricinus communis*
- *Labrador tea*

Cereal leaf Beetle - Oulema melanopous - Пъявица

Identification

EGGS

- cylindrical, rounded, 1 mm in length
- covered with a shiny adhesive which holds the egg to the leaves
- When laid the eggs are bright-yellow with a clear spot at one end
- As mature, the clear spot becomes enlarged and colour becomes darker
- just before hatching further darkening of the yellow colour occurs near the head and near the appendages of the embryo which is visible within the egg

LARVAE

- The larva is eruciform with head, spiracles, and legs moderately chitinized
- brownish-black in colour
- rest of the body is soft, more or less wrinkled, dirty- to bright-yellow
- four larval instars
- mature larvae are 5.0-5.5 mm in length
- fecal coat covers the thorax and abdomen and is beneficial as camouflage, as a repellent to predators, and as a cooling evaporative shield

PUPA

- exarate type
- envelope in a silky transparent membrane
- bright-yellow when newly formed and darken as they develop
- pupate in cells constructed from soil and mucous in the soil

ADULT

- distinct in appearance with metallic bluish-black elytra (wings), and body parts
- pronotum, femora and tibia are red to red-orange
- antennae are greater in length than half the body
- adults ranges from 4.6 to 5.3 mm in length, with the female being larger

Life cycle

- overwinter in clusters in protected places
- Egg laying begins about 14 days after the emergence

- eggs are laid singly or in pairs
- 100 to 400 eggs /female over a 50 day period
- hatch in about 5 days

life cycle 46 days
one generation each year

- 4 instars. Each instar lasting 3-4 days
- Total larval life is 9-16 days

- full-grown larva enters the soil
- pupates in earthen cells about 2.5 cm beneath the surface
- pupal stage lasts 2 to 3 weeks

Biology and Ecology

- overwinters as an adult in numerous sites as in sparse woodlands, fence rows, small grain stubble, crevices of tree bark; under field trash; inside rolled leaves.
- sheltered places are vital for the survival of overwintering adults.
- adults become active in the spring when temperatures reach 9-10°C and may be found feeding and mating on small grains or grasses.
- exposure to -15°C for about a week kills 90% of the overwintering population
- high pupal mortality

Affected Plant Stages

- Post-harvest
- vegetative growing stage

Affected Plant Parts

- Leaves

Symptom by Affected Plant Parts

- Leaves: honeydew or sooty mould

Damage Symptoms

- feed on adaxial leaf surface and from tip of the blade to the base
- consume the chlorophyll but leaving the lower epidermis intact
- feed between the leaf veins, causing a longitudinal feeding scar
- in heavy infestations: damage appears to be **injury by frost**
- tips of the leaves being whitened
- adult damage: the leaf being completely chewed through, creating narrow slits

Damage Symptoms

Detection and Inspection Methods

- visual survey or use a sweep-net
- it is not attracted to light
- spring surveys should begin in succulent grain fields after a few days in which the temperature exceeds 9°C
- **for adults:** use of sweep-net gives a more accurate picture of the degree of infestation
- **Larval inspection** should be visual. Watch for feeding signs on grain and grass tips. Larvae feed on the upper leaf surface leaving the lower epidermis intact
- survey for summer adults should focus on succulent growth of maize, sudan, reed canary, and other grasses

Cultural Control

- use of ploughing stubble immediately after harvest
- populations are increased by fertilization so use balanced fertilizers

Biological Control

Four European parasites

- *Anaphes flavipes* (egg)
- *Tetrastichus julis* (larval)
- *Lemophagus curtus* (larval)
- *Diaparsis temporalis* (larval)




Chemical Control

- *Oulema melanopus* is susceptible to most insecticides
- insecticide treatments in spring during feeding of larvae and beetles
- treatments of field edges
- Malathion, methomyl, carbaryl, and spinosad effectively controlled larval infestations when treatments were applied after most eggs had hatched

Orange wheat blossom midge - Sitodiplosis mosellana (Géhin)

Major hosts

- wheat

Minor hosts

- barley
- rye

Affected Plant Stages

- Flowering stage
- fruiting stage
- post-harvest

Affected Plant Parts

- Inflorescence
- seeds

Biology and Ecology

Orange wheat blossom midge larvae overwinter in small silken cocoons (about 3 mm long) in the soil, and pupate after exposure to a minimum period of about 70 days at an average temperature below 10°C. When this requirement is not satisfied, larvae remain in diapause in the soil for one or more years before pupating. Once the vernalization requirement has been met, larval diapause may be terminated after a period of warmer weather sufficient to give 220 day degrees above a base temperature of 3°C after January 1. Larvae then move upwards in the soil and pupate once soil moisture and temperature are sufficiently high. Duration of the pupal stage varies between 2 and 3 weeks, dependent on prevailing temperatures. Adult emergence is stimulated by rising temperatures following rainfall, and a rise above 15°C is particularly favourable. Emergence is generally closely synchronized with crop development so that adults become active as their host plants come into head in June, and larval development is completed before grain matures in August. Adults usually emerge from pupae at the soil surface in late afternoon or early evening, with male emergence peaking about 1-2 hours before females. Within an hour of emergence, females settle on plants, extend and retract their ovipositors and attract males, presumably by release of pheromones. After mating females cease calling, and at temperatures above 15°C and wind speeds below 10 km/h, fly upwind to locate suitable host plants for oviposition. Directional host-locating flights of at least 1 km can be made by large numbers of midges, and transfer over longer distances may occur when they are caught in thermal currents and strong winds. On subsequent nights females lay eggs on inflorescences, depositing batches of 2-3 eggs on the glume, lemma or palaea of the florets, generally before the anthers have dehisced. Females live for up to a week and lay about 100 eggs each, when conditions are favourable. Males live for only a day or so and both sexes rest during the day on stems and leaves within the crop. Wheat is generally the most attractive host for oviposition. Eggs hatch after 4-10 days, depending on prevailing temperatures within the range 15-20°C, and first-instar larvae move onto the developing ovaries to feed. Digestive enzymes are secreted from the salivary glands and fluid nutrients are ingested. Feeding continues for 2-3 weeks. When fully fed, larvae may remain within the spikelets of the inflorescence during dry weather, until rainfall acts as a stimulus for them to crawl out and drop to the soil. S. mosellana is generally univoltine, with a single generation completing development during the year. Although there have been few intensive ecological studies of S. mosellana, it seems that breeding success is greatly influenced by weather. Temperature directly affects adult emergence and therefore successful synchronization with the required stage of host-plant development that S. mosellana needs to oviposit and develop successfully.

Parasitoids

- Euxestonotus error
- Inostemma horni
- Isostasius inserens attacking eggs
- Isostasius punctiger attacking eggs
- Leptacis tipulae attacking eggs
- Piestopleura thomsoni attacking eggs
- Platygaster attacking eggs

Predators

- Agonum placidum; Atomus pilosus attacking eggs
- Bembidion obscurellum
- Bembidion quadrimaculatum
- Carabidae attacking larvae
- Platypalpus attacking larvae
- Pterostichus madidus
- Pterostichus melanarius

Notes on Natural Enemies

Many natural enemies, mainly parasitic Hymenoptera, have been recorded, but few are considered to be of importance in limiting populations of Orange wheat blossom midge.

Impact

Early attacks may prevent grain formation, in which case there may be some compensation from increased development of surviving grain, but attacks generally result in loss of overall yield and quality of grain.

Symptoms

Generally result in the production of shrunken, under-sized grain. Depressions develop at larval feeding sites and the pericarp is loosened around the feeding area. Grain size is affected primarily by the S. mosellana larvae feeding on developing ovaries, and quality is often reduced through secondary infection by fungi and bacteria.

Symptoms by affected plant part

- Inflorescence
- external feeding
- Seeds
- galls

Detection and Inspection Methods

Field infestations can be detected by sampling earheads and examining them, preferably under a stereoscopic microscope, for the presence of the relatively conspicuous orange larvae on developing grains. At a later stage of crop development larvae will have left the heads for the soil, but it may still be possible to see the characteristic symptoms of S. mosellana on damaged grain. The presence of larvae in soil samples may be detected by standard techniques of extraction or flotation and examination. Adult populations may be monitored by suction or sticky traps, although both methods involve difficulties of identification of mixed catches of midges.

Cultural Control

The main cultural method of Orange wheat blossom midge control is adequate crop rotation to avoid build-up of overwintering larval populations in soil. However, this may not be effective if adjacent areas have been previously cropped with wheat or other susceptible cereals, as Orange wheat blossom midge adults may be attracted onto new crops from a distance of a kilometre or more.

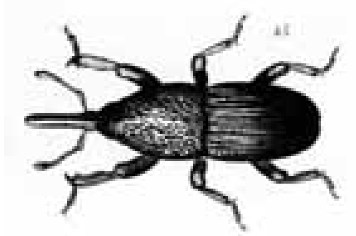
Chemical Control

In the absence of other alternatives, chemical control, preferably linked to forecasting systems and field monitoring, is still the most widely used method of control. Soil sampling during the winter may be used to determine where crops are at risk. Early adult activity may be detected by suction, sticky or yellow-tray traps, or by field examination to detect ovipositing females on ears at dusk. Broad spectrum insecticides, such as chlorpyriphos or fenitrothion, are then applied to kill ovipositing adults and eggs.

Integrated Pest Management

Management of Orange wheat blossom midge still relies heavily on chemical control and there seem to have been no concerted efforts to develop IPM programmes, probably because outbreaks are erratic and still unpredictable.

Grain weevil - Sitophilus granarius Linnaeus



Hosts

- barley
- dried stored products
- wheat

Minor hosts

- oats
- maize

Affected Plant Stages

- Post-harvest
- pre-emergence
- seedling stage

Affected Plant Parts

- Seeds

Biology and Ecology

Grain weevil cannot fly. Adults live for 7 to 8 months on average. Females usually lay around 150 eggs, and up to 300 eggs, throughout their lives. Eggs are laid individually in cavities that the female bores in the grain kernels. Cavities are sealed by a waxy egg plug, which the female secretes. Eggs incubate for about 4-14 days before hatching, depending on temperature and humidity. One larva develops in each infested kernel. Feeding larvae excavate a tunnel and may keep feeding until only the hull remains. There are four larval instars. Pupation occurs inside the grain. The newly emerged adult chews its way out of the grain, leaving a characteristic exit hole. In warm summer conditions the life cycle can be completed within 4 to 6 weeks, but can take as long as 17 to 21 weeks in the winter. Adults can survive for a month or more without food in cooler conditions. Optimum conditions for development are similar to other tropical species of Sitophilus, about 30°C and 70% RH**.**

Pathogens

- Bacillus thuringiensis
- Beauveria bassiana attacking adults

Parasitoids

- Anisopteromalus calandrae attacking larvae
- Cephalonomia tarsalis attacking larvae
- Choetospila elegens attacking larvae

Predators

- Acaropsellina docta

Impact

Grain weevil is a serious pest of stored cereal grains in cool climates, whether in temperate or tropical latitudes. Larval stages feed inside the grain on the kernels, leaving only the hulls. Severe infestations can reduce stored grain to a mass of hulls and frass. It is a severe pest of wheat.

Symptoms

The developmental stages of Grain weevil are not normally seen as they occur inside intact grains. Adult emergence holes with irregular edges are apparent some weeks after initial attack. Adults can be found wandering over the surface of grain especially if the grain has been disturbed.

Symptoms by affected plant part

- Seeds
- internal feeding

Detection and Inspection Methods

Granary weevil infestations in stored cereals are generally difficult to detect, particularly in the initial stages, since the life cycle mainly takes place (from egg to pupa) inside the kernel. Pitfall traps placed on the grain surface and probe traps inserted into grain bulks have been used successfully to detect adult Grain weevil. Larval stages in the grain may be detected using hidden infestation detection techniques. These can involve squashing the grain against indicator papers, testing for changes in specific gravity, or using X-ray.

Chemical Control

Grain may be protected by the admixture of insecticides. Grain weevil has a low susceptibility to synthetic pyrethroids but is readily killed by organophosphorus compounds such as fenitrothion and pirimiphos-methyl. Grain stocks may be fumigated with phosphine or methyl bromide to eliminate existing infestation. However, fumigation treatments provide no protection against reinfestation. As methyl bromide is phased out due to its role in atmospheric ozone depletion, alternatives such as carbonyl sulphide are being tested. Fumigation of S. granarius pupae with phosphine at 20°C resulted in a LT95 of 3.9 days (at 0.5 g/m^2) and 100% mortality after 10. Carbon dioxide fumigation, in controlled-atmosphere storage, can also be used to control Grain weevil in stored grain, although the weevil is more resistant to this treatment than other storage pest species. Inadequate fumigation or controlled-atmosphere treatments are likely to result in some survival.

Biological Control

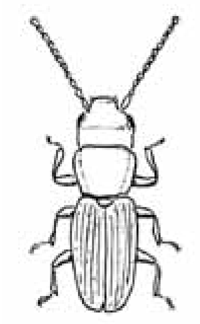
Biological control has not been practised against S Grain weevil.

Cultural Control and Sanitary Methods

Good storage hygiene plays an important role in limiting infestation by Grain weevil. The removal of infested residues from the previous season’s harvest is essential. Ensuring grain is well dried at intake is very important. Moisture content of 10-12% is desirable. Infested grain can be treated with hot air, at an inlet temperature of 300-350°C, as an alternative to fumigation. Good weevil control has been obtained by this method, with heat exposure times (around 6 seconds).

Rusty grain beetle - Cryptolestes ferrugineus (Stephens) -

Hosts



- rice
- sorghum
- dried stored products
- wheat
- maize

Minor hosts

- oats
- barley)

Affected Plant Stages

- Post-harvest

Affected Plant Parts

- Seeds

Biology and Ecology

The eggs are laid singly on or amongst the commodity, are moist, and particles of food material adhere to them. They are white, 0.5-0.8 mm in length and about 3.5 times as long as they are wide. Under favorable conditions (25-35°C, 70% RH), 100-400 eggs may be laid. Small larvae cannot enter totally intact grains, but are able to penetrate if the seed coat is imperfect or is slightly damaged by handling. There are 4 larval instars. The 4^{th} instar prepares a cocoon in which the pupa develops and transforms into the adult. Development takes an average of 23 days under optimum conditions (33°C, 70% RH) and varies from 17-26 days at 38°C to 69-103 days at 21°C. Mortality is high below 50% RH. In its natural habitat, it can be found under the bark of trees.

Pathogens

- Mattesia dispora

Parasitoids

- *Cephalonomia waterstoni* attacking larvae

Notes on Natural Enemies

The bethylid wasp Cephalonomia watersoni parasitizes Cryptolestes spp. These beetles are also attacked by the schizogregarine protozoan, Mattesia dispora, the cysts of which are spread by Cephalonomia watersoni.

Symptoms by affected plant part

- Seeds

- internal feeding

Detection and Inspection Methods

Cryptolestes spp. is sometimes overlooked in stores because they are very small and can hide in small cracks and in the seams of sacks. Trapping methods and pitfall traps can be used, as adults cannot climb clean glass. They are also attracted to refuge traps.

Control

Phosphine is commonly used to control C. ferrugineus but resistance has often occurred. Fumigation with carbon disulphide is also effective. Most stored products insecticides such as deltamethrin, fenitrothion and dichlorvos are effective. Pirimiphos-methyl has been experimentally shown to be effective. Resistance to Malathion is well documented. Fenoxycarb has also been suggested for the control of C. ferrugineus. Inert dusts can be effective against C. ferrugineus and the use of ice-nucleating bacteria has been suggested, to decrease the ability of the beetle to survive in sub-zero temperatures. As for many other stored products pests, aggregation pheromones could be used for trapping. Controlled atmospheres deprived of oxygen have been used for control. Refrigeration of commodities has been used to lower the size of infestations, as well as aeration of stores to control the moisture content of grain. Mechanical cleaning of grain has also been shown to be effective.

Grain aphid - Sitobion avenae F-- Большая злаковая тля

Major hosts

- oats
- barley
- wheat

Minor hosts

- rice
- rye
- maize

Affected Plant Stages

- flowering stage
- fruiting stage
- vegetative growing stage

Affected Plant Parts

- Inflorescence
- leaves

Biology and Ecology

Grain aphid is a monoecious holocyclic aphid laying its eggs on various Poaceae in autumn. Temperature affects the rate of increase of S. avenae it can develop and reproduce at 5-30°C and the optimal rate of increase is between 20 and 22.5°C. Parthenogenetic morphs could withstand cold exposures to -10°C. Grain aphid lives on the leaves of Poaceae before heading, after which it lives preferentially on the ear heads. Its rate of increase on wheat is deeply affected by the growth stage of the host plant, with the highest rate of increase when feeding on ears at the milky-ripe stage The intrinsic rate of natural increase of Grain aphid was found to be reduced on plants infected with barley yellow dwarf virus (BYDV), although more alate morphs developed on virus infected plants. Grain aphid is a good vector of two luteoviruses (BYDV-PAV and BYDV-MAV, belonging to the barley yellow dwarf luteovirus complex).

Pathogens

- Conidiobolus coronatus attacking nymphs, adults
- Conidiobolus thromboides attacking larvae, nymphs, pupae, adults
- Gibberella cyanogena attacking nymphs, adults
- Pandora neoaphidis attacking larvae, nymphs, pupae, adults

Parasitoids

- Aphelinus abdominalis attacking nymphs, adults
- Trioxys indicus attacking nymphs, adults

Predators

- *Adalia bipunctata* attacking nymphs, adults
- *Bembidion quadrimaculatum* attacking nymphs, adults
- *Cantharis lateralis*
- *Erigone atra* attacking nymphs, adults
- *Hippodamia tredecimpunctata* attacking nymphs, adults
- *Malachius geniculatus* attacking nymphs, adults
- *Orius majusculus* attacking nymphs, adults
- *Pterostichus madidus*
- *Syrphus ribesii* attacking nymphs, adults
- *Trechus quadristriatus* attacking nymphs, adults

Notes on Natural Enemies

Among pathogens, fungi (mainly Entomophthorales) are especially efficient in limiting Grain aphid populations in temperate areas with a mild and wet climate. Parasitoids attacking Grain aphid are Hymenoptera and belong mainly to the Aphidiidae. Parasitoids are active early in the year, especially when spring is mild, and seem to be more efficient on scattered aphid populations at the beginning of spring, than later when aphids reach high densities. The level of parasitism in Grain aphid populations may depend on the types of aphid clones involved and especially on their body colour.

Impact

It is a major pest of wheat (Triticum aestivum). Grain aphid causes direct damage by feeding on fruits, leaves, stalks and ears, and indirect damage by excreting honeydew and transmitting viruses. Grain aphid mainly affects cereal yields by removing plant nutrients and reducing photosynthesis via honeydew accumulations.

Direct Feeding Damage

Grain aphid outbreaks can be very damaging to cereal yields, especially in wheat. Damage due to Grain aphid manifests itself as reduced number of heads, reduced number of grains per head, and reduced grain or seed weight (usually expressed as 1000-grain weight). Wheat yields can be reduced by around 20-30% during outbreaks. The effect of Grain aphid damage on yield therefore depends on the size and duration of infestation, the phenological stage of the crop when infested, pesticide applications, cultural practices, use of resistant cultivars, natural enemy abundance, weather conditions, and on other factors, such as foliar disease and dryness, that are liable to increase with aphid damage.

Honeydew and Fungal Pathogens

Honeydew, a sugar-rich aphid secretion, can cause physiological changes and chlorotic symptoms in leaves and affects net carbon dioxide assimilation in wheat. Honeydew from Grain aphid appears to be particularly disruptive to photosynthesis of cereals. Yield losses due to honeydew, as a result of high infestations early in the season, can be considerable; although simulations show that later in the growing season damage caused by honeydew decreased whilst that caused by aphid feeding remained constant. Honeydew production and its effect in encouraging the growth of secondary fungal pathogens may account for more than 60% of total yield loss.

Indirect Damage by Virus Transmission

Grain aphid is an important vector of barley yellow dwarf luteovirus (BYDV), which it transmits in a persistent manner.

Symptoms

There is no set of clear symptoms for Grain aphid infestations on leaves or earheads. Early yellowing of upper leaves and ears could be observed after a heavy infestation but is not specific to Grain aphid. The same type of symptoms could also be due to other aphid species or several plant pathogens.

Symptoms by affected plant part

- Inflorescence: abnormal colour
- Leaves: abnormal colours

Detection and Inspection Methods

The time of field infestation by migrants could be assessed by alate aphid trapping. This can be done with yellow trays placed in the field at crop canopy level or, on a regional scale, by suction trapping.

Cultural Control

In temperate zones early sowing enables aphids to invade early in the autumn, thus enhancing the spread of barley yellow dwarf luteovirus. Early-sown fields may also have larger overwintering Grain aphid populations than late-sown fields, and subsequently earlier and higher aphid populations in spring. When compatible with other agricultural practices, late sowing in autumn leads to a reduction in Grain aphid infestations. Some practices such as increasing seed rate and under sowing could benefit natural enemies High levels of nitrogen fertilization, often applied in split doses, retard alate formation and increase Grain aphid fecundity as the flag leaf remains green during grain-filling.

Chemical Control

Chemical control has to be applied during the period of overlap between aphid flight and seedling emergence and repeated immediately afterwards. In spring, it is usually done on wheat between ear emergence and flowering; delayed sprays are ineffective or uneconomical. Many insecticides are effective on aphids, for example, carbamates and pyrethroids, but most of them are also harmful to parasitoids and predators. Seed treatments with systemic insecticides (e.g. imidacloprid) are efficient to prevent autumn infestations and consequently BYDV spread because of their prolonged persistence in the plants.

European wheat stem sawfly - Cephus pygmaeus L - Хлебный пилильщик обыкновенный

Habitat

- Natural and cultivated grasslands

Major hosts

- oats)
- barley
- rye
- wheat

Wild hosts

- wild oat
- bromegrasses

Host Range

European wheat stem sawfly is a polyphagous species whose larvae attack a wide range of graminaceous hosts of both wild and cultivated species. The hosts are widely distributed among four tribes of the subfamily Pooideae, however, as European wheat stem sawfly is found in the four main crop species, the list is concentrated on tribe Triticeae (Triticum, Hordeum, as well as the weedy Elymus). The Pooideae subfamily accounts for most of the grass species in the insects' range and hence the apparent widespread restriction of European wheat stem sawfly to this subfamily.

Affected Plant Stages

- Flowering stage
- fruiting stage
- vegetative growing stage

Affected Plant Parts

- Fruits/pods
- Inflorescence
- Seeds
- Stems
- whole plant

Biology and Ecology

European wheat stem sawfly is a univoltine species, whose over-wintering adults emerge and are volant from the second week of May until the end of July. Usually, copulation occurs soon afterwards, gravid females laying a single egg per stem, usually before the head of the grass has emerged and between the third and fourth nodes, although ovipostion is often higher up or much further down the stem, toward the root. A maximum of about 50 eggs are laid, incubation lasting from 7-10 days. Newly-emerged larvae are characterized by the considerably enlarged head, and are armed with a powerful pair of mandibles. They commence feeding immediately on parenchymatous cells, tunneling through nodes when these are encountered. Frass is found both fore and aft of larvae when stems are examined, which indicates the larvae make their way up and down the stem several times during their life. The larvae undergoes two or three moulds (3-4 instars are found), however, the precise number of instars is uncertain, as only head masks and part of the anal region have been found. The larval phase lasts for about one month, after which pupation occurs, usually near the roots. It is at this stage, during the construction of the hibernation and pupation chamber, that European wheat stem sawfly causes most damage. The mature larva compacts a mound of frass about 38-50 mm above the ground line and just below this, cuts a V-shaped groove around the interior of the culm, leaving a thin layer of uncut epidermis. Below this incision another plug of frass is placed. This is deeply concave on its upper surface, whilst the lower surface to which the exarate pupa is attached is flattened. Below this plug a pupal case is spun and over-wintering occurs, the resultant adults forcing their way out through the plug.

Pathogens

- Beauveria bassiana

Parasitoids

- *Bracon stschegolevi*
- *Endromopoda detrita*
- *Picroscytoides erdoesi*

Predators

- *Machimus annulipes* attacking adults

Symptoms by affected plant part

- Fruits/pods: abnormal shape
- Inflorescence: abnormal colour
- Seeds: discolorations
- Stems: internal discoloration; external discoloration; internal feeding
- Whole plant: plant dead; dieback; uprooted or toppled

Detection and Inspection Methods

Examine kernel for smaller than usual size, and lighter weight and colour; examine stem for signs of ‘girdling’ and for signs of stem breakage and lodging.

Cultural control

The burning of stubble to kill off over-wintering larvae remains popular but its value is highly debatable. Whilst this practice may kill off those larvae in the above-ground stalks, the hollow part of a stalk is below-ground (up to 5 cm). Over-wintering larvae in the lower reaches of the stalk will be unaffected, thus failing to eradicate the problem. There is also a concomitant risk of soil erosion on burned fields. Deep-ploughing (12-15 cm depth) is effective but wind-erosion of soil is a subsequent danger, although this is less of a problem if a single blade is ploughed in at the level of the stubble roots, thus exposing the larvae to the effects of desiccation or frost. Crop-rotation and delayed seeding often reduces the local populations of European wheat stem sawfly, particularly when less favourable graminaceous hosts are sown. At the same time, delayed seeding may result in reduced crop yield. Trap-crops of Graminae may be sown around the margins of grain fields as a control measure (sometimes, with a fallow strip in between trap- and cash-crop), in order that they may receive heavy infestations, or be parasitized more readily. However, the loss of time and acreage is considered prohibitive.

Biological control

In general, biological control has had limited effect on pest species of Cephidae.

Chemical control

No foliar sprays are known to be effective against European wheat stem sawfly, and systemic insecticides (for example, organophosphates), which may be effective against the short-lived adults, are few in number and may be ineffective against eggs and larvae laid inside stems.

Hessian fly - Mayetiola destructor (Say)

Major hosts

- wheat

Minor hosts

- barley
- rye

Affected Plant Stages

- Flowering stage
- post-harvest
- seedling stage
- vegetative growing stage

Affected Plant Parts

- Growing points
- Inflorescence
- Stems
- whole plant

Biology and Ecology

Females mate soon after emergence from pupae and start to oviposit an hour or so after mating. They fly at low levels within crops to locate host plants. In calm weather they fly above crops and are then likely to be taken up in thermals and dispersed over distances of up to 5 miles from emergence sites. Eggs are laid in lines along the furrows on the upper surfaces of leaves and each female may continue to oviposit for 2-3 days, laying a total of 100-200 eggs. Adults may live for up to 6 days in moist cool weather. Eggs hatch after 3-12 days, depending on prevailing temperatures, and the main daily hatching period is between 17.00 h and 08.00 h. Eggs can withstand severe frost but both eggs and first-instar larvae are susceptible to desiccation. First-instar larvae spend 12-15 hours crawling down the leaves to feeding sites under the leaf sheaths and against the stems. They then moult to the second instar and feed for 2-3 weeks when temperatures are high, or for up to 2 months when the weather is cooler. Feeding larvae are virtually static throughout this period and feed by secreting digestive enzymes and ingesting plant sap. When fully fed, the larva moults to form a distinctive spindle-shaped dark-brown puparium, about 2-6 mm long, which is sometimes referred to as the ‘flax seed stage’. The diapause which facilitates carry-over from one growing season to the next. Larvae eventually pupate within the puparia and the pupal stage lasts from 6-33 days, depending on temperature. The total duration of the life-cycle is therefore extremely variable with a minimum of about 20 days, and an observed maximum of at least 49 months.

Parasitoids

- Aprostocetus zosimus attacking pupae
- Pseudoderimus mayetiolae attacking pupae
- Trichomalopsis subapterus

Symptoms

In autumn and spring, larval feeding on young plants stunts growth and the central shoots yellow and die. Severe infestations at this stage may kill plants, resulting in gaps in the crop. At later stages of crop growth the developing stems are weakened by larvae feeding at the nodes. This results in withering and lodging, which causes loss of yield since the earheads fail to develop. Any grain developing in affected heads tends to be of poor quality.

Symptoms by affected plant part

- Growing points: dead heart
- Inflorescence: abnormal forms
- Stems: abnormal forms; abnormal growth
- dieback
- Whole plant: dwarfing

Detection and Inspection Methods

Field infestations can be detected by visual inspection for symptoms, supported by dissection of samples of plants to establish the presence of larvae and/or puparia. Adult activity may be monitored by light, suction, sticky or water traps, but mixed catches will make identification difficult at times.

Cultural Control

Cultural control include crop rotation, ploughing-in stubbles, destruction of volunteer wheat plants, good soil preparation with the use of good seed to ensure quick germination, and moderately late sowing of winter wheat to avoid infestation by the autumn generation of adults. These practices must be modified to meet local conditions.

Biological Control

High levels of natural parasitism have been recorded in many areas where Hessian fly is a pest.

Chemical Control

Chemical control measures (based on the use of systemic or non-systemic insecticides) against ovipositing females, eggs and first-instar larvae, have been developed, but are not always effective.

Pheromonal Control

Behavioural studies indicate that females attract males by releasing a sex pheromone from the ovipositor. Pheromone biosynthesis has been studied and the pheromone has been identified.

Integrated Diseases Management in Winter Wheat

Identification and Management

Disease management in winter wheat hinges primarily on prevention. Unlike many weed and insect problems, diseases and the yield losses they impose are difficult to control once infection and disease development have occurred. Chemical controls, often sought after disease symptoms and crop damage are apparent, are frequently not available or economical once wheat diseases become established.

Three conditions must be met before diseases caused by biological pathogens (disease causing organisms) will develop and spread:

- The pathogen must be present
- There must be a susceptible host plant
- Environmental conditions must be favorable for infection and spread of the disease

Disease management, therefore, involves manipulating one or more of these three elements to suppress disease and achieve a biological or economic benefit. Complete disease control is seldom necessary and frequently not economically feasible. Selected crop rotations and seeding dates, for example, can be utilized to avoid pathogens that may be present in soil or crop debris. Utilizing certified pathogen free seed and disease-resistant varieties is encouraged not only to limit disease development but to reduce pathogen populations. Other cultural practices such as nutrient supplementation or application of chemical pesticides may discourage disease development and augment crop performance.

In a broad sense, a disease is any abnormality that induces physiological changes in plants that eventually may be expressed as visible symptoms. Yellowing distorted or stunted growth, wilting, spots, rots, and discolored tissues are some of the indications of disease. Such symptoms may result from infectious or noninfectious agents and may not be sufficiently specific to easily identify their cause. Noninfectious diseases include disorders and stresses caused by mechanical or environmental variables such as nutrition, temperature, moisture, and toxicants. Infectious diseases, which are the primary focus of this discussion, are caused by biotic or living plant pathogens such as bacteria, fungi, and nematodes. Viruses and virus-like agents, although not technically living organisms, also cause infectious disease. These agents of infectious disease are able to multiply or replicate, be dispersed from plant to plant, and cause new host infections.

Farmers have many weapons available for use in the war against crop diseases. Following are the main components of an integrated **disease management** program.

Field monitoring

Frequent field monitoring is important for identifying problems in the early stages before they become severe. The frequency of field visits should be increased during potential problem periods and when weather conditions favor disease development. The potential for crop damage is normally greatest in high yield environments where good moisture distribution favors disease infection and development. Periods of hot, dry weather stall the development of many diseases. Correct diagnosis is crucial because control measures are different for the different diseases.

Disease identification

Diseases must be correctly identified before effective measures for control can be put in place. Most diseases have characteristic symptoms that can be used for identification. However, some diseases have similar symptoms and the symptoms of the same disease may be different on different wheat varieties.

Resistant Varieties

Resistant varieties are often the most effective, economical, and environmentally friendly method of disease control. Planting several different varieties with different strengths and weaknesses is a good disease management strategy. It reduces the risk that any particular disease will cause catastrophic losses. Diversification of variety maturity also reduces risk of some diseases.

Crop Rotation

Crop rotation is a "best management practice" because it reduces the carryover of diseases, insects, and weeds between crops. One year of rotation or fallow is enough to break the cycle for most diseases.

Delayed Planting

Early planting is sometimes necessary for forage production or erosion control. However, early planting is also a risk factor for several diseases.

Seed Treatments

Seed treatments are excellent for control of seed borne diseases. In order to keep our seed supply clean, seed treatments are highly recommended for all seed production fields.

Foliar Fungicides

Foliar fungicides are one of the few disease management tools that can be used in the spring.

Bio control

Bio control is the use of natural biological competition, predation, or antagonism to control a pest. Use of bio control to manage wheat diseases is currently limited.

Disease Classification

it is important that farmers have a basic understanding of the diseases that damage their crops and the control options available to minimize or prevent economic loses.

Crop management

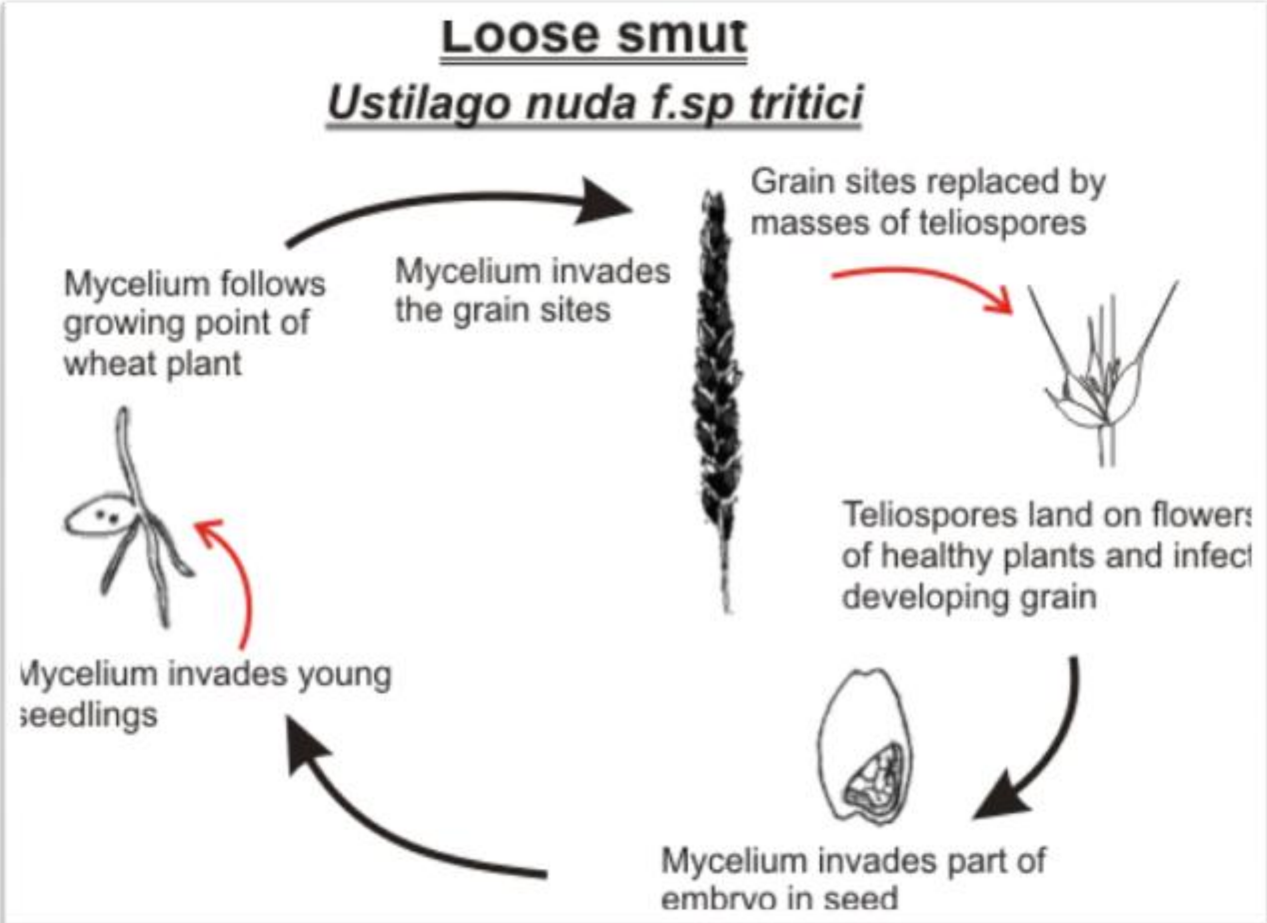
Crop management practices that promote healthy growth and vigorous root development help the plant to defend against attacks by diseases.

Loose wheat smut - Ustilago nuda f.sp. tritici (Schaffnit) -

Пыльная головня пшеницы

Host Plants

- barley
- Oat
- wheat



Symptoms

- loose smut symptoms do not become apparent until ear emergence
- ears of infected plants emerge earlier
    - darker colour
    - slightly taller than the ears of healthy plants
- On infected ears the florets are full of a mass of black spores
- These spores are initially held by a thin membrane, which soon ruptures releasing spores
- eventually all that remains of the head is the bare stalk

Incidence

- **seed infection** begins with telio spores disseminated from systemically infected inflorescences
- within 1 day, telio spores germinate by basidia or promycelia and infective hyphae penetrate the ovary wall
- **during maturation**, the mycelium is changed to a thick-walled, swollen, dormant mycelium
- **optimum time for infection** occurs before pollination and within 1-2 days of pollination

Effect on Seed Quality

No definitive symptoms of seed infection are evident on infected seeds. A blue fluorescence noted under UV light has been associated with smutted kernels, but this was not well correlated with embryo infection.

Pathogen Transmission

- incidence of infection of kernels is strongly related to infection of the plants grown from infected seeds
- when infected seed germinates, the pathogen follows the growing point of the plant, It then enters the seed primordia
- flowering heads, except the rachis, are invaded intracellulary and converted to sori
- The mycelium in sori differentiates into teliospores, which fragment and are dispersed by wind to infect healthy inflorescences

Seed Treatment

Fungicides

- Seed treatment with systemic fungicides is an effective method of controlling seed transmission
- Carboxin has been shown to be particularly effective
- Triademinol and difenoconazole are also effective

Hot water

- seeds are dipped in water at 45°C for 2 h then air-dried at 40°C for 5 h, although less effective, still give satisfactory control
- no damaging effect on germination or field emergence

Stem rust of cereals - Puccinia graminis - Септориоз злаковых

Major hosts

- wheat
- Oats
- Barley
- Rye

Affected Plant Stages

- Flowering stage
- fruiting stage
- seedling stage
- vegetative growing stage

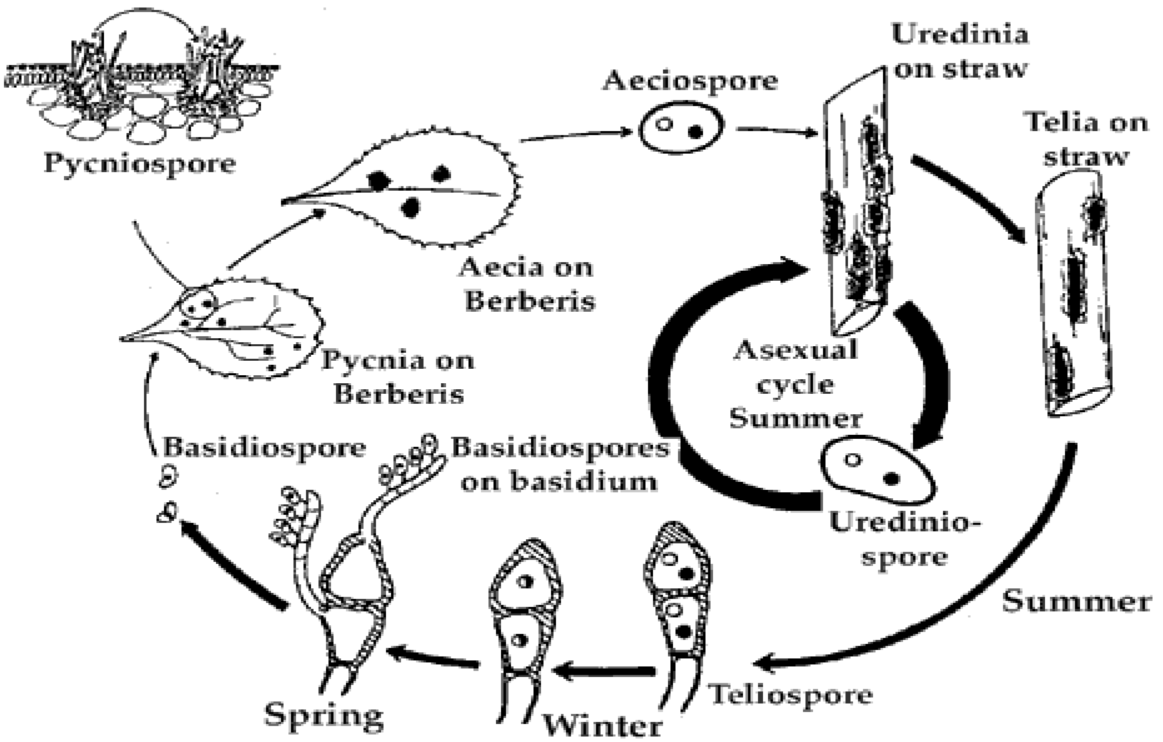
Affected Plant Parts

- **Inflorescence:** lesions
- **Leaves:** fungal growth
- **Seeds:** lesions
- **Stems:** mycelium visible

Impact

- Stem rust cause major devastation to wheat crop
- Widespread epidemics occur relatively infrequently, but disease within a region or in individual fields is frequently severe, often completely destroying the crop

Life Cycle of *Puccina graminis*



Symptoms

- elongate elliptical blisters on the leaves and stems of the plant
- run parallel to the long axis of the leaf or stem
- after some days, a mass of rust-coloure d spores
- later in the season, a new spore type, the telospore, forms and the lesions turn black

Uredinial Stage

The uredinia may occur on leaves, stems, leaf sheaths, spikes, glumes, awns and occasionally on grains of their grassy hosts; stems and leaf sheaths are the main tissues affected. On stems, the uredinia are elongated and reddish-brown; loose epidermal tissue is conspicuous at the margins of the uredinia, giving a roughened feel to the stem surface. The uredinia coalesce to cover large areas of the host tissue in heavy infection. Since the urediniospores are dehiscent, they are released as powdery masses from the uredinia.

Telial Stage

The telial stage occurs in the same tissue as the uredinial stage, but becomes shiny-black. The teliospores are sessile, and the telial tissue is, therefore, firmer than the uredinial tissue; no spores are released.

Pycnial Stage

The pycnial stage occurs on the young leaves of the alternate host, mainly Berberis vulgaris. Pycnial infections initially appear as light, chlorotic areas on the adaxial leaf surface, then become light orange-brown lesions, consisting of individual small cone-shaped eruptions (the pycnia), often occurring in clusters.

Aecial Stage

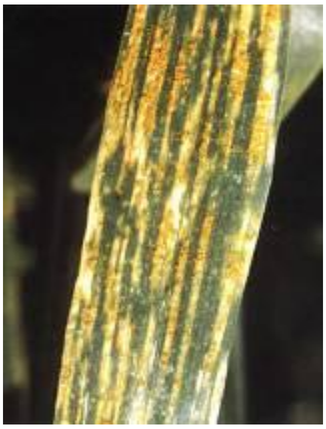
The aecia develop on the abaxial surfaces of the leaves of the alternate host. When mature, they appear as brightorange, closely-packed, raised clusters of individual aecia. The aecia are cylindrical in shape and flare out at their apices, appearing as a grouping of rings within the aecial cluster.

Symptoms by affected plant part

- Inflorescence: lesions
- Leaves: fungal growth
- Seeds: lesions
- Stems: mycelium visible

Comparison of Different Wheat Rusts

Diseases	Leaf Rust	Stripe Rust	Stem Rust
Plant parts affected	leaf	leaf and head	stem and leaf
Lesion (pustule) colour	orange	yellow	dark red
Lesion shape	single	stripes	single
Temperature range	15°C-27°C	12°C-21°C	18°C-30°C


Detection and Inspection Methods

- inspect disease at any stage of growth: the seedling stage until about the five- or six-leaf stage
- stem rust infections are most obvious on the leaves
- main time for inspection: the crop begins to head (late boot stage) until near maturity
- detection of stem rust pustules: sweep aside the canopy of growth and look into the crop with strong sunlight coming from behind
- the red-brown pustules are easily recognized against the normally blue-green colour of healthy stem tissue
- differentiate infections due to stem rust from other causes by gently feeling the plant tissue between the thumb and forefinger for the roughened surface caused by rust infection

Diagnosis

The diagnosis of stem rust infections is principally by means of their symptoms.

Control

There are three main methods of controlling Stem rust: the use of resistant cultivars, chemical control and cultural control.

Host-Plant Resistance

Genetic resistance is the most effective, least expensive and most environmentally safe means of control.

Chemical Control

- A number of fungicides are highly effective against stem rust
- Chemical control is usually only considered where losses are expected to be very high

Cultural Control

- Planting as late as possible in the autumn help to reduce the time of exposure of the crop to the pathogen
- The success or practicality of this approach depends on a detailed knowledge of the epidemiology of the rust in a particular area

Biological Control

- *Darluca filum* is one of the more aggressive hyperparasites which are capable of infecting a range of rust fungi

Brown wheat rust - Puccinia triticina - Ржавчина

Major hosts

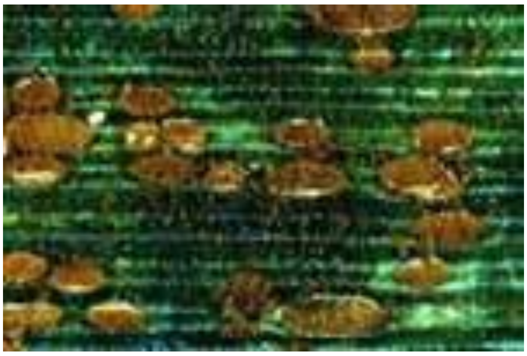
- wheat

Minor hosts

- Bugloss
- meadow-rue

Wild hosts

- quackgrass



Affected Plant Stages

- Flowering stage
- fruiting stage
- seedling stage
- vegetative growing stage

Affected Plant Parts

- Leaves
- stems

Biology and Ecology

Epidemics in areas where alternate hosts are functional, occur when the overwintered telia from wheat produce basidiospores and infect the young leaves of Thalictrum. Pycnia bearing the spermatia (pycniospores) and receptive hyphae are produced on the upper surface of Thalictrum leaves in 7-10 days. These gametes are heterothallic and are carried between pycnia when insects visit in search of the nectar. Fertilization takes place when compatible spermatia come in contact with receptive hyphae; this is followed by the appearance of aecia on the lower side of the infected leaves. The binucleate aeciospores are capable of infecting nearby wheat plants and producing viable urediniospores. When the source of inoculum to initiate epidemics is not aeciospores from alternate hosts, but urediniospores produced on infected wheat leaves, the inoculum may be either local or exogenous in nature. Aerial dispersal occurs as urediniospores are passively released from uredinia on wheat leaves. The urediniospores become airborne and may be transported up to several hundred kilometres in an air mass before being deposited by gravity or washed out of the atmosphere by rain.

Impact

Leaf rust seldom kills wheat, but it is capable of causing 35-50% yield loss in endemic areas where severity levels of 25-40% are reached at the tillering stage and 100% at the flowering stage. The disease causes more damage worldwide than other wheat rusts. Losses caused by leaf rust particularly originate from reductions of the wheat photosynthetic area. Infected plants normally produce a lower number of tillers, lower amounts of grains per head and smaller grains.

Symptoms

On wheat, the disease is recognized by small to relatively large yellowish-brown to cinnamon-brown pustules scattered on the upper leaf surface and leaf sheath. Small secondary pustules may develop in a circle around older pustules on susceptible host cultivars. On resistant cultivars, pustules may be small or appear only as necrotic spots, which do not develop spores. A halo of pale green or yellow appears around the uredinium when host resistance is incomplete. When the temperature increases, some pustules turn black due to the production of teliospores. Telia remain covered by the host epidermis and are blackish-brown in colour. On Thalictrum, pycnia are clustered in small groups on slightly swollen yellowish to reddish-brown areas on the upper leaf surface. Aecia are usually cupulate in clusters on gall-like areas on the undersurface of the leaf.

Symptoms by affected plant part

- Leaves: lesions; abnormal colours; fungal growth
- Stems: mycelium visible

Detection and Inspection Methods

Early infection appears on the lower leaves of host plants. Methods, techniques and analysis of data vary depending on the final use of the data collected. The intensity of leaf rust in the field is scored using a modification of Cobb's scale or as percent leaf area covered. The basic idea of the Cobb scale is that when 37% of the leaf surface is covered by pustules, disease severity is equal to 100%. Both pustule size and their intensity on the leaf may be considered. Disease severity is rated on the Cobb scale as discrete class intervals (10%, 20% etc.). Both severity and pustule type are taken into account while recording disease in the field; for example, 20 MS (moderately susceptible) represents the 20% severity of susceptible pustules type, while a rating of 15 MR represents 15% severity of moderately resistant pustule type. This is one method of scoring used to evaluate field resistance to leaf rust.

Chemical Control

For almost a century, chemicals have been tested for control of leaf rust; however, this method of control has been found to be unfeasible. Systemic fungicides showed promise, in particular fenbuconazole due to its specificity to leaf rust. Triadimefon was also effective against leaf rust but was more effective against stripe rust, caused by Puccinia striiformis f.sp. tritici. It is necessary to keep the flag leaf healthy as it contributes significantly towards grain filling. It is also important that fungicides used for control do not leave residues in the grain.

Yellow rust - Puccinia striiformis - Ржавчина

Major hosts

- barley
- rye
- wheat

Minor hosts

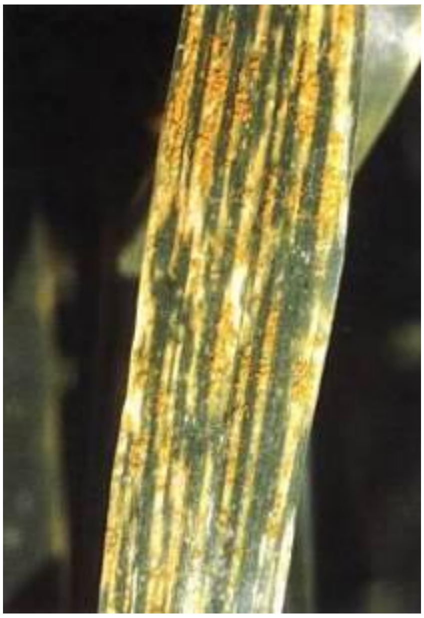
- *turfgrasses*

Wild hosts

- wheatgrass

Affected Plant Stages

- Flowering stage
- seedling stage
- vegetative growing stage



Affected Plant Parts

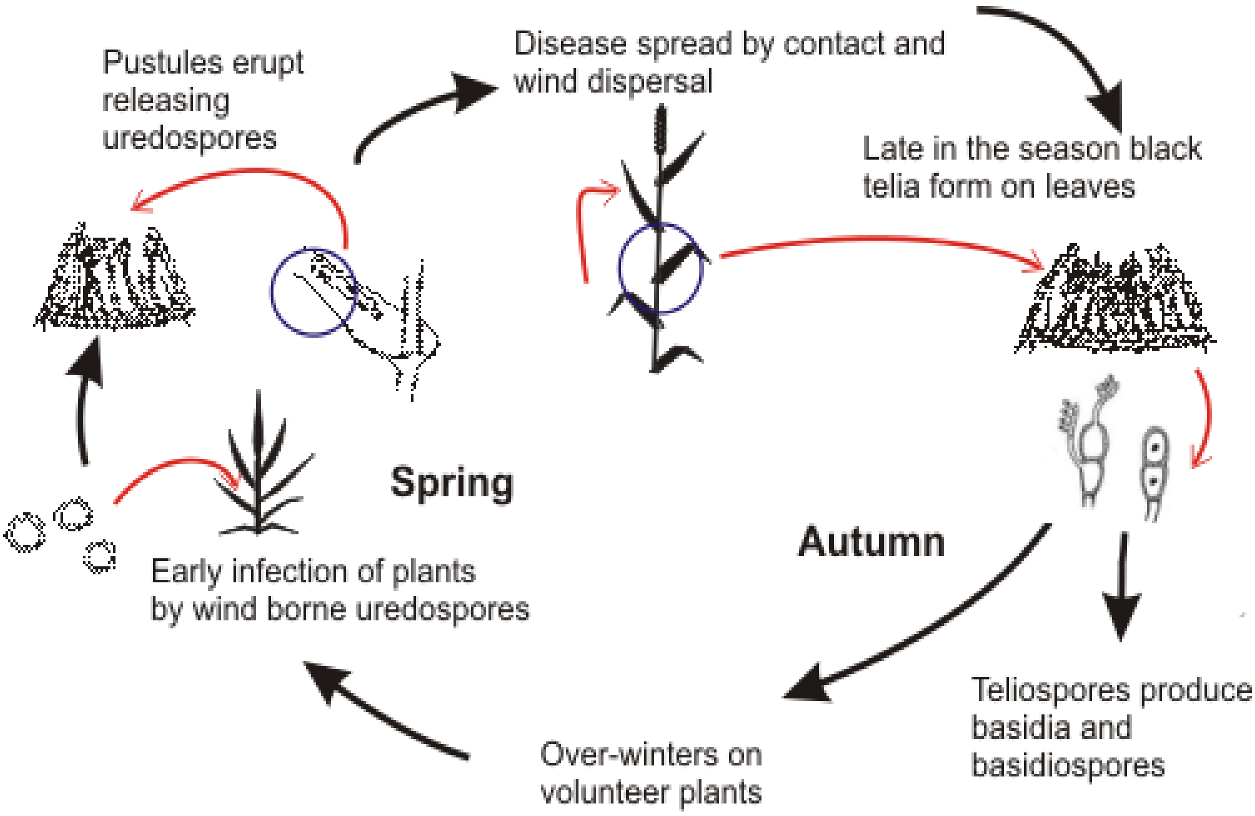
- Inflorescence
- leaves
- stems

Identification/ symptoms

- Yellow pustules of stripe rust can occur on all aerial parts of the plant, but are most frequently seen on the leaves
- Individual pustules (uredia) are roughly circular and about 0.5- 1 mm in diameter
- The pustules are often arranged into conspicuous stripes and their linear orientation between vascular bundles can progress the length of the leaf blade
- On seedlings: pustules appear individually rather than in lines
- During the summer: the formation of masses of spores between the glume and the lemma
- At the end of the season, black telia may form in patches of tissue that have been killed by stripe rust uredia

Yellow rust

Puccinia striiformis



Symptoms by affected plant part

- Inflorescence: lesions
- Leaves: lesions; fungal growth
- Stems: mycelium visible

Detection and Inspection Methods

- Yellow rust mainly infects leaves of wheat
- pustules (uredia) are yellow and arranged into conspicuous stripes
- powdery masses of yellow-orange spores in each pustule
- spore masses may also be observed between the glume and the lemma if the ears are infected by the pathogen



Impact

- Yellow rust occurs on wheat crops in the cooler areas in which wheat is cultivated
- major method of control is the use of resistant cultivars
- The pathogen spreads by means of airborne urediospores and when they land on wheat plants they germinate in high humidity, usually at temperatures of less than 15°C
- Sporulation is mainly on the upper surface of the leaves
- Infections also occur on the ears, and spores accumulate inside the glumes
- In resistant cultivars there are signs of incompatibility between the host and pathogen and host cells die, thus limiting the growth of the pathogen

Biology and Ecology

- yellow rust does not form any specialized resting spores to overwinter and is an obligate parasite (i.e. it requires living green plant material in order to survive)
- in winter survive as dormant mycelium or uredia on volunteer plants and early autumn-sown wheat
- in spring, particularly in cool moist weather, the fungus starts to grow again and more urediniospores are produced
- temperatures of 10-15°C and a relative humidity of 100% are optimal for spore germination, penetration and production of new, wind-dispersed spores
- life cycle may take as little as 7 days during such conditions
- disease cycle may be repeated many times in one season
- stripe rust epidemics tend to start from disease foci in the field
- pattern of spread may be related to wind direction
- local inoculum initiates disease epidemics
- possibility of urediniospores being blown for long distances and into a crop
- Stripe rust epidemics tend to occur in spring and early summer
- fungus is inhibited by temperatures over 20°C
- late summer, telia may form which give rise to teliospores. The latter can form basidiospores
- no alternative host has been found and the teliospores therefore appear to have no function in the life cycle
- stripe rust may debilitate and kill young plants
- it increases water losses of infected plants, and reduces foliage, root growth and yield by reducing the rate of photosynthesis, and increasing the rate of respiration
- infected tissue acts as a ‘sink’ for photosynthate

- grain may be of low quality because it may lack starch and contain cellulosic materials that are of little or no nutritional value

Seed Treatments

Seed treatments are considered an important strategy to protect against plant infection by yellow rust in the field. Triadimenol + fuberidazole seed treatment are effective in controlling early infection by yellow rust and are superior to a range of spray treatments applied in late autumn. Stripe rust head infections are most effectively controlled by the application of fungicides closely to, or just after, head emergence.

Chemical Control

- Chemical control against P. striiformis can be attempted if resistant varieties are scarce
- On very susceptible varieties, fungicides should be applied as soon as the disease appears
- On less susceptible varieties, fungicides should be applied if weather conditions are favourable for disease development and there is evidence of the disease spreading in the crop
- Disease at the seedling stage can be controlled by treating seed with fungicide
- Fungicides approved against yellow rust include carbendazim, fenpropidin, propiconazole, triadimenol and tridemorph

Bacterial leaf streak - Xanthomonas translucens

Major hosts

- barley
- rye
- wheat

Minor hosts

- oats

Wild hosts

- Awnless brome

Affected Plant Stages

- Flowering stage
- fruiting stage
- vegetative growing stage

Affected Plant Parts

- Inflorescence
- Leaves
- Seeds
- stems

Morphology

Bacterial leaf streak is an aerobic, Gram-negative rod with one polar flagellum. Cells measure 0.5 x 1.0 µm. On YDC agar medium, the colonies are pale yellow, mucoid, convex and smooth with entire margins. On Bacterial leaf streak agar isolation medium, colonies have a similar appearance except that they tend to be clearer (less mucoid), and some colonies appear flattened rather than convex.

Biology and Ecology

Bacterial leaf streak is adapted to grow as an epiphyte on wheat. Epiphytic growth of plant pathogenic bacteria is probably a prerequisite to infection.There is probably little saprophytic growth and multiplication of Bacterial leaf streak in the absence of green plants. Transmission by seed is the most likely means of long-distance dissemination and survival from year to year. The pathogen can remain viable in infested seeds for more than 5 years. Little is known about the location of the pathogen in seed, but it is suspected that the most important inoculum is carried internally.

Incidence

Bacterial leaf streak is seedborne. Producing seed in dry environments using furrow irrigation will reduce bacterial streak and the level of seedborne Bacterial leaf streak. Some contamination is likely unless the production field is planted with seed free of the pathogen and is well isolated from other sources of inoculum. Seed produced under such conditions would probably have a low risk of initiating an epidemic. Bacterial streak, can be responsible for great damage in winter cereals. Infected seeds and crop debris are the main form of survival and dissemination of these pathogens.

Effect on Seed Quality

Seeds from diseased plants may be shrivelled and usually have reduced test weight. No information is available on the effects of infection on germination or seedling emergence, but it is not likely that these variables would be affected greatly unless the seed was severely shrivelled.

Pathogen Transmission

Seed

Transmission by seed is the most likely means of long-distance dissemination and survival from year to year. However, more information is needed on thresholds for transmission of seedborne inoculum.

Other sources

The pathogen does not survive long periods in soil unless it is associated with infested crop debris.

Seed Treatments

There are no seed treatments that eradicate Bacterial leaf streak from seed without excessive damage to the seed. Hot, acidified cupric acetate, dry heat have been shown to greatly reduce seedborne populations of Bacterial leaf streak and bacterial streak in the field. However, acidified cupric acetate and dry heat are best suited to small seed lots, and none of the treatments are 100% effective in eradicating the pathogen or preventing transmission to plants.

Impact

Yield losses for bacterial streak and black chaff were estimated to be 30-40% in the most severely diseased wheat fields.

Symptoms

Under field conditions, symptoms may be found at all growth stages, but are most frequently observed after flowering. On leaves, bacterial streak symptoms begin as small, light-brown, water-soaked streaks that tend to be confined by the veins. Often the lesions will begin at the edges or midrib of leaves. On very susceptible hosts under moist conditions, the streaks will elongate, parallel to the veins, and develop a dark-brown water-soaking that is translucent when held up to light. Bacterial exudate in the form of small yellow droplets may be associated with the streaks when leaves are wet. Under dry conditions, the exudate will appear as small yellow granules, or thin shiny scales. Symptoms on the heads are called ‘black chaff’ and appear as distinct thin black streaks between the veins beginning at the tips of the glumes and lemmas. Under severe conditions, the streaks may coalesce giving the heads a dark appearance and the grain may be brown and shrivelled. The pathogen may also attack the stem and peduncle, causing black streaks or uniformly black lesions. Seeds from diseased plants may be shrivelled and usually have reduced up to a 34% loss in kernel weight. No information is available on the effects of infection on germination or seedling emergence, but it is not likely that these variables would be affected greatly unless the seed was severely shrivelled.

Symptoms by affected plant part

- Inflorescence: lesions
- Leaves: lesions; abnormal colours; odour
- Seeds: discolorations; galls; lesions
- Stems: external discoloration

Detection and Inspection Methods

Inspect heads, peduncles and uppermost leaves for characteristic symptoms and dried exudate between the flowering and soft dough stages. It may be necessary to use a hand lens and hold the specimen at the proper angle to observe thin scales of dried bacterial exudate. Suspect lesions on leaves can be examined for bacterial streaming to confirm the bacterial nature of the symptoms. Cut across the lesion perpendicular to the veins, mount the cut tissue in water between a glass slide and cover slip, and observe under low magnification (approximately 40 X). Fresh water-soaked lesions caused by Bacterial leaf streak will ooze masses of bacterial cells that are easily seen streaming from the cut ends of the lesion. A cell suspension can be dilution plated to isolate the pathogen. Older necrotic leaf lesions, and lesions on glumes and peduncles, will stream a few bacterial cells or none at all, but it is still possible to isolate the pathogen from these tissues by dilution plating. It is not possible to inspect seeds visually for the pathogen.

Diagnosis

Dilution plating on a semi-selective medium has been the traditional method for confirming Bacterial leaf streak as the pathogen.

Control

Where bacterial streak does not yet occur, it may be possible to exclude the pathogen through diligent enforcement of quarantine measures for the import of seed. Where bacterial streak is well established, no one method is likely to provide complete control, and several methods appropriate to specific situations should be integrated into a programme designed to limit economic losses.

Seed Treatments

There are no seed treatments that eradicate Bacterial leaf streak without excessive damage to the seed. Hot, acidified cupric acetate, dry and Guzatine Plus have been shown to greatly reduce seedborne populations of Bacterial leaf streak and bacterial streak in the field. However, acidified cupric acetate and dry heat are best suited to small seedlots, and none of the treatments are 100% effective for eradicating the pathogen or preventing transmission to plants.

Host-Plant Resistance

Genetic resistance to bacterial streak has been identified among a wide range of wheat genotypes. Resistance should be integrated into control programmes where bacterial streak has been a problem and sources of resistance can be found. Resistance in wheat appears to be quantitative and polygenic Pictorial disease assessment keys may be useful for rating disease severity in the field. Resistance is probably due to reduced ability of the pathogen to multiply in the host. There has been no definitive evidence for races of Bacterial leaf streak on wheat, so it appears that resistance will be durable.

Cultural Methods

Bacterial leaf streak may survive in volunteer crop plants, on crop debris or on alternative hosts, but these possible sources of inoculum are likely to be much less important than seedborne inoculum. Therefore, crop rotation, tillage and weed control are not likely to have a large impact on disease severity, but these practices may be useful when attempting to produce seed with low levels of the pathogen.

Wheat bunt - Tilletia tritici

Major hosts

- rye
- wheat
- durum wheat

Minor hosts

- ryegrasses
- meadow grass

Biology and Ecology

Ustilospores of Wheat bunt on seed or in soil germinate, eventually producing infection hyphae that penetrate the coleoptiles of the germinating wheat seedling. These infection hyphae grow to the apical meristem and must reach it before the internodes of the plant begin to elongate. Infection is optimum when soil moisture is midway between field capacity and permanent wilting point and soil temperature is 5-10°C. The dikaryotic hyphae move with the apical meristem. During formation of the floral tissue, the fungus ramifies in the ovarian tissue to produce the ustilospores. Just before the ustilospores form, the fungus becomes diploid, with one diploid nucleus moving into each ustilospore. Theovary wall is modified to become the exterior of the kernel-shaped sorus. The bunt sorus remains intact until harvest, when it is broken up. Ustilospores are admixed with grain or fall to the soil. Ustilospores of Wheat bunt can survive for several years on contaminated seed and in soil. The nucleus in the ustilospore is diploid and undergoes meiosis just before germination. Germination occurs over a wide temperature range, being most rapid at 18-20°C, and taking 4-5 days at 15°C and 10-14 days at 5°C. Germination is by a promycelium and haploid nuclei move into this. Basidiospores (primary sporidia) grow from the tip of the promycelium in a compact bundle. One haploid nucleus migrates into each basidiospore. The basidiospores are of two mating types, arbitrarily designated + and -. Pairs of basidiospores of opposite mating type fuse near their middles to form characteristic H-bodies. The fused basidiospores produce hyphae or secondary sporidia, both of which are dikaryotic and usually binuclueate. The fungus remains dikaryotic until shortly before formation of ustilospores. The bunt sorus remains intact until harvest, when it is broken up. Ustilospores are admixed with grain or fall to the soil. Ustilospores can occur admixed with seed. At high levels, they are obvious from the grey discolouration and foetid odour. Dispersal is mainly by movement of grain and farm machinery contaminated with ustilospores. Up to five emptyings of contaminated grain handling machinery with clean grain was needed to reduce spore numbers to an acceptable level.

Incidence

Seed lots of wheat can be contaminated with ustilospores of Wheat bunt.

Effect on Seed Quality

Infected seeds are replaced by bunt balls full of ustilospores. When harvested, many bunt balls break open, covering sound seed with black, foul-smelling powder and severely reducing the grain.

Pathogen Transmission

Seed; Ustilospores that contaminate seed lots are introduced into the soil when bunt balls break open at harvest time; these ustilospores can germinate and infect healthy seedlings.

Other sources

Soil is a source of the pathogen as it also can become contaminated by bunt balls breaking at harvest time. These infections may be due to unusually dry weather, favouring the survival of spores in the soil, or to the presence of a more persistent strain of Wheat bunt.

Seed Treatment

Fluoxastrobin is a novel broad-spectrum strobilurin fungicide from the chemical class of dihydro-dioxazines. Applied as a seed treatment, fluoxastrobin shows very good efficacy at 5-10 g a.i./100 kg seed against seed- and soil-borne pathogens including Wheat bunt on wheat. Spores on the seed are readily controlled by a range of contact and systemic fungicides, which may also prevent infection of seedlings. Treatment of all seed wheat will reduce common bunt to trace levels.

Inorganic fungicides

Copper carbonate dusts were the first widely used dry seed treatment, and during the 1920s reduced bunt from a major to a minor problem in wheat.

Other

In organic agriculture, seedborne diseases are important due to their strong potential for increase and the limited range of effective seed treatments that are acceptable for this form of agriculture. Thermal treatment with humid air and direct seed treatments with skimmed milk powder, wheat flour, powdered seaweed, hot water, mustard extracts and acetic acid have been studied. Seed dressing based on mustard extracts and seed rinsing plus coating with milk powder were the most effective organic treatments found by Plakolm and Sollinger (2000). Seed treatment with skimmed milk powder and skimmed milk gave similar control to chemical seed treatments in field trials over 4 years in Egypt (El Naimi et al., 2000). Winter et al. (1997) found that skimmed milk powder and warm water treatments were suitable at low infection pressure but less effective than chemical fungicides at higher disease pressure.

Discontinued treatments

Although very effective, organomercurial compounds have been discontinued in most countries because of environmental and human health concerns. Fenaminosulf is highly effective against bunt, but its use has been discontinued because of environmental and health concerns. Mancozeb and maneb are also highly effective. However, emergence declines when treated seed is stored for 1 year before sowing; such seed should be sown within 2 months of treatment to avoid phytotoxicity. Dithiocarbamates provide good control of bunt but their effect on seed emergence after prolonged storage of treated seed has not been reported. Hexachlorobenzene was widely used to control bunt. Its use was discontinued after both Wheat bunt and T. laevis developed resistance to the chemical, the first recorded instance of fungi becoming resistant to a fungicide.

Impact

Common bunt caused by Wheat bunt and Smooth-spored wheat bunt is potentially very important in most wheat-growing areas of the world. However, these two fungi are readily controlled with chemical seed treatments and the disease is now usually rare or minor. Common bunt has a greater effect on the value of wheat because contaminated grain has an objectionable odour and will be rejected by most growers. Untreated, common bunt can destroy more than 50% of grain, but losses are usually 5-10%. Infection by Wheat bunt has been shown to increase with depth of sowing, and to be greater on sandy soil than on moderate or heavy soil.

Symptoms

Affected plants are slightly to moderately stunted. The heads are slender and remain green longer than healthy heads; the glumes have a tendency to gape open, exposing the bunt balls. However, affected heads can often be difficult to distinguish from healthy heads. Usually, all ovaries in a head are affected, but not all heads on a plant may be infected. The entire kernel is usually replaced by bunt balls. Occasionally, the kernel is only partially affected. Bunt balls are about the same shape and size as normal kernels but are grey-brown in colour. When crushed, they release a black, powdery mass of spores with a characteristic fishy smell. Many bunt balls are crushed at harvest and the grain can be discoloured grey by masses of bunt spores. This grain will smell of rotten fish. When infection is high, a dark smoke-like cloud can be released from the harvester.

Symptoms by affected plant part

- Inflorescence: visible mycelium; abnormal colour
- Seeds: galls
- Whole plant: dwarfing

Detection and Inspection Methods

In Crop

Inspect crop for slender heads with gaping glumes, and heads that remain green longer than the others. Crush grain in fingers and examine for black powder with fishy smell.

In Mature Heads

Rub heads between hands and look for black powder with fishy smell.

In Harvested Grain

Be alert for fishy or foetid smell. Examine grain for grey powder and broken and intact bunt balls.

Diagnosis

Seed washing will quantify the spore load in seed lots. A weighed sample of grain is shaken in a fixed quantity of water containing a detergent for a standard time. The suspension may be examined directly by microscopy, or the suspended spores concentrated by centrifuging, evaporating or filtering the liquid. The centrifuge pellet or material on the filter is resuspended in a small amount of water, a drop placed on a slide and examined under a microscope. Spore numbers can be counted using a haemocytometer.

Control

Control is essential where Wheat bunt is endemic. Resistance is available but its use is made difficult by pathogenic variation in the fungus. Chemical control is readily achieved and relatively inexpensive.

Seed Treatments

The Smooth-spored wheat bunt / Wheat bunt spores up to 50 per grain as satisfactory for sowing, whereas rates up to 100 per grain can be sown if seed treatment is applied. Spores on the seed are readily controlled by a range of contact and systemic fungicides, which may also prevent infection of seedlings.

Inorganic fungicides

Copper carbonate dusts were the first widely used dry seed treatment, and during the 1920s reduced bunt from a major to a minor problem in wheat. Hydrogen peroxide vapour is useful for killing spores admixed with seed but does not kill spores within sori.

Cultural Control

Wheat sown into soil while the temperatures remain above 15°C will escape infection.

Foot rot of cereals - Monographella nivalis

Major hosts

- Oats
- Barley
- Rye
- wheat

Minor hosts

- velvet bentgrass
- brown bentgrass

Wild hosts

- bromegrasses

Affected Plant Stages

- Flowering stage
- pre-emergence
- seedling stage
- vegetative growing stage

Affected Plant Parts

- Inflorescence
- Leaves
- Seeds
- Stems
- whole plant

Biology and Ecology

Soil-borne inoculum, which survives as saprophytic mycelium, is central to the generalized life cycle for the three cereal diseases (seedling blight, foot rot and ear blight) caused by Foot rot of cereals. Sowing cereal seed into infested soil may result in the infection of plants and the development of both seedling blight and foot rot. Later in the growing season, air-borne inoculum, usually in the form of conidia or ascospores, can infect the ears of plants resulting in ear blight and the subsequent development of seed-borne inoculum. Sources of inoculums As Foot rot of cereals does not produce chlamydospores, it is rarely isolated directly from soil. However, if soil is taken and used to grow bait plants, infection by the fungus has been reported suggesting that it is soil-borne on infected straw. A second primary source of inoculum is that of seed-borne inoculums.

Effect on Seed Quality

Seed severely infected by Foot rot of cereals s may be small and shrivelled and is associated with reduced germination and reduced emergence of seedlings. However, individual seed weight provides a poor indication of the level of infection. Infected heavy seed results in better germination and more vigorous seedlings than infected lighter seeds; however, due to a slower rate of emergence, heavy seed results in more severe symptoms of seedling blight than light seed.

Pathogen Transmission

Sowing wheat seed artificially inoculated with Foot rot of cereals has been shown to result in rapid infection of the coleorhiza and coleoptile of emerging seedlings. Although several studies using artificially inoculated or naturally infected cereal grains have demonstrated that seed infected with Foot rot of cereals significantly reduces germination and results in pre- and post-emergence blight of cereal seedlings, the efficiency with which the fungus is transmitted from seed to plant is unclear. Soil-borne inoculum, although less significant than seedborne inoculum, provides a consistent source of Foot rot of cereals inoculum.

Seed Treatments

Seed treatments have been investigated extensively for the control of Foot rot of cereals in cereals. Early treatments were primarily based on phenylmercury acetate, which is very effective at removing seedborne Foot rot of cereals inoculum present on or near the seed surface. However, incomplete control by this fungicide is observed when infection is deep-seated in the endosperm and embryonic tissue. Due to the hazardous properties of mercury, many seed treatments used presently are based on systemic fungicides, which are able to control deep-seated infection of seed by Foot rot of cereals. Triadimenol, fuberidazole, thiabendazole, fenpiclonil, fludioxinil, guazatine, bitertanol and carboxin are all effective at reducing seedborne transmission and significantly improve seedling emergence and vigour.

Pathogens

- *Papulaspora byssinia*

Parasitoids

- *Aphelenchoides hamatus*

Impact

Since Foot rot of cereals usually occurs in complexes with other low-temperature fungi such as species of Fusarium, Typhula, Rhizoctonia, Magnaporthe, Leptosphaeria, or Gaeumannomyces graminis and Pseudocercosporella herpotrichoides, it is difficult to estimate the economic impact, which this fungus has on cereals. Most significant losses have been recorded where the fungus has caused seedling blight in cereals.

Symptoms

Seedling blight

Infection of cereal seedlings can cause both pre- and post-emergence damage. Symptoms range from death soon after germination to browning of the coleoptile and the development of superficial lesions on emerged plants. In some cases, lens-shaped, pale-brown lesions can be seen on the first and second leaves. Often the first leaf takes on a shredded appearance or may be seen lying on the soil surface.

Foot rot

During the vegetative growth stage of cereal crops (tillering), symptoms consist of a brown decay of the lowest leaf sheaths and sometimes a shredded first leaf blade that lies on the soil surface. The oldest two leaves may bear red/brown spots. Following stem elongation, dark fruiting bodies (ascoma) may appear in the brown areas of the lowest leaf sheaths. As crops approach anthesis, symptoms of foot rot are visible as a greyish-brown discoloration that may girdle the lowest internode above the crown roots, or vertically as dark brown stripes. Later in the season, usually after anthesis, brown or black streaking or blotching (mottling) of higher internodes may occur and nodes exhibit a darkbrown discoloration. Severely infected stems are rotten and may bear the orange mycelium of the fungus. In some cases, affected stems break at ground level causing 'lodging' in the crop. The premature death of tillers caused by severe foot rot may show as whiteheads.

Ear blight

Early symptoms of ear blight in cereals consist of small, brown, water-soaked lesions on the outer glumes of florets. Under humid or wet conditions, florets, or more usually whole spikelets, become infected. Affected tissues lose their chlorophyll and take on a bleached straw coloured appearance at a stage when unaffected ears are still quite green. Under warm humid conditions, orange sporodochia are visible on the rachis at the base of infected spikelets. Purplishbrown coloured ascoma may also develop on the bracts.

Microdochium patch

Symptoms first appear in turf as circular orange-brown patches 2.5 to 5 cm diam. Under moist conditions, a faint fringe of white, orange or pale-pink mycelium may be seen growing around the margins of infected patches which can mat together aerial plant parts. Patches may increase to over 25 cm diam and adjacent patches may coalesce. Occasionally, patches may show 'frog-eye' symptoms where fungal mycelium is visible around the periphery of the patch and the centre of the patch tends to recover and begins to green up.

Pink snow mould

Symptoms appear in turf after prolonged thick snow cover as bleached patches covered with an abundance of white mycelium, which may mat together leaf blades. Patches gradually turn pink due to colour changes in the mycelium and the development of sporodochia.

Symptoms by affected plant part

- Inflorescence: lesions; abnormal colour
- Leaves: lesions; abnormal colours
- Seeds: discolorations; shrivelled
- Stems: mycelium visible
- Whole plant: damping off; seedling blight

Detection and Inspection Methods

Disease symptoms are easily visible under field conditions. When lesions are unclear or where confirmation is needed, infected plant material should be placed on a suitable agar medium and mycelium colony and conidia morphology used for identification.

Cultural Control

Since Foot rot of cereals is able to survive saprophytically on crop debris, those cultivation techniques such as ploughing which remove or reduce the presence of debris can reduce significantly disease problems in cereals. Excessive applications of nitrogen and lime can increase disease problems in both cereals and turfgrass. Therefore, judicious use of nitrogen and lime is recommended. In turf, avoiding surface moisture can minimize the development of Microdochium patch. This can be achieved by drainage, pricking, spiking, and scarifying and by dispersing dew by ‘switching’ or hose dragging.

Varietal Resistance

No cereal varieties are immune from infection by Foot rot of cereals, however, varieties do vary in their degree of resistance. Of the three diseases that affect cereals, only ear blight is considered during breeding programmes for the selection of resistant genotypes. Recent work has demonstrated that taller varieties are more resistant to ear blight than shorter varieties.

Chemical Control

Effective chemical control of seedling blight in cereals can be achieved by the use of seed treatments Some of these seed treatments including fludioxinil and bitertanol are not only effective at controlling seedling blight but can reduce the problems of foot rot well into spring. No foliar applied fungicides are effective at controlling foot rot. A range of fungicides is available for the control of ear blight in cereals including azoxystrobin, tebuconazole and metconazole. Benzimidazole fungicides such as benomyl, carbendazim and thiophanate-methyl are also effective.The effectiveness of fungicides against ear blight is inconsistent under field conditions. The timing of fungicide applications is critical and that the current formulations and application techniques that are used, failed to deliver the chemical to the required site of action. Control is most effective when fungicides are applied just prior to anthesis

Powdery mildew - Blumeria graminis - Мучнистая роса зерновых

Minor hosts

- meadowgrass
- turfgrasses

Wild hosts

- grasses

Affected Plant Stages

- Flowering stage
- fruiting stage
- seedling stage
- vegetative growing stage

Affected Plant Parts

- Inflorescence
- Leaves
- Roots
- stems

Biology and Ecology

Powdery mildew overwinters mainly as a mycelial mat on leaves of grasses and autumn-sown cereals. Although the ascomata produced during the late summer are fairly resistant to cold and drying out, they appear to be of secondary importance in overwintering and as a source of inoculum in the spring. This is because in temperate regions, fresh host plant material is nearly always available over the winter period. Nevertheless, in humid weather, ascomata release ascospores which can start infections on autumn-sown crops in the autumn and perhaps also in the spring. As temperatures rise in the spring, dormant mycelium commences growth and conidia are produced rapidly. Conidia usually germinate over a range of temperatures from about 3 to 31°C, although 15°C is probably optimal for germination, together with a relative humidity about 95%. Conidial germination is inhibited by free water. Under favourable conditions, fresh conidia can be found in about 7 days and are dispersed within the crop and further afield in the wind. Crucially, therefore, epidemics of powdery mildew will tend to occur during conditions of alternating wet and dry weather, with some wind to ensure dispersal on the conidia. Mildew is encouraged by very early autumn sowing, especially in barley. In the autumn, heavily infected plants may be less resistant to winter frosts and plants may die. Cereals grown late in the autumn and spring may also be more prone to attack. Powdery mildew is also encouraged by excessive use of nitrogen fertilizer and can be particularly severe in dense crops grown in a sheltered, humid environment.

Impact

Powdery mildew is one of the most common and destructive diseases of cereals. Actual losses depend on the time of disease epidemic onset and its severity, and can at the extreme reach up to 60%. Although it occurs in most, if not all, parts of the world where cereals are grown, it is not considered to be a major problem in every region. This disease can be very destructive to cereals, but generally seems to cause most damage in temperate latitudes, where economically important cereals are more frequently cultivated. Yield losses by powdery mildews are generally complex to estimate and depend on several factors such as climate, year, cropping system, cereal species and cultivar.

Symptoms

Powdery mildew appears in the form of white, later grey-tan areas on all aerial parts of cereals and grasses i.e. leaves, stems and ears, although leaves are most commonly infected. Initial symptoms are easily overlooked and take the form of chlorotic flecks on plant tissue. This is quickly followed by the development of white patches which produce masses of conidia (asexual spores) and assume a powdery appearance. If the plant is shaken even gently, clouds of conidia are released from the patches. Ascomata (fruit bodies forming sexual spores) may or may not form, but when they do, they occur late in the season and can be found embedded in the mildew colonies as tiny, dark-coloured dots.

Symptoms by affected plant part

- Inflorescence: lesions
- Leaves: abnormal colours; fungal growth
- Roots: reduced root system
- Stems: mycelium visible

Detection and Inspection Methods

Powdery mildew is easily detected in the crop since the white, fluffy colonies are easily seen on the foliage.

Diagnosis

Because, under favourable conditions, powdery mildew can infect leaves and commence sporulating within 7-8 days, and is easily identified, specific diagnostic methods are usually not required. B. graminis is an obligate biotroph and cannot be cultured axenically.

Cultural Control and Sanitary Methods

Since volunteer cereals act as overwintering sources of inoculum and stubble and crop debris may be infested with cleistothecia, eradication of volunteers and disposing of stubble and debris are important aspects of cultural control. Isolation of autumn-sown and spring-sown cereals (i.e. not growing them too close together) will reduce the risk of infection of the autumn-sown crop spreading to the spring-sown crop. In addition, because nitrogen fertilizer promotes lush crop growth and encourages mildew development, excessive use of nitrogen should be avoided.

Host-Plant Resistance

Host-plant resistance is very important in the control of powdery mildew on cereals. A wide range of resistance to powdery mildew is exhibited by varieties of wheat and in those countries where mildew is widespread, it is prudent to choose a variety with a good disease resistant rating. If the variety grown has poor resistance to powdery mildew, careful crop monitoring will be necessary in order to optimise the timing of fungicide applications. Spread of mildew from one field to another can be reduced by the correct diversification of varieties.

Chemical Control

Fungicides are widely used in the control of powdery mildew in cereals. Mildew on wheat can be controlled using morpholines (e.g., fenpropidin), triazoles (e.g., tebuconazole and cyproconazole) and the more recent strobilurin fungicides. Differences in the efficacy of fungicides used in mildew control are due, in large part, to the development of isolates of B. graminis which are tolerant to fungicide groups. Tolerance has been detected to the triazoles, for example, flutriafol, propiconazole and triadimefon. However, these are often combined with another active ingredient, commonly a morpholine such as tridemorph,

Barley yellow dwarf virus - Barley yellow dwarf viruses

Major hosts

- Oats
- Barley
- wheat
- durum wheat
- maize

Minor hosts

- creeping bentgrass
- false oatgrass
- bromegrasses

Wild hosts

- crested wheatgrass
- wild oat

Affected Plant Stages

- Flowering stage
- seedling stage
- vegetative growing stage

Affected Plant Parts

- Leaves
- whole plant

Biology and Ecology

Transmission

Barley yellow dwarf virus are not mechanically or seed transmissible, but are transmitted by aphids in a persistent, circulative but nonpropagative manner. They are not transmitted to the progeny. Aphids acquire and transmit Barley yellow dwarf virus while feeding on the phloem sieve tube elements of host plants. Minimum feeding access times reported for aphids to acquire or inoculate luteoviruses range from 0.1-4.0 h and 0.2-1.0 h, respectively. These reported times include the time required for the aphid's stylets to penetrate to the phloem tissue. Efficient transmission of most luteoviruses requires acquisition (AAP) and inoculation access period (IAP), each of 24 h. The minimum latent period (time from the start of acquisition feeding period until the insect becomes able to infect a plant) is normally between 12 and 24 h. After acquisition through the phloem, virions are transported to the aphid hindgut. They cross the hindgut epithelium and are transported in the hemocoel in coated vesicles. The virions must then penetrate the accessory salivary gland basal lamina and plasmalemma to be released into the salivary canals. The virions will then be excreted while the aphid is feeding. It is suggested that the accessory salivary gland basal lamina possess a selective function that regulates vector specificity through receptors on the plasmalemma and domains of the Barley yellow dwarf virus virions that interact with these receptors.

Vectors

Many species of aphids infest cereal crops. Twenty-five have been reported as vectors of BYDVs. The most important vectors include Rhopalosiphum padi, R. maidis, R. rufiabdominalis, Sitobion avenae, Metopolophium dirhodum and Schizaphis graminum.

Interaction between Barley yellow dwarf viruses

Cross-protection is a phenomenon by which prior-infection by a first (protecting) plant virus prevents or interferes with infection by a second (challenge) virus. Cross-protection exists amongst BYDVs and is correlated with the serological relatedness between the isolates or strains. Generally, there is cross-protection between group I BYDVs but not between group I and II viruses. On the contrary, mixed-infection in a plant with BYDV-PAV and BYDV-RPV can result in a strong symptom aggravation.

Epidemiology

BYDVs are introduced to a new crop by alate aphids originating from infected sources. This is called primary infection. Depending on weather conditions are favourable to aphid development and spread, the virus will spread in the crop (secondary spread). The relative importance of these two phases (primary and secondary infection) is important to consider when deciding on what control strategies to adopt. The primary infection is dependent on the aphid numbers and their ability to transmit the virus. This depends on their species, their previous hosts, the timing of their arrival, the morph (sexual, parthogenetic), their infectivity and their survival and multiplication in the new crops. In different regions of the world and in different climates, reservoirs for the virus have been identified. The level of infection in this crop and the concordance between autumn flights and sowing of cereals will influence the level of primary infection in the following cereal crops In many regions, pasture grasses and volunteers are important reservoirs.

Seedborne Aspects

Barley yellow dwarf virus are not transmitted through seeds.

Symptoms

Symptoms caused by Barley yellow dwarf virus differ with the host species and cultivar, the age and the physiological state of the host plant at the time of infection, the strain and the environmental conditions and can be easily confused with nutritional and abiotic disorders. Symptoms include leaf discoloration from tip to base and from margin to centre. The discoloration takes on different colours depending on the plant. In barley, the leaf turns bright yellow; in oat, an orange, red or purple discoloration is seen and in wheat, rye and triticale, the infected leaves are generally yellow and sometimes red. In maize, a conspicuous reddening occurs on the lower leaves, while in rice, infected leaves turn yellow to orange Plants are usually stunted, with a decrease in tiller number and biomass and a weak root system. Suppressed heading, sterility and failure of grains to fill occur in the most severe cases. In the field, symptoms appear usually as yellow or red patches of stunted plants. In general, PAV causes severe symptoms, MAV moderately severe and RPV, RMV and SGV produce mild symptoms. However, there is a high variability amongst the severity of isolates from the same Barley yellow dwarf virus strain.

Symptoms by affected plant part

- Leaves: abnormal colours; abnormal forms
- Whole plant: dwarfing

Diagnosis

Barley yellow dwarf virus are distinct from the other viruses infecting cereals in their symptomatology, the morphology and size of their particles and the type of transmission. The symptoms can easily be confused with those of other biotic stresses. Therefore, diagnosis cannot be solely based on symptomatology but must be supported by other techniques such as transmission pattern, serology or PCR.

Cultural Practices

Cultural practices that could help reduce Barley yellow dwarf virus incidence include changing sowing dates in order to avoid primary infection through viruliferous aphids, removal of cereal regrowths and stubble that can act as reservoirs of virus and vectors and the adoption of adequate cultivation methods

Chemical Control

As there is no chemical treatment effective against the virus, chemical control of Barley yellow dwarf virus can only be achieved through control of its vectors. The critical time for control is at an early growth stage. The need for aphid control can either be prophylactic or based on a forecasting system. The most commonly used aphicides are organophosphates or synthetic pyrethroids. Imidacloprid, an insecticidal seed treatment, reduced BYD infection under certain conditions. New generation synthetic pyrethroids (alpha-cypermethrin or beta-cyflurin) have been reported to be effective against Barley yellow dwarf virus.

Biological Control

In most areas, natural enemies limit aphid populations and it is important to integrate chemical and natural control methods.

Genetic Resistance

Incorporating resistance or tolerance to Barley yellow dwarf virus or their vectors is one of the most promising approaches to control. Most of the screening for field ‘resistance’ to BYD has been directed to the identification of tolerance. In wheat, sources of tolerance have been reported by several researchers.

Beneficial Insects of Wheat

Natural Enemies

- **Predators:** eat many prey in a lifetime, feeding both as young and as adults (Lady Bird beetle, Chrysoperla sp., Sirphid Fly, Birds)
- **Parasitoids*:*** specialized insects that develop as a young in one host, eventually killing it (*Diaeretiella rapae Aphidius spp*)
- **Pathogens:** nematodes, viruses, bacteria, fungi, protozoans (*Entomopathogenic fungus)*

PARASITOIDS

Diaeretiella rapae

Taxonomic position: Hymenoptera: Braconidae: Aphidiinae

- Head and thorax black, gaster and legs yellowish brown
- Ovipositor sheath more or less straight or little curved upwards with obtuse apex and sparse hair

Antennae

Antennae dark brown except first three segments much lighter and yellowish brown, Antenna filiform, with 14-17 segments

Wings

Wings hyaline, veins light brown to greenish brown, pterostigma greenish in freshly emerged specimens, later turns brown

Thorax

Scutellar sulcus smooth. Mesopleuron with a deep, finely crenulate transverse carina ("sternalus" in literature / keys)

Lateral view (arrow mark indicates sternaulus on mesopleuron)

Adult parasitizing aphids

Mummies of *B. brassicae* with parasitoid emergence

Healthy and parasitised by D. rapae

Biology

- The adult females lay a single egg directly into an aphid's body
- The parasitized aphid continues to feed for 3-4 days and typically remains in the same location after being attacked
- The larva has four instars and feeds on the internal tissues of the aphid, eventually killing it
- Parasitized aphids can be easily identified by naked eye by their distinctive appearance
- When the host dies it becomes a mummy consisting of the hardened exoskeleton of the aphid and turns golden yellow to golden brownand shiny
- The wasp pupates within the aphid host and emerges from the mummy as an adult
- The life cycle from egg to adult takes about 9-10 days

Aphidius colemani

Parasitizing an aphid

Mummies due to *A. colemani*

Aphidius ervi

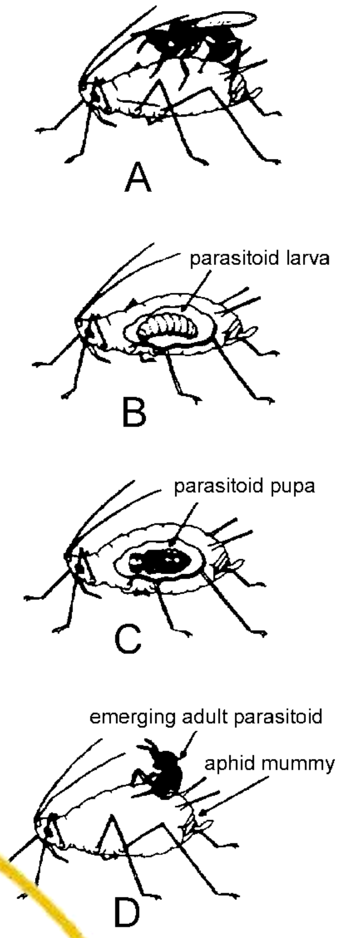
A. ervi emerging from a mummy

A. ervi can eradicate whole the aphid colony

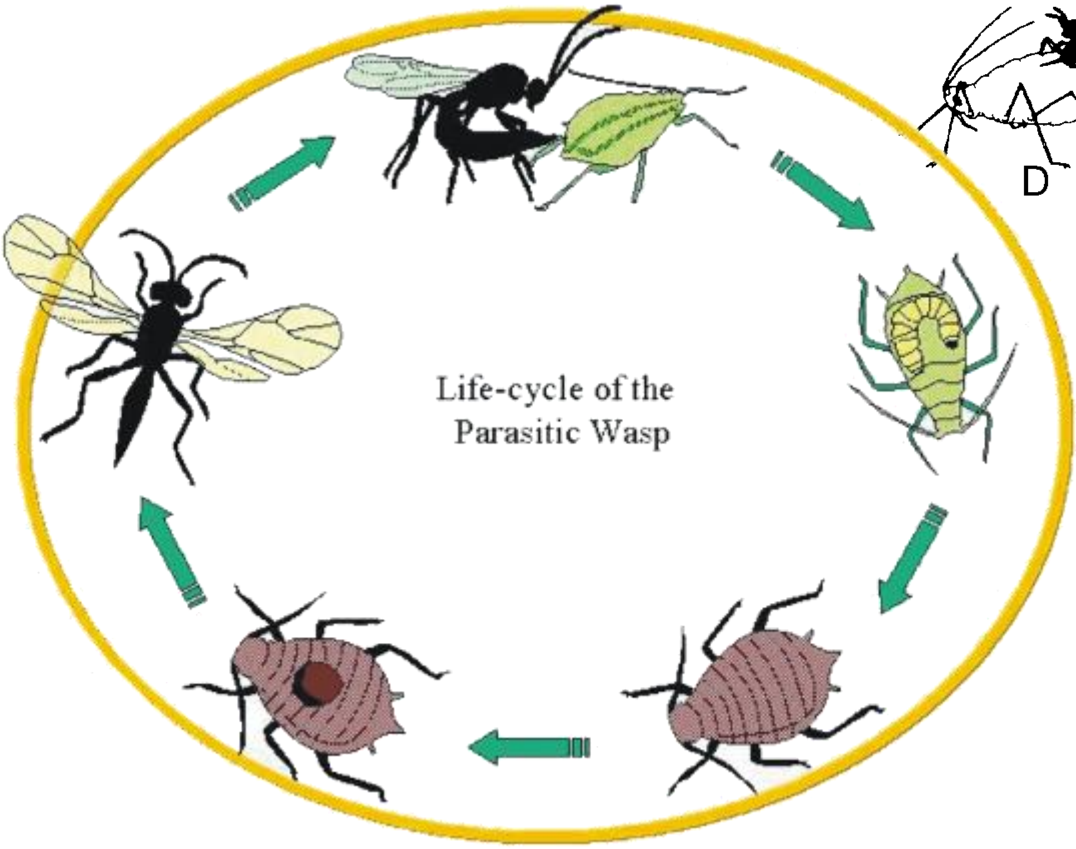
Aphidius avenae

Biology

- Adults are tiny, dark coloured, non-stinging wasps, up to 2-3 mm (1/8 inch) long
- Aphidius is an outstanding searcher, and can locate new aphid colonies even when aphid populations are low
- A complete life cycle takes 10 days at 25 ºC (77 ºF) and 2 weeks at 21 ºC (70ºF)
- Sex ratio in the population is about equal, although there may be slightly more females than males (50-60% females)
- Larvae develop entirely inside host aphids, which eventually become rigid mummies when the larvae pupate



General Life Cycle



PREDATORS

Green lacewings

Biology

Eggs are laid on slender stalks on the underside of leaves. The **larvae** grow to about 1 cm in length and feed on aphids. The larvae camouflage themselves by covering their bodies in prey debris. After pupation they emerge as **adults** that feed only on nectar and pollen

Predation

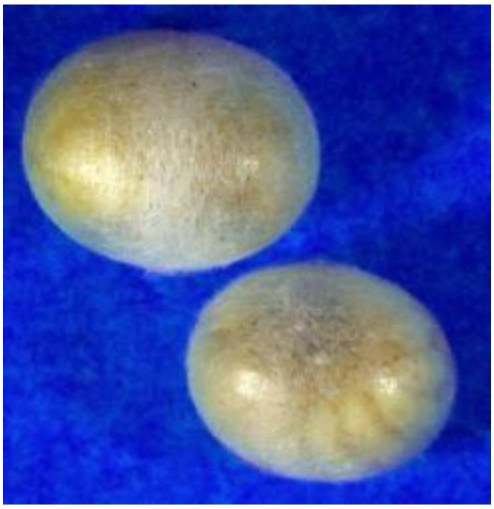
– Larvae will consume over 400 aphids during development. Older larvae can consume between 30 and 50 aphids per day

Egg laying

– The adult lays more than 100 eggs

Larvae

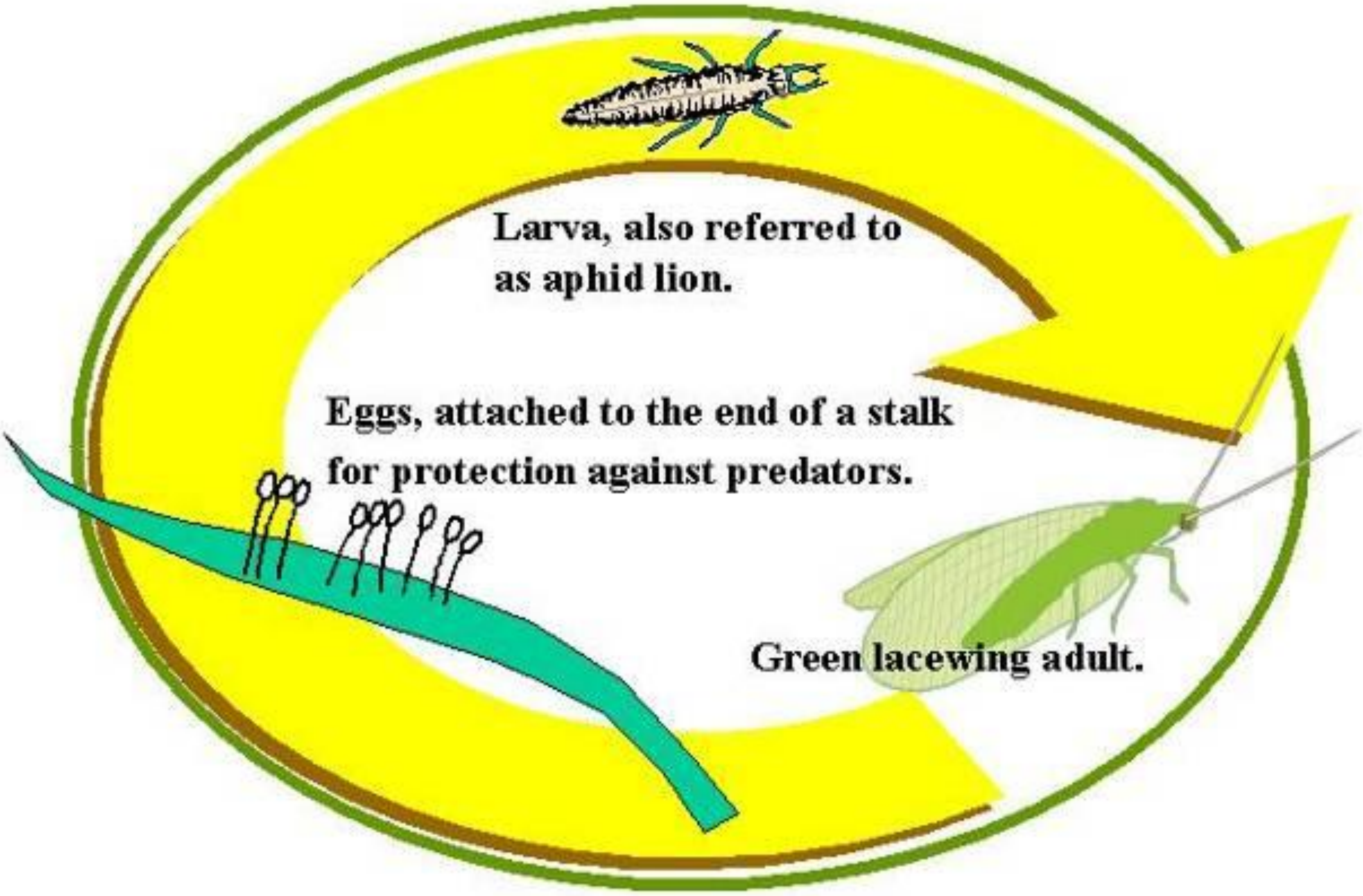
Pupae



Adult

Head markings in adult

General Life Cycle



Duration of development

- Larvae feed for three to four weeks undergoing three moults before pupation
- Adults emerge after about seven days
- begin to lay eggs after a further six days and live for about 14 days depending upon temperature

Efficacy

- Very active and aggressive predator of aphids and other insects
- Will consume beneficial as well as phytophagous insects and may even be cannabalistic although most beneficial move too quickly for *C. carnea* to catch them
- The common name, aphid lion, relates to its voracious appetite

Ladybird Beetles

Eggs

Larva

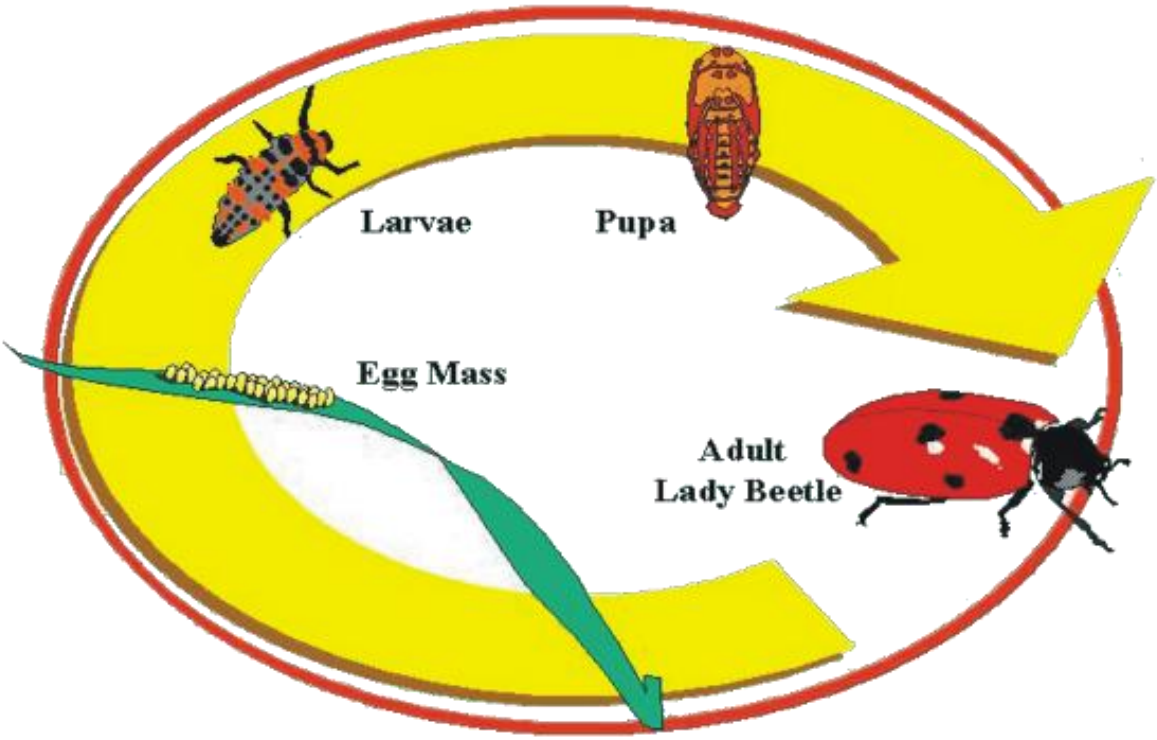

Pupa


Adult



Adult -Elytral Pattern Variations

Life Cycle



Uses

Harlequin ladybird has been used as a classical biological control agent of. It has many attributes that contribute to its economic viability as a biological control agent. Perhaps most notable is its polyphagous nature. Harlequin ladybird preys on a wide variety of tree-dwelling homopteran insects, such as aphids, psyllids, coccids, adelgids and other insects. The spread and increase of Harlequin ladybird may therefore prove to be beneficial to crop systems through reduction in aphid numbers below economically damaging levels and thus an associated reduction in the use of chemical pesticides. General insecticides were found to be lethal to Harlequin ladybird even at low doses. However, synthetic pyrethroids and some relatively new pesticides, such as spinosad, indoxacarb and pyriproxyfen, showed minimal toxic effects or were less toxic to Harlequin ladybird s than to aphids Biorational pesticides, such as the fungus Beauvaria bassiana and soap, were also shown to be less toxic than conventional pesticides. Fungicides have little effect on Harlequin ladybird

Impact descriptors

Negative impact on: biodiversity; environment; rare / protected species; native fauna; animal / plant products

Positive impact on: crop production; forestry production

Symptoms by affected plant part

Fruits/pods: lesions; abnormal exudates; external feeding; discoloration

Similarities to other species/conditions

Harlequin ladybird could be confused with a number of other polymorphic species from the Coccinellidae such as the two-spot ladybird, Adalia bipunctata, or ten-spot ladybird, Adalia decimpunctata.

Syrphid or Hover Flies

Common prey Predaceous on aphids and other small, soft-bodied insects

Some common syrphids

Episyrphus blateatus

Eupeodes corolla

Ischiodon scutellaris

Parragus serratus

Melanostoma sp.

Scaeva latimacullata

Egg of syrphid fly (hover fly)

Larva of the large hover fly

Pupa of syrphid fly (hover fly)

Adult Syrphid Fly

Harvesting

Management of a winter wheat crop for optimum production potential must continue through harvest. There are several factors to consider both during and after winter wheat harvest. Harvest begins with the cutting of a standing crop. Harvest may be accomplished in a single step by straight (direct) combining or in a series of steps that may include windrowing (swathing), combining, and drying the grain to a safe moisture level for storage. Warm summer weather during the harvest season means that windrowing offers few advantages and often increases the risk of crop loss. Windrowing can start once the wheat has reached physiological maturity (33 to 43 percent kernel moisture). At this stage the kernel can still be crushed when squeezed between the thumb and forefingers, but beads of moisture should not appear when pressure is applied. Most of the grain yield and all of the grain protein will have been accumulated by the stiff dough stage. Consequently, windrowing at this stage should not cause a change in protein concentration or a reduction in test weight or seed weight unless the weather is extremely hot and dry and drying takes place at a very rapid rate. Grain filling may continue for a short time when the crop is windrowed at a kernel moisture content above 30 percent. The slower the drying rate, the longer grain filling can be expected to continue after cutting and the earlier the crop can be windrowed. Weather conditions, straw length, and windrow size all influence the windrow drying rate and, hence, the length of the grain filling period after the crop has been windrowed.

Grain moisture and the harvest

Ideally, harvest begins as soon as the crop is mature or ripe. A cereal crop can be harvested any time after it reaches physiological maturity and dries down from about 20% MC.

Delaying harvest

Every day a crop stands it is exposed to ongoing yield loss and quality degradation. Yield is reduced by shedding, head loss and general exposure to the elements. This is measured as a loss of yield each day in dry matter (DM).

The effect of rain

When a crop is exposed to rain after physiological maturity, the process of quality loss occurs more quickly. Mould and fungi development increase, colour darkens and the exposure of the grain to moisture starts to stimulate germination, commonly referred to as sprouting. The sprouting process consumes part of the grain’s starch energy stores, which reduces bulk density, overall weight and hence yield.

Losses Due to Insects, Weather, and the Harvesting Operations

The longer a crop stands in the field, the greater the risk of weather damage.

Weathering and Sprouting

Kernel soundness and sprouting are wheat grading factors. Sound grain is mature and reasonably free from kernels damaged by frost, mildew, bleaching, or weather staining. Winter wheat has little or no seed dormancy and warm, wet weather can cause sprouting and rapid deterioration in quality. Therefore, it is important that every effort be made to minimize the opportunity for weathering once winter wheat is mature.

Kernel moisture may be as high or higher in standing wheat crops following a rain, but standing wheat crops usually dry more quickly than wheat in a windrow. Consequently, the quality of windrowed wheat often deteriorates more quickly than standing wheat during long periods of warm, wet harvest weather.

Moisture Content

Moisture content is critical in preventing pre harvest and postharvest losses. To minimize pre harvest losses, winter wheat must be harvested before wind causes shattering under dry conditions or rain causes sprouting in the head. The grain must be dry enough for safe storage, preferably less than 12 to 12.5 percent moisture by weight. If moisture content is higher than this, the grain must be dried prior to storage. The general recommendation is to thresh at moistures not greater than 20 percent and to dry with air not exceeding 43 C, especially if the wheat is to be used for seed, since higher temperatures can damage germination.

Combine Settings

Combines must be properly adjusted to minimize combine harvest losses and to avoid cracking the grain, which invites greater damage from storage molds and insects. Grain left on the ground, either because of shattering or improper combine adjustments, represents grain that cannot be sold as well as a source of future volunteer plants to host diseases and insects. Straw and chaff must be spread as uniformly as possible to reduce problems in planting and performance of the following crop.

Minimizing Losses from Shattering and Sprouting

The first step in minimizing losses from shattering and sprout damage is to choose the appropriate variety of wheat. Harvesting at the ideal time and moisture content can reduce shattering and sprouting, but this is often beyond the grower’s control. Wheat can be harvested at a moisture content higher than what is recommended, but this grain will have to be dried before or immediately after it is placed in the bin. A second option for dealing with wet wheat is swathing and allowing it to dry in windrows on the stubble. Once the grain has reached the maximum-weight phase of grain fill, the wheat can be swathed with no loss of yield. The grain is at physiological maturity by this stage, but the plant is still alive and has considerable moisture in the straw as well as in the grain. Swathing speeds the drying process for the plant and grain.

Minimizing Cracking and Combine Losses

Final combine adjustments to minimize cracking and combine losses must be made in the field, several times each day and in each new field. The tendency for kernels to crack or thresh out varies by day and even by time of day, depending on the moisture content of the grain and straw. Threshability of the grain also varies by wheat variety and by weed population. Late-season green weeds may require swathing or a pre harvest burn down herbicide.

Grain Storage

Effective grain storage systems maintain grain quality and prevent grain losses. In order to prevent spoilage, storage structures must be designed and maintained to protect the grain from weather, bird, animal, insect, mite, and mold damage. Grain that is to be stored for any length of time must be kept under conditions that are uniformly cool and dry.

Grain Moisture Content and Temperature

Moisture content and temperature are the main factors that determine the length of time that grain can be safely stored. Enzyme activity and micro-organism growth can be expected to increase dramatically when the moisture content of the air (relative humidity) in a storage bin rises above 70 percent, i.e., the relative humidity levels found in tough and damp grain. The rate of enzyme activity and micro-organism growth and development is also a function of temperature. As a consequence, tough and damp grain that is stored at warm temperatures will rapidly spoil while dry grain stored at cool temperatures can be safely stored for a long period of time.

The quality of wheat will deteriorate if it is harvested and stored at high moisture content. The safe storage time of grain decreases as temperature increases. The uniformity of grain temperatures within a storage bin can also affect the safe storage time of grain. Condensation occurs when moist, warm air comes in contact with cold objects. Consequently, temperature differences within a grain bin cause moisture migration from warmer to colder areas and, if air movement is insufficient to remove the moist warm air from the storage bin, conditions may become favorable for rapid grain spoilage. These conditions are most likely to develop when grain is stored in large quantity, poorly ventilated bins. Differences in grain temperature and the outside air can also create high moisture areas within a bin. Moisture usually migrates to the top center of the bin when the grain is warmer than the outside air and to the center bottom of the bin when the grain is colder than the outside air.

Approaches to dealing with high moisture grain

Blending

- Higher moisture grain up to about 13.5%MC is combined with lower moisture grain to result in a sample with a required overall average moisture content

Swathing

- eliminate green grains and promote slightly faster drying down of the crop, Ideal for removing a small margin of moisture (0.5%)

Aeration

- Enables safe storage of high moisture grain by passing small volumes of air through the grain
- The stored grain will still require blending or drying before delivery or export
- Requires moderate expenditure and often depends on existing storage facilities
- Able to handle grain up to 1 5%MC, depending on aeration system

Drying

- Large volumes of heated air are used to remove moisture from grain
- Often interlinked with blending, swathing and aeration to increase dryer capacity

Blending

Blending involves mixing several parcels of grain with different moisture contents, to result in one mass of grain with suitable moisture content for delivery. This technique of moisture management requires on–farm storage for quantities of grain, which may need to be held for a period of time. Blending to manage moisture content largely depends on the storage capacity available. It is a cost-effective way of dealing with small moisture margins and can also help accommodate other grain quality characteristics. Blending does involve significant double handling of grain and this is a factor which needs to be remembered when making cost calculations and comparisons.

Swathing

Swathing can be a useful tool to manage small margins of moisture at harvest. Swathing is used to accelerate crop maturity and help moisture management. Laying the crop down in rows allows it to heat more quickly, resulting in quicker drying and moisture reduction. By lying the crop down, swathing increases the risk of soil, rock and animal dropping contamination during the harvesting process, particularly if heavy rain has fallen on the swathed rows.

Aeration

Aeration involves passing relatively small volumes of air through grain while it is in storage. The air is generally distributed by a ducting system so it enters the storage area and has to pass through the grain before being able to exit the storage area. Aeration is primarily aimed at temperature control to prevent grain spoilage, allowing high moisture grain to be held safely until it can be blended, dried or processed when convenient. Higher rates of airflow and more uniform air distribution enable an aeration system to manage higher moisture levels, but these factors also increase the capital and operation cost of the system.

Drying

Grain drying involves using large quantities of air to remove moisture from the grain. This is generally the most expensive technique to manage high moisture grain, but it offers the greatest degree of flexibility and capacity to harvest in high moisture conditions.

Grain Quality in Storage

Storage conditions should maintain the quality of the grain. The value of grain depends not only on the market situation but also on the condition of the grain. Grain quality is judged on characteristics including grain cleanness, shininess, plumpness, color, odor, and test weight; insect-damaged kernels; presence of live insects and foreign material; and proportion of germinated and broken kernels.

Length of time in storage and seed viability

The length of time that seed grain can be stored without loss of viability depends on the storage environment. The main factors are the moisture content of the seed while in storage and the storage temperature. Grain that contains 11 to 13 percent moisture or less can be stored in weather proof bins or silos for many years in most climates without deterioration, provided it is protected from insects, rodents, external moisture, and high humidity. The composition of sound dry grain remains almost unchanged except for some increase in fatty acids and a slight loss of energy content from respiration. At average air temperatures weight loss in dry matter is about 1 percent over 20 years of storage. Prolonged storage results in a slight loss in protein. Under proper storage conditions, seed germination after 20 year storage is about 45 to 50 percent.

Insects and Mites

Insects and mites are difficult to see in grain and the damage they cause is often the first indication of their presence. High grain temperature, distinctive odors, hollowed out kernels, and eaten out germ ends all indicate that insects or mites are present and a closer inspection of the grain is warranted.

Prevention of Grain Spoilage

There are a number of grain storage management practices that should be followed in order to minimize grain losses due to spoilage. Bins, air ducts, perforated floors, etc. should be swept clean or vacuumed and spoiled grain in and around storage and harvest facilities should be cleaned-up and buried or burned. Holes and leaks in bins should be patched to prevent grain loss, keep out the rain, and limit the access of rodents. Cleaned bins should be sprayed for insects well before harvest starts, especially if there is a history of insect problems in the storage facility. Always read and follow the instructions on the label when applying insecticides, fungicides, fumigants, and rodent poisons.

Properly sample the grain as it goes into the bin. This will provide a clear picture of the grain condition at the start of storage and help to identify potential problems that should be monitored and/or corrected.

Avoid mixing newly harvested grain with grain that has been in storage. Grain that has been in storage may contain insects. Freshly harvested grain may also heat if it is placed on top of grain that has been in storage. Regularly monitor grain temperature and moisture. The frequency that bins should be checked depends upon the moisture and temperature of the grain when it goes into storage. When potential problems exist, inspection every two weeks during the winter and once a week during the rest of the year is recommended to allow the opportunity for corrective action to be taken before significant grain spoilage occurs. Surface inspection is not sufficient for the early detection of high moisture areas, hot spots, or the presence of mold and insects. Use natural or heated-air to artificially dry high moisture grain. Use aeration to keep high moisture grain cool if it cannot be dried immediately. Keep detailed records on the condition of the grain in storage. Accurate records can help in identifying potential storage problems and in planning preventative action.

Seed Wheat

Winter wheat has little or no seed dormancy and it may be used for seed without drying once it reaches physiological maturity. There is, however, a greater risk of seed damage when wheat is harvested damp. As a result, subsequent field emergence is usually highest for seed wheat that has been harvested when kernel moisture content is below 17 percent. Harvesting when the grain is dry eliminates storage problems and the need for drying when the seed is not sown immediately after harvest. These considerations are especially important because damp grain requires much closer attention when it is being dried and stored for seed rather than as commercial wheat. The maximum temperature for safe drying of seed depends on its moisture content and the length of time it is exposed to the drying temperature. The higher the moisture content, the more sensitive seed is to high temperatures. However, moisture evaporation from damp grain causes cooling that delays the damaging effects of high dryer temperatures. Consequently, safe drying temperatures vary with the type of drying system used. As a general recommendation, the temperature for drying wheat seed should not exceed 60°C for high-speed dryers and 40°C to 50°C for batch-type dryers where the grain is held at the drying temperature for longer periods of time. Low temperature and low relative humidity provide the best storage conditions for seed. As a general rule of thumb, the life of the seed is doubled for every one percent decrease in moisture content (between 4 and 14 percent) and every 5°C decrease in storage temperature.

Storage Management

The benefits of managing for optimal productivity of the wheat crop and harvesting with the highest possible efficiency can be lost if the grain deteriorates in storage because of molds or insects. Management of the grain must continue until the wheat is removed from storage. The hazards to grain during storage, including molds, insects, loss of weight, and chemical changes, are all related directly or indirectly to higher moisture or temperature of the grain. Grain deterioration in storage can be minimized or prevented altogether by keeping the grain dry, cool, and free from insects. Grain moisture content should be 12 percent or less. Air should be below 10 C, and preferably lower. Every effort should be made to eliminate all sources of grain-storage insects from old grain left in the bin or grain auger or other sources. Even a few insects harbored in the bin or introduced with the grain can lead to a serious infestation over time, given the right conditions. Bins should be checked for insects and mold at least every two to three weeks, and more frequently during periods of large temperature fluctuations. It is almost impossible to have a bin of grain with uniform moisture content. Consequently, aeration is the safest way to reduce both grain moisture in the bin and to reduce grain temperature. Integrated pest management techniques during wheat storage require proper use of sanitation, chemicals, monitoring and aeration to maintain the wheat quality.

Storage Structures

The structure in which wheat is binned can help prevent loss and quality deterioration during storage. Structures used for grain storage should:

- Hold the grain without loss from leaks or spills
- Prevent rain, snow, or soil moisture from reaching the grain
- Protect grain from rodents, birds, poultry
- objectionable odors
- Provide safety from fire and wind damage
- Permit effective treatment to prevent or control insect infestation
- Provide headroom over the binned grain for sampling, inspecting, and ventilating

A suitable storage for grain includes a weather tight, rodent-proof, metal structure that is separated from hay and feed areas and animal housing. It should be easy to clean and inspect. It should have an aeration system that will allow you to cool the grain and thus limit insect development, and minimize moisture migration through the grain.

Stored grain Insect pests

More than 50 species of insects are found in stored grain and grain products. The most common and destructive stored-grain insect pests include:

- granary weevil (Sitophilus granarius)
- rice weevil (Sitophilus oryzae)
- maize weevil (Sitophilus zeamais)
- saw-toothed grain beetle (Oryzaephilus surinamensis)
- red flour beetle (Tribolium castaneum)
- lesser grain borer (Rhyzopertha dominica)
- rusty grain beetle (Cryptolestes ferrugineus)

Fungal (mold) pests

Various fungi (molds) are an important part of the natural microflora of grain, both in field crops and in stored grain. The term "field fungi" is used to describe fungi growing on grains before harvest. Common field fungi include Alternaria alternata, Cladosporium cladosporiodes, C. herbarum, Epicoccum nigrum, Fusarium spp., and others. The term "storage fungi" is used to describe fungi involved in the deterioration of grains during storage. Aspergillus and Penicillium are the most important genera in this group, which includes Aspergillus candidus, A. fumigatus, A. nidulans, A. repens, Penicillium brevicompactum, P verrucosum, P hordei, P roquefortii, and others.

Fungal growth and mycotoxin production can be important causes of loss of quality in stored grain, especially in grain held at a high moisture content. Mycotoxins are produced by both field fungi and storage fungi.

Vertebrate pests

Rodents, birds, and other wildlife can infest or damage stored grain. Rodent-proofing buildings and other storage areas is the best method of managing these pests. Secure any opening larger than 6 mm in foundations, walls, floors, roofs, and eaves. Inspect grain storage facilities frequently for new infestations.

Insect Development

Common stored grain insects have a life cycle of 4 to 12 months. They may pass from egg to adult under optimal conditions in 30 days or less. Females of some common species can leave 300 or more eggs in the wheat within a few weeks. Not all insects cause damage and it is important to be able to recognize those that do, such as lesser grain borers or weevils.

Insect reproduction is directly related to temperature through the life requirement ranges. Optimal feeding and reproduction of most storage insects typically occurs from 21 to 32 C. As grain temperatures drop near 15 C, reproduction falls off rapidly. Most visible insect activity, including feeding, ceases when grain temperatures fall below 10 C.

Sanitation

Sanitation is critical to maintaining wheat quality while in storage. The optimum time to clean a bin is immediately after emptying and again 4 to 6 weeks prior to refilling. Critical areas where infestation can normally be found include the floor area and unloading pits or sumps. Other areas may include the bin walls, ladder rungs, and openings if debris remains attached to them after unloading. Handling equipment should be used to remove debris and aeration ducts removed and cleaned. The area around a bin must also be kept free of debris, not only while the grain is in storage, but also while the bin is empty. New grain should not be stored on top of grain that has been in storage. If the old grain has even a low-level infestation, the problem will spread upward into the most recently added grain.

Protectants

Grain protectants are insecticides designed to be placed on the grain kernels entering storage. Grain protectants retain their insect-toxic properties for an extended time period, depending on the grain moisture content and temperature. They are not highly volatile and penetration into infested kernels is very limited. Protectants do not destroy eggs and internally feeding insects since fatal amounts of insecticide are probably not absorbed by these forms after application.

Aeration

The purpose of aeration is to cool the wheat. This reduces an insect’s ability to reproduce in it and minimizes temperature gradients. Aeration cools grain by forcing ambient air through the wheat with fans. Grain is cooled using aeration or drying fans.

Monitoring

Best management practices require monthly inspection throughout the storage period. Risk of major deterioration can effectively be eliminated by frequent monitoring. Monitoring requires a grain probe, moisture meter, temperature measuring device, and screening pans. Changes in moisture content, insect activity, odor, or temperature can best be detected by inspections. An inspection log or diary should be maintained for future reference.

PART II; DISCOVERY BASED PARTICIPATORY LEARNING EXERCISES

Observing the Crop Field

Exercise 1. Ballot Box Test (BBT)

Background

The ballot box test, or BBT, is a formative or developmental evaluation exercise conducted to measure the observed outcomes against the intended outcomes of the training programme in a Farmer Field School (FFS). Conducted as a pre- and post training evaluation, it measures farmer's knowledge and skills in identifying Wheat morphology and growth stages, physiological disorders, diseases, weeds, insect pests, the damage they cause, and their natural enemies. A BBT has to address those questions to identify knowledge gaps and plan the FFS sessions according to farmers needs. Progress during the field seasons should be measured by repeating the test at the end of the season. The activities of this first exercise are explained from a facilitator's point of view.

Objectives

- To evaluate farmers' level of knowledge before and after training
- To find main knowledge gaps.

What You Need

- Wheat Field
- Pieces of cardboard
- Transparent vials
- Sticks
- Actual, live or preserved specimens
- Marking pens
- Flip chart paper
- Colour markers

Procedure

Collect actual or preserved specimens (e.g. plant parts, diseased samples, insect pests or friendly insects, etc).

Keep each specimen (preferably alive or otherwise preserved) in an appropriate vial and mount the latter on cardboard. The number of specimens mounted will depend on the learning objective and question asked. Usually, not more than four specimens may be mounted.

Prepare the questions. Examples include those focusing on identification of growth stages, plant parts, disease symptoms, insect pests, the damage they cause, and their natural enemies.

Write the questions on cardboard. The answers (each assigned an identification letter) should be of multiple-choice type so that participants will only have to choose the correct one by simply selecting the corresponding letter). Examples of some questions are as follows:

- What insect causes this damage?
- Which of these insects is a pest?
- Which of these insects is a friend?

(Answers on a scale from 1 = no information to 5 = a lot of information)

- Mount the cardboard with the specimens in vials and their attached ballot boxes
- During this exercise, each participant selects his/her answer by dropping a piece of paper with his/her assigned number in the corresponding ballot box he/she chooses as the answer.
- When all participants have completed the BBT, process the results to determine participant's performance and to solicit their comments on the BBT.
- In addition to the calendar, which indicates the frequency of activities, write the information on a separate sheet of paper.

Guide questions for analysis

How useful is the exercise to you?

- Are the specimens in sufficiently good condition for easy viewing and identification?
- Are there substitutes for actual specimens (live or preserved)?
- Do you think these substitutes will be as effective as using actual specimens?
- Can you share some ideas on how to improve the exercise?

Exercise 2. Wheat Cropping Calendar

Background

A cropping calendar is an important tool in farmer field schools as it serves as the guideline for activities carried out in the farmer practice plot. Cropping calendars therefore depict current farmer practice and not recommended practices. For the IPM plot, there is no cropping calendar, as decisions on the implementation of practices are based on regular field observations and the discoveries made over the course of the ToT / FFS.

Objectives

- To develop farmers' capacity for making valid comparisons of their current practices with IPM practices

NOTE: This exercise should be done twice: during community sensitization and during the first or second FFS session.

What You Need

- Flip chart paper
- Colour markers

Procedure

A cropping calendar is a representation of all crop production tasks performed during a season. It is depicted as a timeline (X-axis) divided into monthly periods, with drawings of crop stages at the top of the matrix. Tasks are listed along the negative Y-axis, and the times these are applied are indicated as horizontal bars.

- Ask participants to list all activities done in crop production. As this calendar will be used to implement practices in the farmer practice plot of the farmer field school, it is important to be specific and detailed.
- Go through the entire crop production cycle, including land preparation, seedling management, planting, weeding, pruning, spraying, harvesting, storage etc.
- Have participants fill out the calendar in as much detail as possible using different colours.

Example of a cropping calendar

Activities	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

When drafting a cropping calendar with FFS participants, the calendar should reflect either the actual practices of the farmer or the common practice in the area (to be decided by participants) rather than practices that would be implemented if farmers had the resources.

Exercise 3. Monitoring Wheat Field

Background

Regular monitoring is one of the essential requirements for the integrated production management.

Objective

- To understand the importance of field monitoring

What You Need

- Vials
- Polythene bags
- Hand lens
- Flip charts
- Colour pens

Procedure

- In small groups, visit different places in the field, covering whole plot
- Observe on insects, diseased leaves, etc.
- In each field, each group selects and tags one or more part (1Sq meter)
- Each tagged part is observed systematically
- how many different types of insects are found
- how many disease affected leaves are found
- To record the results, draw a picture of the wheat crop in the correct colours
- Present the results per group.
- During the discussions, establish the local names of insects and diseases observed
- Differentiate as much as possible the various insect pests from the natural enemies
- Arrive at a consensus on why wheat field should be observed

Guide questions for analysis

- Which insects were found and what are the local names for these?
- Can you differentiate those insects that are pest insects and those that are natural enemies ('friends of the farmers')? If not, please introduce the concept of Insect Zoo.
- Was there a difference in results between the various fields? Why (/why not)
- Is there a need to observe wheat field regularly? Why (/why not)?
- What can we learn from these observations?

Exercise 4. Agro-Ecosystem Analysis (AESA) in Winter Wheat

Objective

- Analyze the field situation by making observations, drawing findings and discussing potential management actions needed
- Study the wheat agro-ecosystem for informed decision making
- Understand the various interactions that occur amongst the components in the wheat ecosystem and demonstrate their balance
- Improve participants' observational skills and decision-making abilities
- Teach farmers the need to make management decisions based on close observation of the agro-ecosystem of wheat

What You Need

- Wheat field
- Vials
- Polythene bags
- Cotton wool
- Sweep nets
- Hand lenses
- Notebooks, pencils, sharpeners and erasers, colour markers and crayons
- Flip charts and markers
- Board and masking tape
- Ruler and tape measure

Note: It is important to have present AESA presentations from the previous FFS sessions

Procedure

Agro-ecosystem analysis preparation

The FFS typically has 2 plots. One plot is the common farmers' practice in the area, following a traditional cropping calendar and the other one is the IPM practice plot, where decisions are made about crop management based on the Agro-Ecosystem Analysis (AESA). AESA data is collected from the both plots (IPM versus Farmers' Practice) to learn about the impacts of different practices.

Divide participants into groups of 5, depending on the total number of participants. Each group can observe in both IPM and FP plots. However, to make the working time as shorter as possible, if you have three groups, 2 groups can make observations in IPM plot and one group in FP plot. These groups should be maintained throughout the training period, but the plot they observe should be changed from time to time. Each group selects one person to record all data and this task can be rotated among group members.

Agro-ecosystem analysis observation

Early in the morning (about 9 a.m.), the participants enter the IPM and FP plots in groups of 5 persons each. Each group should move diagonally across the field and select and tag at least 3 quadrates for agronomic observations. These quadrates will be observed for agronomic characteristics throughout the season.

General data

During the first AESA, record the following information on wheat in the both plots

- Varieties
- Soil fertility (high, medium, low)

The participants make note on general field conditions, weather, plant physiology, type and number of insects and diseases, attack symptoms, environmental conditions around the field and to gather live specimens. They should collect the data indicated on the AESA record sheet from the sets of three quadrates that were selected.

Environmental conditions

At each session, record the following conditions at the time you made the observations:

- Weather (sunny, cloudy, rainy)
- Temperature (cold, lukewarm, hot)
- Soil moisture

Agronomic observations

Record the following agronomic observations during each session from the selected tagged quadrates:

- The average number of tillers
- The average height
- The health of the soil (structure, organic matter)
- The general condition of the crop (Healthy, Moderately Healthy, Weak)

Plant protection observations

Carefully observe and count all insects you can find, and whether they are a pest or a beneficial. Collect any insects that you do not recognize in the vials or in plastic bags. Take them back to the meeting place to see if any of the other groups can identify.

Carefully observe wheat plant at the lower, middle and higher up levels, recording disease or other symptoms of damage. Observe and record how many of the leaves are diseased. If you recognize the diseases, record them. If you don't recognize them, collect them in vials and take them back to the meeting place.

After counting the total number of insects and disease found in the three quadrates, calculate the average, that is the total number found divided by 3.

Record the number and species of any weeds in the three quadrates. If you are not sure whether a plant is a weed, collect it in a polythene bag, and take it back to the meeting place. The other groups may be able to identify it.

Agro ecosystem data recording / chart preparation

Each group draws all the observations made in the field on flip chart. Draw a single representative wheat plant at its present state of growth, with the sun or clouds symbolizing weather conditions. Show weeds found and indicate the number and species. To the right of the plant draw the natural enemies found and indicate the number or abundance. To the left of the tree, draw the insect pests and the disease symptoms found and indicate the number or abundance.

Agro-ecosystem analysis

After a discussion, group members analyze the field information. They discuss the growing stage of the plant and compare the growth between the observed both plots. Comparisons are made between numbers and types of pests, natural enemies and diseases of the wheat crop. The group draws conclusions about the overall situation at present compared to the previous AESA. Observations of specific problem areas are listed in the AESA drawing with the possible causes.

Agro-ecosystem decision making / Guide questions for decision-making

The final stage of the AESA is the decision-making. Discuss in the group what management decisions to take. For example, given the relative pest and natural enemy populations, diseases levels, what crop management options you have?

If you do need to do something, how, when and what will be the impact on the agro ecosystem. For example if you opt to spray a pesticide, what chemical should you use? What will happen to the natural enemies if you spray? And what effect would you expect if natural enemies would be killed by spraying?

What is the condition of the soil? What is the structure of the soil? If it is poor, can we improve it? Do we need to take measures against soil erosion? If so, what measures should be? Etc.

Some examples of action decisions are:

- Crop management operations
- We don’t understand how wheat disease is transmitted. Let’s do an exercise on this.
- We heard that spraying of micro elements can improve plant health. Let’s have an experiment to find out if this works.
- A discovery learning exercise to learn about a topic—the “special topic” (for example, insect life cycle)

- There is a balance in the relationship of natural enemies to pests so there is no need to spray.
- We need to make “insect zoo” to understand how this natural enemy control this pests.
- The soil humidity is enough for normal growing of plants.
- We will continue to observe our field.

Group Presentation

A representative of each group presents its findings and conclusions to the whole group for further discussion, questioning and refinement. Participants are encouraged to challenge and ask the presenting group questions. Sometimes, the decision made by a group is modified or rejected by the rest of the school.

An important role of the facilitator is to draw out differences observed between the FP and IPM plots by asking, for example, Is there a difference in the FP and IPPM plots? How do we explain this difference?

After presentations, the facilitators and farmers must come to a consensus on whether any crop management operations are necessary. These decisions are implemented during the following ToT / FFS session.

General, Environmental, Agronomic and Protection Data

Day: _______

Name of Group:__________________

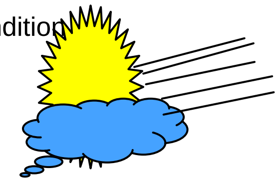
Date: ______

Agro Ecosystem Analysis No. _____

Starting Time: ______

Ending Time: _______

Weather Condition



Picture of Wheat Plant

Beneficial Insects

Diseases symptoms

Insect Pests

Vegetative Data (Avg.)

Plot	Plant height	Plant population per square meter	plant age	leaf colour	growth stage	Plant shaping	No. of tillers	internodes distance	length of leaf plant height no. of leaves	no. of spikelet's per spike	No. weeds per square meter	broad leaf	narrow leaf
FFS plot													
FP plot													

Pests, Diseases & Beneficials Data

Plot	Sucking pest per Leaf				Chewing pest per Plant			Beneficial Insect per plant		Diseases			
	Aphids		Mites	White fly				Spider	Lady bird beetle	Root rot			
FFS plot													
FP plot													

General Observations

Recommendation

Decisions

New Findings:

Implementation

Design of agro-ecosystem analysis presentation

Group name: …………………………… Type of plot: IPM / FP……………………………

Date: …………………………… AESA No: ……………………………

General information	Agronomic data

Weather (Draw the weather at the time when you made your observation)

Left of the plant	Draw one large picture of wheat plant	Right of the plant
Draw the insects pests and the diseases symptoms found and indicate the number or abundance	At the base of the plant draw, the weeds found and indicate the number and the species.	Draw the natural enemies found and indicate the number or abundance

Analysis

Observations	Possible Causes	Group recommendations

Exercise 5. Inter-relationship with in ecosystem (Role Play)

Background

Everything in the ecosystem is related. The ecosystem is quiet fragile and changes made may affect its stability. For example Agricultural development and modern techniques (chemical pesticide, machinery) may cause drastic disruption to the ecosystem or original landscape. In training activities, sharing of experiences through role playing by farmers can help them understand the interrelationships and the fragile conditions of the ecosystem. Role playing can also help them to care and place priority values of crucial elements in the environment and to avoid and minimize disturbances that may create imbalances. For example, farmers can learn about the important role that natural enemies play in keeping pest in check and how the injudicious use of chemical pesticides can upset biological control and cause pest resurgence or outbreak.

Objective

- To understand the interaction between different components of agro ecosystem

What You Need

- Plastic string one roll
- Masking tape
- Marker, pens
- Card

Procedure

In one big circle, each person thinks of element (e.g. water, plant, others) or an organism (e.g. pest, natural enemy, others) that he wishes to represent. The name of the element or organism is then written on the card that is pinned on to the dress of the person to identify him from the other place. To maintain liveliness in the role playing, the players should act out in body language how these elements or organisms look like in nature. For example, the person representing the frog can hop while the one playing a caterpillar wriggles. Each player is connected to another that has a relationship by holding the string that connects him to the other person e.g. a caterpillar pest to the plant, water with the plant, a ladybird beetle with the aphid, etc. this goes on until everyone has found at least one relationship, while some may have several connections.

When the connection has done, it will be noticed that everything is somehow connected to another. During role playing when everyone is actively acting out his role, it will be observed that everyone is moving, some may feel a stronger pull than others. The players will quickly appreciate how the environment is closely knitted together and how the various elements/ organisms in the environment are dependent on one another in different ways. The interdependence and wholeness of the ecosystem will become even more apparent. Once the facilitator begins to cut some of the connecting strings when the players are in the midst of activity acting out their roles. When the straws are cut observe what happens?

Guide questions for discussion

- Did you enjoy the game?
- What do you think is the name of the game? Why?
- How many interactions did each have? Is the same for every one? Why?
- What happened when someone pulled the string?

Insect Zoo

Exercise 1. A Basic Study of Insect Biology: Friend or Foe?

Background

Some arthropods are pests, feeding on plant parts, others feed on insect prey, others live inside other arthropods and while others come from weeds or neighboring crops, and are simply resting in the crop.

Objective

To learn about the biology of arthropods, the 'insect zoo' and variations on the insect zoo can be conducted. This Exercise helps to study arthropods, their feeding and life cycles.

What You Need

- Small plastic vials or empty water bottles containers
- Plastic bags
- Plastic buckets/jars (transparent if available),
- Wheat leaves
- Tissue paper
- Camel or fine hair brush
- Labels
- Muslin cloth or fine mesh screen
- Rubber bands/pieces of string
- Hand lens
- Optional: insect collection box and pins

Procedure

Introduce and discuss the concepts of pests (“enemy of the farmer”), natural enemies (“friends of the farmer”) and neutral (“a visitor”).

Is it a pest?

- To find out whether an arthropod is a pest, collect it in the field and place it in a jar or vial. Be careful when handling the insects that you want to study, as they won’t feed if they have been roughly handled.
- Record the local name of the arthropod (if you know it), the location from where it was collected, and describe your observations on poster paper
- Offer it leaves, stems and/or fruits of the plant you found it on. Close the tube and place a piece of tissue paper between the tube and the lid to avoid condensation inside the tube. Keep the tubes out of direct sunlight.

- Observe the insect for a few minutes to see whether you can observe it feeding. After 2 or 3 hours observe the insect again, and note whether any of the plant material has been eaten, and if so, which plant parts have been attacked. Observe the insect every day, and supply fresh plant material as and when required. Observe and draw each stage of development of the insect.

Is it a predator?

- To find out whether an arthropod is a predator, collect it in a vial, and give it some prey. The prey should be other insects found on the same plant, and might include aphids, eggs or small caterpillars. Offer it several different types of prey.
- Close the tube and place a piece of tissue paper between the tube and the lid to avoid condensation inside the tube. Keep the tubes out of direct sunlight. Observe whether the insect feeds and on what it feeds; check again after 1 hour.
- Observe the insect for a few minutes to see whether you can see it feeding.
- After 2 or 3 hours observe the insect again, and note whether any of the prey insects have been eaten, and if so, which ones.
- Observe and draw each stage of development of the predator.
- At the end of the exercise, participants should present their observations to the wider group.

Observations

Have participants recorded the local names of the arthropods that were collected, the location where they were collected and described their observations on poster paper.

Participants should explain in presentation session:

- Insect(s) collected, Where they collected them
- What they fed on, Whether they changed development stages
- How long they remained in certain development stages

They should illustrate their observations with drawings.

Guide Questions for Discussion

- Did the insect feed in the zoo? If no, why not (was the insect damaged, not hungry, or is the insect not a wheat pest)?
- Did you learn more about the arthropod you studied in the insect zoo?
- How long did the insect survive in the zoo?
- Was the studied arthropod a 'friend of the farmer' or an 'enemy of the farmer'?
- How could the information about duration of development stages help you in the management of arthropod pests?

Exercise 2. Insect Damage Symptom Development

Objective

To study insect feeding patterns and understand which insect causes which damage symptoms

What You Need

- Small plastic vials, empty water bottles containers or plastic bags
- Three transparent plastic extra large jar
- Wheat spikes, branches and leaves
- Tissue paper
- Camel or fine hair brush
- Muslin cloth or fine mesh screen
- Rubber bands/pieces of string
- Masking tape
- Marker or pen
- Hand lens
- Optional: insect collection box and pins or glue and paper

Procedure

- Give participants two or three plastic bags, vials or empty water bottles in sets of three, with each container labeled "branches", "leaves" and "spikes".
- Participants should collect insects from spikes, branches and leaves and place them in the appropriately marked container.
- The facilitator should also collect insects and ensure that he/she collects the insect(s) participants are interested in studying during the exercise, in case participants are unable to identify that insect(s). Be careful when handling the insects that you want to study, as they won't feed if they have been roughly handled.
- Ask participants to study the insects collected and give the local name of each. Discuss what the insects might feed on.
- Ask participants to categorize the insects collected by species and location found and decides on which species to include in the insect "zoos".
- To set-up zoos, line three plastic buckets with tissue paper to avoid condensation.
- Put a clean wheat spike in bucket one, some wheat leaves in bucket two and pieces of a branch in bucket three.
- Select one insect per species and put it in the appropriate bucket. Put different insect species in each "zoo".
- Label each bucket with the local name of the insects being studied.

- Keep a sample of all insects in the "zoos" by gluing dead insects on a piece of paper (one piece of paper corresponding to each "zoo").
- Remember to indicate the local name of the insect (if known).
- It is a good idea to build up a reference collection of some pests and natural enemies during a field school training cycle. To make a reference collection, pierce or glue studied, dead insects on insect pins or fine tailor pins (pierce the pin through the thorax--the middle part of the body). Add a small paper label with details of the collection date, place and crop. Very small insects may be kept in glass vials with alcohol.

Observations

Divide participants into 3 groups to observe the "zoos". Each "zoo" should be kept by one participant in a place out of direct sunlight and observed regularly every day for 3-4 days for the following:

- What they fed on
- What the damage symptom looks like
- Number and type of insect that survived
- Number and type of insect that died
- Possible cause of death (lack of food? killed by another insect?)

At the end of the exercise, groups should describe and draw their observations on poster paper and make a presentation to the whole school.

Guide questions for discussion

- Did the insect feed in the zoo? If no, why not (was the insect damaged, not hungry, or is the insect not a wheat pest)?
- How long did the insect survive in the zoo?
- How could the information about feeding patterns help you in managing pests?

Exercise 3. Identification of disease symptoms

Background

Different types of diseases are present in the wheat field and majority of them are not economically very important. Consequently, farmers do not give any importance to these diseases. However, it is important that farmers should at least be able to group these diseases into types and their developmental stages studies.

Objective:

- To distinguish between different groups of diseases symptoms and learn about the developmental stages

What You Need

- Wheat field
- Magnifying glass
- White papers
- Color pencils
- Plastic bags

Procedure:

- Visit the wheat field and ask each group to collect as many leaves, branches and spikes as possible with possible disease symptoms such as leaf with color change, leaves with spots, shriveled leaves, etc.
- Ask each group to rank the disease symptoms in order of severity.
- Use the magnifying glass for close observations.
- Ask each group to make drawing of different disease symptoms according to their perception whether it's the different stages of the same disease or different diseases altogether.
- Have a presentation by each group on disease symptoms.

Guide questions for discussion

While concluding the exercise, the facilitator should lead the discussion by asking following possible leading questions.

- How do you know these were some kind of diseases?
- How many diseases were present?
- What are the local names of these diseases?
- What are the impacts of these diseases on plant health?
- Which plant parts are affected with different diseases?
- What practice (s) you carry out to eradicate these diseases?

Exercise 4. Study of Symptom for Disease Life Cycle Development

Background

A disease zoo can be set up using infected leaves or plants to study symptoms development. The study helps to recognize diseases in their early phases before they become severe.

Objective:

To familiarize farmers with symptomatically of the diseases

What You Need

- Wheat field
- Magnifying glass
- Plastic bags
- Plastic jars/ Glass bottle
- Rubber band/Thread
- Marker
- White sheet

Procedure:

- Collect the leaves with twigs having some disease symptoms from wheat field
- Encircle and measure the spot (s) on the leaf that you want to study
- Take a plastic jar or glass bottle which ever is available having half filled with water, top of which is covered with coarse cloth.
- Cut a small hole in the middle of the cloth covering the top and place the branch with leaf of disease symptoms in the hole in such a manner that bottom end of leaf twig should be in the water.
- Draw each spot and the area around it in detail.
- Measure its diameter and continue observing the marked spots and measure the size/diameter of the spot.
- After one week ask the group to present their finding.

Observations

Have participants observe the disease symptoms in the zoo as often as possible, or at least every two days.

They should try and describe a development in life cycle of disease by observing leaf closely through magnifying glass.

Guide questions for discussion

While concluding the exercise, the facilitator should lead the discussion by asking following possible leading questions.

- What happened with the spots over the time?
- Why the size of the spot increased with the passage of time?
- What is the difference between the disease symptoms and insect injury?
- How the disease spread?
- Is the spot disease harmful to crop productivity?

Practical Exercises

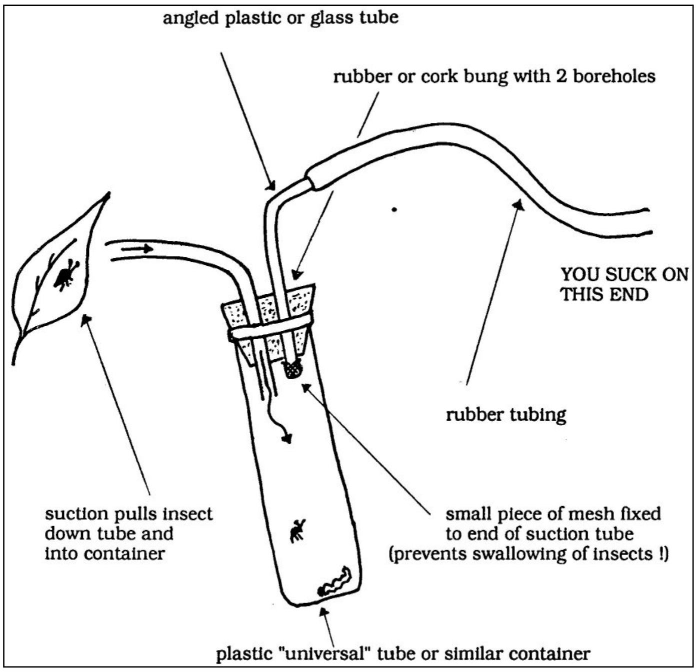
Practical 1.Investigating the diversity of natural enemies on a native plant species

Background

This practical demonstrates the huge biodiversity of natural enemies that are found attacking/infecting just one native plant species, and why native species rarely become invasive.

What You Need

- plant with obvious natural enemy infestation
- sweep net
- aspirator for sucking up insects from leaves (see diagram)
- small specimen tubes / 80% alcohol
- hand lens
- microscope



Procedure

Step 1. Collecting insects

Sweep nets

These are useful for collecting sturdy insects, e.g. bugs and beetles active on foliage, but not so good for delicate flying insects because it is easy to damage them.

- Walk through the vegetation swinging the net from side to side with a regular motion
- Avoid disturbing the vegetation before passing the net
- Allow the net to fold over the frame after a pass thereby preventing escape of the insects
- Use a small tube or jar to capture the insects once they are inside the net

Beating trays

These are useful for collecting many plant dwelling species hiding amongst leaves etc. It is often easier to work in pairs with a beating tray, especially when collecting fast moving species.

- Hold the tray under the plants to be sampled, or simply spread an old white sheet on the ground underneath.
- Shake the plant or use a stick to beat the vegetation vigorously so that the insects fall onto the white sheet where you can spot them easily
- make sure your first attack is strong because some insects will cling tightly to foliage once they are slightly disturbed!

- Collect the insects with your aspirator —take care with aspirator not to inhale dust and do not use them with insects that secrete unpleasant defense chemicals when alarmed.

Hand collecting arthropods

You can collect many arthropod natural enemies on plants by carefully examining plants. This is often effective for nocturnal species such as some beetle larvae, which may be hiding in leaf folds or buds. Plants can also be dissected to look for larvae that may be feeding internally. It is also a way of learning more about the feeding method. It may be easier to remove and bag samples of the plant to examine later back at base. This will also help you to quantify sampling.

Recording results

Count the number of different natural enemy groups present on the native plant. With the hand collected species, what part of the plant were they attacking/infecting? Use the microscope to observe the pathogen infected plant parts.

Questions for Discussion

- How many different natural enemy groups are there?
- Do you think that any types would be more suitable for use in biological control than the other species?
- What may happen if all the natural enemies were removed permanently from this plant species?
- Discuss natural spread and long term impact of natural enemies on weed populations

Notes to facilitators

It is important that a native non-crop plant is selected for this practical exercise. A perennial species would increase the probability of there being a suite of natural enemies attacking/infecting it.

It should be noted that some of the arthropods found on the study plants might just be ‘tourists’, causally present, rather than actual natural enemies.

Practical 2. Assessing the impact of natural enemies on a native plant species

Background

This practical examines the effect of natural enemies by comparing the growth rate of plants with and without their natural enemies. It should be set up as a demonstration plot in advance of observations.

What You Need

- population of a plant species consisting of at least 10 plants, with obvious natural enemy infestation
- general systemic fungicide and insecticide
- protective clothing and spray apparatus
- tape measure, scales

Procedure

Day 1: Setting up exclusion cages

1. Select 10 plants with high numbers of natural enemies. Randomly label five of the plants as 'without natural enemies' and five as 'with natural enemies'. If annual plants are being used or the stand is dense, it may be easier to divide up the plot and spray/not spray sections of it.
2. Remove natural enemies from all the 'without natural enemies' plants by spraying with a systemic insecticide and a fungicide.

Day 2: Assessing the impact of natural enemies

1. Observe any obvious difference in growth form.
2. After the selected length of time measure the height (and any other suitable characteristics to define vigour, e.g. seed set) of each the plant (or randomly selected plants if areas were spayed). If an annual, cut and measure wet weight of each plant. Record if any natural enemies have returned.
3. Calculate the difference in plant stature between those with and without natural enemies.

Questions for Discussion

- What affect do the natural enemies have on the vigour of the plant?
- What may happen if all the natural enemies were removed permanently from this plant species?
- Discuss natural spread and long term impact of natural enemies on weed populations
- What man-made situation is like this
- How could the balance be restored

Practical 3. Selectivity of insect weed biological control agents

Background

Natural enemies of plants can be monophagous – feeding on only one species, oligophagous - feeding on a few plant species or polyphagous - feeding on many different plant species. This practical will demonstrate this and how feeding tests are used to distinguish between the different types of natural enemies when selecting agents for the classical biological control of a invasive alien weed.

What You Need

- ✔ hand lens
- ✔ insect collection box containing damp filter paper
- ✔ plastic bags
- ✔ labels
- ✔ camel- or fine-hair brush
- ✔ small plastic dishes with lids (eg Petri dishes) containing damp filter paper

Procedure

Choice and no choice feeding tests

1. Find a common chewing insect feeding on a plant (eg beetle or caterpillar).
2. Collect at least 25 of these insects (more if easy to find, in multiples of 25), collecting those of same size. Place in insect collection box with food source.
3. Collect fresh leaves of the same age the insect was feeding on, place in a plastic bag and label.
4. Collect similar leaves from closely related plant species and distantly related species, bag and label separately.
5. Set up the following combinations of undamaged leaves in labeled Petri dishes containing filter paper in the base, 3-5 replicate dishes per combination:
   - Host plant only (control)
   - Host plant and related species (choice)
   - Host plant and unrelated species (choice)
   - Related species only (no choice)
   - Non-related species only (no choice)
6. Add one or more (as available) insects to each dish using a brush; close the dishes and place out of direct sunlight.
7. Observe the insects for a few minutes to see whether they start feeding or on which plant they are resting on (if any).
8. After 2 or 3 hours observe the insects again, and note whether any of the plant material has been eaten, and if so, which plant has been attacked. Repeat until insects have eaten the

samples or died.

Questions for Discussion

- What type feeding behavior does the insect have?
- If it was a natural enemy of an invasive alien weed, does it appear to be a possible candidate that could it be used for classical biological control if the plant was a weed?
- Discuss Oviposition and life-cycle completion on plant species
- Discuss host specificity principles
- Discuss when the insect makes its host choice and the appropriateness of the test.

Notes to facilitators

It is necessary to test-out this experiment in advance of the practical in order to ensure the selection of suitable insect test species. Caterpillars on crop plants are a good target agent to try. If possible, select another plant species that is related to the crop and one or more that are not.

Sessions Exercises to crop farmer's interest

Session No – 1. Community Participation

Objectives of the Session:

By the end of this session the participants would be able to:

- Understand the concept of community participation
- Explain people's participation in development activities
- Identify the importance of community participation in development
- Define the strategies for ensuring community participation

Total Time: 4 hours

Process	Method	Time	Materials
Ask participants why community participation is important for development Explain concept of community participation Assess participant understanding about community participation Add explanation if necessary	Question & Answer Discussion	15 minutes	Whiteboard Whiteboard marker
Divide participants into two groups, give them white chart and paper marker, ask them to write & present how community can participate in development activities	Presentation & Discussion	20 minutes	White chart & paper marker
Explain ten forms of participation	Interactive Lecture	15 minutes	
Ask participants the difference between supply-based development activities & demand-driven development activities and explain the difference between the two.	Question & Answer / Interactive Lecture	15 minutes	
Ask about areas of community participation and later explain them	Question & Answer / Interactive Lecture	10 minutes	
Provide details of advantages of community participation in development	Interactive Lecture	10 minutes	

Divide participants into two groups and give them white chart and paper marker. Ask them to write & present in which areas there is need for community participation in development program.	Presentations & Discussion	30 minutes	White chart & paper marker
Divide participants into two groups, give them white chart and paper marker, and ask them to identify the process of community participation in development related activities. Groups have to follow following sample format: Areas of Work Possible Activities (different for each area) Strategies to Ensure Participation (different for each area) Later ask groups to present. Afterwards, the concept will be explained by the facilitator.	Group Work Presentation & Discussion	1 hour	White chart & paper marker
Assess learning of participants by asking different questions: 1: Explain various forms of participation. 2: What are advantages of community participation? 3 What steps need to be initiated to ensure community participation in development?	Question & Answer	10 minutes	Whiteboard Whiteboard marker

Session No – 2.Contact Persons

Objectives of the Session:

By the end of this session the participants would be able to:

- Understand the concept of contact persons
- Explain the characteristics of contact persons
- Identify tools for identifying contact persons

Total Time: 1 hour

Process	**Method**	**Time**	**Materials**
Ask the participants what is meant by contact persons. Define contact persons.	Question & Answer Discussion	10 minutes	Whiteboard Whiteboard marker
Divide participants into two groups, give them white chart and paper marker, ask them to write & present characteristics of contact persons.	Presentation & Discussion	30 minutes	White chart & paper marker
Explain characteristics of contact persons.	Interactive Lecture	5 minutes	
Ask participants what tools exist for identifying contact persons. Later explain the steps for identifying contact persons.	Question & Answer Interactive Lecture	10 minutes	
Assess the learning of participants by asking different questions: 1: Define contact persons. 2: What are characteristics of contact persons?	Question & Answer	5 minutes	Whiteboard Whiteboard marker

Session No – 3. Social Mobilization

Objectives of the Session:

By the end of this session the participants would be able to:

- Understand the concept of social mobilization
- Explain the importance of social mobilization
- Identify the strategies of social mobilization

Total Time: 2:30 hours

Process	Method	Time	Materials
- Ask the participants what they understand about social mobilization. - Explain the concept of social mobilization. Assess the participants' understanding about social mobilization. - Add explanation if necessary.	Question & Answer Discussion	15 minutes	Whiteboard Whiteboard marker
Explain ways to mobilize society.	Discussion	10 minutes	
- Divide participants into two groups, give them white chart and paper marker, ask them to write & present the steps of social mobilization. Later explain the different steps of social mobilization.	Presentation & Discussion	30 minutes	White chart & paper marker
Explain four stages of social mobilization.	Interactive Lecture	15 minutes	
Ask participants how to conduct social mobilization.	Question & Answer	10 minutes	
Introduce and conduct a game with the help of provided guidelines; discuss learning points from the game.	Game & discussion	20 minutes	Whiteboard Whiteboard marker
Give details of advantages of community participation in development.	Interactive lecture	10 minutes	
Divide participants into two groups, give them white chart and paper marker, and ask them to identify media that can be used for social mobilization. Explain the	Group work Discussion	30 minutes	

mass media usually used for group work.			
Ask the possible stakeholders to play their roles for organizing social mobilization.	Question & Answer	10 minutes	
Divide participants into two groups, give them white chart and paper marker, and ask them to discuss possible strategies for organizing social mobilization. Explain strategies commonly adopted for organizing social mobilization.	Group work Discussion	30 minutes	
Assess the learning of participants by asking different questions: 1: Explain social mobilization. 2: What are stages of social mobilization? 3 What are the strategies for organizing social mobilization?	Question & Answer	10 minutes	Whiteboard Whiteboard marker

Session No – 4. Brainstorming

Objectives of the Session:

By the end of this session the participants would be able to:

- Understand the concept of brainstorming
- Explain the steps involved in brainstorming

Total Time: 0:30 minutes

Process	Method	Time	Materials
Ask the participants what they understand about brainstorming. Explain the concept of brainstorming. Assess participant understanding about brainstorming. Add explanation if necessary.	Question & Answer Discussion	15 minutes	Whiteboard Whiteboard marker
Explain the steps involved in the brainstorming process.	Interactive Lecture	10 minutes	
Assess the learning of participants by asking different questions: 1: Explain brainstorming. 2: What are the steps involved in brainstorming?	Question & Answer	5 minutes	Whiteboard Whiteboard marker

Session No – 5. Motivation

Objectives of the Session:

By the end of this session the participants would be able to:

- Understand the concept of motivation
- Explain the importance of motivation
- Identify the strategies of motivation in livestock development
- Define the role of development workers in motivation

Total Time: 4 hours

Process	**Method**	**Time**	**Materials**
Ask participants what they know about motivation. Explain the concept of motivation. Explain the difference between awareness & motivation. Assess participant understanding about motivation.	Question & Answer Discussion	15 minutes	Whiteboard Whiteboard marker
Divide participants into two groups, give them white chart and paper marker, and ask them to write & present what the importance of the motivation is.	Presentation & Discussion	20 minutes	White chart & paper marker
Explain ten forms of motivation through showing TS-5.3 & Handout.	Interactive Lecture	15 minutes	
Ask participants about the role of development workers in community motivation.	Question & Answer Interactive Lecture	10 minutes	
Give details of advantages of community participation in development.	Interactive Lecture	10 minutes	
Divide participants into two groups, give them white chart and paper marker, and ask them to write & present strategies for motivation in development program.	Presentation & Discussion	30 minutes	White Chart & paper marker
Assess the learning of participants by	Question &	10 minutes	Whiteboard

asking different questions: 1. Explain the concept of motivation. 2. What is the importance of motivation? 3. What is the role of development workers in community motivation?	Answer		Whiteboard marker

Session No – 6. Effective Communication

Objectives of the Session:

By the end of this session the participants would be able to:

- Describe what effective communication is
- Explain the process of communication
- Identify the skills required for communication by a development worker
- Explain the importance of communication in basic education
- Identify the strategies for communication in development

Total Time: 4 hours

Process	Method	Time	Materials
Ask participants what should be done to motivate people, and collect the responses. Emphasize on Communication.	Question & Answer Discussion	15 minutes	Whiteboard Whiteboard marker
Ask what is understood by "communication" and note down the answers.	Presentation & Discussion	5 minutes	Whiteboard Whiteboard marker
Invite participants to stand in circle in such a way so that all can see you, and then tell them about the game they have to play Explain that it is general human nature to follow what is seen, rather than remember what is heard	Game	10 minutes	Game Play
Explain ten ways how communication takes place using TS-6.2 & Handout.	Discussion	10 minutes	
Ask participants the components of communication. Facilitate their responses	Question & Answer	5 minutes	
Explain the media for communication and the nature of each	Discussion	15 minutes	
Invite four participants separately and brief them on their role-play. Explain their individual roles and allow time for their preparation. - Invite them to perform.- Take help of the guidelines provided.- Role-play. -	Role-play	35 minutes	Role-play

Discuss the learning points from the role-play and explain the reasons for disruption in communication.			
Divide participants into two groups, give them white chart and paper marker, and ask them to write & present the essential duties of message senders for effective communication	Group work Presentation & Discussion	30 minutes	Chart & markers
Ask participants about the skills required for effective communication. Explain the skills of communication	Question & Answer	1 hours	
Introduce role of communication in management	Discussion	5 Minutes	
Explain the span of communication in management.	Discussion	5 minutes	
Invite the participants to work in groups and identify activities and strategies required for effective communication Ask to present group works in plenary. Generalize the discussion at the end.	Group work	1 hrs	Chart & markers
Assess the conceptual clarity of the participants by asking the following questions: What do they understand about effective communication What kind of communication skills need to be developed in development workers?	Question & Answer	5 Minutes	Whiteboard Whiteboard marker

Session No – 7. Team Building

Objectives of the Session:

By the end of this session the participants would be able to:

- Describe what is meant by 'Team'
- Why team-building is important
- Identify characteristics of teams
- Explain the need for teams
- Identify leadership in teams

Total Time: 2 hours

Process	Method	Time	Materials
Ask the participants what does 'team' mean and collect the response. Emphasize on Team.	Question & Answer Discussion	15 minutes	Whiteboard Whiteboard marker
Ask what the participants understand by "Team Building". Listen to and write the answers	Question & Answer	10 minutes	Whiteboard Whiteboard marker
Ask participants about the principles of 'team'	Question & Answer	15 minutes	Whiteboard marker
Explain the activities of a team with the help of the handouts.	Interactive Lecturing	15 minutes	
Divide participants into two groups, give them white chart and paper marker, and ask them to write & present the essential needs of a team.	Group work Presentation Discussion	30 minutes	Chart & markers
Ask participants about leadership in a team. Explain leadership in team	Question & Answer	30 minutes	
Assess the conceptual clarity of the participants by asking the following questions: What do you understand about team building? What are the needs of a team?	Question & Answer	5 Minutes	Whiteboard marker

Session No – 8. Leadership

Objectives of the Session:

By the end of the session the participants would be able to:

- Explain leadership and its nature
- Describe the importance of leadership
- Identify the traits of a leadership
- Describe leadership roles in development

Total Time: 2 hours

Process	Method	Time	Materials
Ask who should come up to ensure people's participation and note the responses.	Question & Answer Discussion	5 minutes	Whiteboard Whiteboard marker
Ask what leadership means and note the answers. Explain the concept of leadership.	Question & Answer	5 minutes	Whiteboard Whiteboard marker
Explain the forms of leadership	Discussion	10 minutes	
Explain the nature of leadership	Discussion	10 minutes	
Write the question "Why leadership is required in development?" on the whiteboard and write participants responses under it. Distribute a slip of paper to each of the participants and request them all to write their view on the slip of paper and paste those on the board. Read the papers and generalize the points.	Paper slip & Discussion	20 minutes	VIPP card & scotch tape
Explain the importance of leadership.	Discussion	10 minutes	
Ask about what traits a leader requires to lead management in a participatory manner and note the responses	Brainstorming & Discussion	25 Minutes	Whiteboard Whiteboard marker
Assess the achievement of the participants by putting following questions: What are the traits of leaders? What are the roles of leaders?	Questions & Answers	5 Minutes	Whiteboard Whiteboard marker

Session No – 9. Conflict Resolution

Objectives of the Session:

By the end of this session the participants would be able to:

- Explain the term 'conflict' and its nature
- Describe types of conflict
- Identify conflict management
- Describe suggestions for conflict management

Total Time: 2 hours

Process	**Method**	**Time**	**Materials**
Ask what is meant by 'conflict' and collect the responses.	Question & Answer Discussion	5 minutes	Whiteboard Whiteboard marker
Ask about the types of conflict and make a record of the responses. Clarify the concept of 'conflict'.	Question & Answer	5 minutes	Whiteboard Whiteboard marker
Divide the participants into two groups, give them white chart and paper markers, and ask them to write on how to manage conflict. Ask the groups to present their work. Explain conflict management	Presentation & Discussion	30 minutes	Whiteboard
Ask participants about suggestion for conflict management.	Question & Answer Discussion	20 minutes	
Assess achievement of the participants by putting to them the following questions: What are the types of conflict? How is it possible to manage conflict?	Questions & Answers	5 Minutes	Whiteboard Whiteboard marker

Session No – 10. Plan of Action

Objectives of the Session:

By the end of this session the participants would be able to:

- Explain what is a Plan of Action
- Explain how to develop a Plan of Action

Total Time: 1 hour

Process	Method	Time	Materials
Ask what is a Plan of Action & explain its various types. Note the responses.	Question & Answer Discussion	5 minutes	Whiteboard Whiteboard marker
Explain what are the requirements of a Plan of Action. Explain the factors that are considered to develop a Plan of Action.	Interactive Lecturing	10 minutes	Whiteboard Whiteboard marker
Divide the participants into two groups, give them white chart and paper markers, and ask them to develop a Plan of Action. Ask groups to present their Plans of Action. Explain the advantages of a Plan of Action.	Group work Presentation & Discussion	40 minutes	Whiteboard
Assess the achievement of the participants by putting them the following questions: What is a Plan of Action & its various types? How is a Plan of Action developed?	Question & Answer	5 Minutes	Whiteboard Whiteboard marker

Session No – 11. Leadership

Introduction:

The advancement of a community or an institution largely depends on appropriate and active leadership. Generally-speaking people in our society largely depend on leaders, especially for progress and development. At any level in a society the influence of appropriate leadership is very significant for development.

Leadership is a trait that enables one to influence the opinion of others to do something according to his choice. There may be different forms of leadership in a society. Some examples are as follows:

- Elected leaders
- Nominated leaders
- Acceptable leaders
- Appointed leaders
- Informal leaders
- Self-proclaimed leaders
- Empowered leaders
- Political leaders

Position of Leadership within the Context of Community

The position of leadership varies from one situation to another. For example:

Situational Form of Leadership:

- Family – Head of family
- Group – Elected leader
- Society – Elected or accepted leader
- Community – Elected leader

Different Styles / Nature of Leadership

Styles of leadership may vary according to the behavior of the leader. Leadership behavior is generally classified into three types. These are:

- Uncensored / Laissez-Faire leadership
- Participatory leadership / Leadership in partnership
- Autocratic leadership

These three types are explained below:

Characteristics of Uncensored Leadership:

- Team members are given unlimited freedom to decide; the leader does not interfere.
- The leader ensures supply of materials and equipment.
- The leader remains aloof from participation.

- Only when there is a crisis does the leader attempt to control the team members.

Characteristics of Partnership / Participatory Leadership

- All decisions and strategies are taken through group discussions, decisions and cooperation between the team members.
- Methods and steps to be adopted are decided through discussion. The leader explains the goals and general strategies.
- Team members can distribute the work between them through mutual discussion.
- The leader takes into account the realities and maintains confidence of the team members through praising their initiatives.

Characteristics of Autocratic Leadership:

- The leader makes all the decisions himself.
- The leader directs the strategies and steps to be adopted. Uncertainty remains for future course of actions.
- Leader instructs specific persons to do specific things.
- Leader prefers to flourish individualism in all aspects. Praises own initiatives and criticizes the efforts of team members. Remains aside from active participation in team activities.

Comparison between the three types of Leaderships:

Although in an autocratic leadership the scope of work is faster, in terms of quality of work the partnership leadership is better. In the autocratic style everything is damaged except the leader. But in partnership leadership very little quality is affected due to change in leadership. In the uncensored leadership form, both speed and quality of work is found to be the worst.

Foundation of Leaderships:

In community development the foundation of leadership is a participatory or democratic practice. Dictatorship of undemocratic leadership cannot lead to sustainable development. In community development, development is facilitated by the extent of the participatory process in leadership. Since in our society the people are not able to participate effectively, the leaders should create scope to enhance their capacity for participation.

Absence of Leadership in Development:

For there to be social and economic development, there is no alternative to expansion of development. Development is a significant step towards turning this population into a productive resource. Though they live within our communities, that too as a majority, the poor are deprived of many facilities. On one hand they do not have any interest, but moreover they are not in any position to even avail opportunities to acquire skills in development, the basic reason behind which could be the lack of leadership among them.

Importance of Leadership:

Local leaders play a vital role in ensuring peoples' participation in development activities. The rural population, mainly due to its ignorance and illiteracy, often depends on the opinions of these local leaders. A development worker cannot go to every individual personally, particularly when resources and time is limited. But it is essential to involve every single individual in the process of development. This message can be effectively communicated through a good leader.

Desired Traits of a Leader for Development Program:

To gain confidence of the people, the leader for development should acquire the following traits. Education level, economic conditions, status in the society, age, etc., largely influence these traits:

- Knowledge of the subject
- Ability to work in a group
- Honest and attractive leadership
- Good behavior with all
- Analytical skills
- Inter-personal communication skills
- Patience
- Interest and willingness to work for the poor
- Interested to work for society
- Positive attitude towards helping out

Role of a Leader:

Local leaders have an enormous responsibility for expanding basic awareness programs. Using their influences they can involve the people properly and positively. They can discharge the following responsibilities towards this effort:

- Realize the need for management
- Help people from all walks of life to join hands in this area
- Create social awareness
- Mobilize materials, resources and facilities
- Communicate with development partners
- Remain respectful to neglected populations
- Maintain discipline in the society
- Maintain good relations at all levels
- Enable participation of people at all possible levels
- Help the poor population
- Inform the population about development initiatives
- Distribute responsibility among the population and ensure performance by them

Field workers should undertake similar responsibilities also and in addition, they should:

- Play the role of an appropriate leader
- Promote leadership in the society
- Maintain liaison with other local leaders
- Provide necessary guidance and support for appropriate leadership

Nature of Leadership:

- Autocratic
- Participatory
- Laissez-Faire