Practical Application Wheat Production

2012

This publication was produced for review by the United States Agency for International Development. It was prepared by USAID-*Inma* Agribusiness team for a consortium led by The Louis Berger Group, Inc.

Practical Application in Wheat Production

General information: info@inma-iraq.com
Website: www.inma-iraq.com

DISCLAIMER

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Introduction

The demand on Iraqi agriculture to rapidly increase production of cereals may be effectively addressed, through modifications in the present farming systems. Some of the techniques and technology used in the traditional wheat farming system, which may be beneficial to change include:

- Adaption of proven newer production technology:
- Improved varieties and seeds:
- Improved fertilizer management;

Maximizing the efficient use of the water resources.
This seminar booklet will discuss various systems and techniques, which USAID-Inma thinks will provide wheat farmers and extension agents with the knowledge to adapt these systems to Iraqi conditions.

Production Systems

- **Conventional Production Systems (Irrigated and Rainfed)**

  Soil type and condition as well as the previous cropping pattern dictate the amount and type of tillage necessary to prepare the seedbed. A field with a large amount of residue from the previous crop, may require deep plowing or deep tillage to bury and help decompose the residue and to minimize the amount of debris on the soil surface.

Soil should be plowed or disked as deeply as possible to help break up compaction and reduce the risk of herbicide carryover. In irrigated production, deep sub-tilling (40 to 50 cm), plowing, or at least two diskings, may be necessary, based on soil texture, and compaction. The expense of deep tillage or plowing may not be cost effective in more risky rainfed wheat production. Disking and/or harrowing normally follow plowing or chiseling to prepare the final seed bed. Soils should not be tilled when wet since this contributes to soil compaction, creates clods, and other physical conditions unfavorable for germination and growth of wheat and other small grains.

The seedbed should be 10 to 15 cm deep, and free of soil clods, which could interfere with wheat planting. Seedbeds with large clods and heavy crop residue, which will not pass freely through grain drill, may plug up and cause an uneven stand. Conversely, an over prepared seedbed creates a powdery surface soil that is prone to crusting, which can delay or prevent emergence.

Seedbed preparation for broadcast seeding is less critical because the broadcasting equipment is not affected by clods and residue. The seed bed, however, must be properly prepared to allow for good seed to soil contact to allow good germination.

Rainfed production is only widespread in northern Iraq. Annual cropping is most commonly used in northern Iraqi rainfed areas. Seedbed preparation for annual rainfed cropping begins with disking or chiseling dry soil in early summer. The seed-bed is prepared after fall rains begin and is completed with shallow disking or harrow-ing. There is a greater risk of crop failure with this system because of inadequate moisture.

- **Minimum-Till and No-Till Systems**

Minimum-till and no-till seedbed preparation can be very beneficial in rainfed crop-ping 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. Problems occur when residue is not cut but stuffed into the seed slot by the openers, preventing the soil-seed contact necessary for optimal germination.

Strip Fallow Rotation for Rain-Fed Production in Minimum or No-Till Systems.

Fallow in a crop rotation describes a field that is not occupied by crops during an entire growing season and is a proven technique for raising soil fertility, accumulating moisture in the soil, and increasing the yield of crops in the rotation. A strip-fallow rotation refers to one, which leaves alternating strips of one half of the land fallow each production season. The weeds are controlled on the fallow land through the wheat growing season, allowing moisture to accumulate in the soil for the next growing season. This system may increase yields per donum, from the planted portion of the field, in marginal rainfed areas by 10 to 25 percent. It most certainly decreases the total yield from the entire field. It proportionally reduces the cost of inputs such as seed and fertilizer, but may increase weed control costs proportional to planted area. The system should reduce the likelihood of a crop failure because of inadequate moisture during the growing period. The fallowed soil is kept loose and weed-free. Each farmer will have to make his own calculation as to the financial benefits of a strip fallow system over an annual planting system.

- **Other Techniques for Consideration**

Pre-irrigation / Mulching

Mulch may be used in irrigated production in Iraq when rain is not expected before stand establishment. Fields are pre-pared, fertilized, and irrigated approximately 3 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 3 to 6 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 and conditions for germination.

Planting on the Flat Versus Planting on Beds

Small grains grown under well-drained conditions can be successfully sown flat or on raised beds. Soil type and surface drainage determine the best method for a given field.

Wheat growers use raised beds to allow for better drainage and provide efficient irrigation. Raised beds can be especially effective on heavy soils that hold moisture for long periods. They improve drainage, keeping the root system and plant crown aerated and reducing the chance of root rot, and they can also reduce nitrogen loss due to de-nitrification and leaching. The beds are spaced up to 1.5 m apart; the width of beds depends on the equipment used, rotation crops planted in the same field, soil type, and how well the soil moves water laterally to the center of the bed, or “subs,” during irrigation. The tops of raised beds should be flat or rounded so that water does not accumulate around plant crowns, where it can cause waterlogging. Beds can be formed with listing shovels on a tool bar. Furrows should run with the field’s slope, and drainage should be provided at the end of the field. Planting systems for raised beds include:

- bedding and shaping the bed top followed by drilling the seed parallel or diagonally to the beds (the preferred method)
- bedding and shaping the bed top followed by broadcast seeding and harrowing to cover the seed
- broadcast or drilling the seed followed by harrowing and furrowing (which saves time)

Drilling Versus Broadcasting

Most plantings on irrigated soils are drilled. The advantages of drilling over broadcasting include a more uniform depth, some reduction (up to 20 percent) of seeding rate, more uni-form emergence, and the ability to place a starter fertilizer (a low-nitrogen, high-phos-phorus fertilizer) with the seed. The advantage of broadcast seeding is that it permits large acreages to be planted 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.

- **Options for Irrigated Production**

Seeding into Moisture

Pre-irrigate, then sow into moist soil. Pre-irrigation of fine-textured soils such as clay loams and clays should be done early enough in the fall to allow time for the topsoil to dry sufficiently to permit seedbed preparation and planting before rain begins in mid-October to mid-December in Iraq. Pre-irrigation can be done later on loam and fine sandy loam soils that drain more quickly. One advantage of pre-irrigation is that weeds germinate before seeding and can be removed by tillage during seedbed preparation. Pre-irrigation can also provide ideal soil-water content in the seedbed so that uniform germination begins soon after seeding.

Seeding into a dry seedbed and then irrigating to germinate the seed is a second option. In Iraq seeding in mid-October to early November are more successfully germinated by pre-irrigation. Pre-irrigating early fields assures warm soil temperatures at germination, while the risk of rainfall immediately after irrigating is relatively low. Significant rainfall after irrigating for germination prolongs standing water and creates poor aeration around the seed, retards seedling growth that will lead to seedling disease. Irrigating for germination is more successful on fine sandy loam and silt.

Seeding into a dry seedbed and waiting for rain is a third alternative. Seed retains its viability in dry soil for an extended time (several months), and stands will generally be adequate once rainfall induces germination. If seed germinates by the end of December, losses in yield potential will be minimal. This alternative is cost-effective in areas where surface water is unavailable and groundwater is expensive to pump or is of undesirable quality. However, in years when rain-fall during December is insufficient for germination and the field is not irrigated to germinate the seed, emergence will be late, the production season will be shorter, with lower yields.

- **Seeding Depth**

The recommended planting depth is 2.5 to 4 cm for wheat. If small grains are planted deeper than 5 centimeters, germination is delayed, emergence is impeded, and stands may be reduced. The sheath that surrounds and protects the embryonic plant as it emerges from the seed (the coleoptile) is only about 5 to 6.5 cm inches long, and it will not emerge if buried below that depth.

- **Seeding Date**

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 donum 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.

Recommended planting dates for wheat in Iraq:

Growing Region	Wheat
Northern	Nov/Dec
Central	Nov.
South	Nov.

Iraqi wheat is usually planted in October through December, and harvested in May and June. Choosing the correct planting date can reduce the likelihood of damage by heat, certain diseases, makes weeds easier to control therefore increase yield. Planting early increases chances of disease and insect problems. Planting later reduces chance of survival and generally delays maturity, increases the chance of disease and reduces yield.

- **Seeding Rate**

  Optimal seeding rate is determined by sowing method and growing conditions.

Crop	Seeding Rate Kg./Donum
Irrigated Wheat	28 - 42
Rain fed Wheat	16 - 28

  Increase rate by 5.5 -8.5 Kg/Donum for broadcast plantings.
  Increase rate by 7.0 – 14 kg./Donum using narrower row spacing for late plantings.
  Higher rates are used for broadcast planting, since a smaller proportion of broadcast seed emerges. Higher rates and narrower row spacing are recommended for late sowing to compensate for fewer tillers that will form and higher sowing density tend to shorten the time to flowering. Higher rates are also recommended if poor growing conditions, such as competition from weeds are anticipated. Higher seeding rate help control weed and weed. Lower seeding rages can help avoid lodging.

- **Residue Management**

  When crop residues interfere with planting operations, management practices must remove or reduce them. These practices include baling and removing straw, grazing, plowing, or burning, alone or in combina-tion. Choppers or spreaders should be attached to the combine unless the straw is to be baled. Removing, deep plowing, or burning residue may help reduce the buildup of disease-causing organisms that survive on crop residue, such as those that cause Septoria tritici leaf blotch (wheat) and net blotch and scald (barley). Incorporating crop residue improves soil structure and in many instances is a major benefit of a small grain crop.

Conservation tillage, defined as a tillage program that keeps at least 30 percent of the soil surface covered by crop residue at all times, which is appropriate for many rain-fed small grain production areas. Maintaining a surface cover of crop residue to reduce soil erosion is an important part of conservation tillage operations. Straw chopper and spreader attachments should be used on the combine to spread crop residue uniformly. This helps control erosion and improves distribution of the straw. Areas of straw accu-mulation may tie up nitrogen fertilizer during the following crop season. In no-till oper-ations, uniform distribution of crop residue is critical to providing favorable planting conditions for the next crop.

Growth and Development of Wheat

The growth and development of the small grains- wheat, triticale, barley, and oat-follow very similar patterns. Plant development is divided into several stages: germination and early seedling growth, tillering and vegetative growth, elon-gation and heading, flowering, and kernel development.

Wheat growth stages utilizing Feekes' scale:

Tillering	
1	One shoot – (number of leaves can be added through the Coleoptile) Sheath protecting a young shoot tips.
2	Beginning of tillering , main shoot and one tiller- (count leaves on main stem)
3	Tillers formed, leaves often twisted spirally. Main shoot and six tillers
4	Beginning of erection for the pseudo-stem, leaf sheaths be-ginning to lengthen
5	Pseudo-stem – strongly erected
Stem Extension	
6	First node of stem visible at base of shoot
7	Second node of stem formed: next- to- last leaf just visible.
8	Flag leaf (last leaf) visible but still rolled up; ear beginning to swell
9	Ligule of flag leaf just visible
10	Sheath of flag leaf completely grown out, ear swollen but not visible

Stage	Description
Heading	
10.1	First spikelet of head just visible
10.2	One quarter of heading process completed
10.3	Half of heading process completed
10.4	Three – quarters of heading process completed
10.5	All heads out of sheath
Flowering	
10.51	Beginning of flowering
10.52	Flowering complete to top of head
10.53	Flowering completed at base of head
10.54	Flowering completed, kernel watery ripe
Ripening	
11.1	Milk ripe
11.2	Mealy ripe- content of kernel soft but dry (Soft dough)
11.3	Kernel hard (difficult to divide with thumbnail).
11.4	Ripe for cutting – Straw dead

- **Germination and Seedling Emergence**

  As wheat yields have increased, roughly half that increase has been due to improved varieties with the remaining half due to improved management. With environmental conditions so unpredictable and variable, proper variety selection can make the difference between profit and loss so it deserves careful attention each year. Obviously, the primary objective is to pick varieties that will give high per-donum yields and the highest possible net income, but this is not a simple matter.

Quality seed is essential for establishing a productive stand. Seed should have at least 85 percent germination and 75 kg/hl test weight 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. Two parts of the wheat seed are of greatest importance in germination. The embryo, or "germ," gives rise to the radicle, or the seedling root, and the epicotyl, or the first leaf. The other important part of the seed is the endosperm, which contains food in the form of starch and protein for germination and emergence. The coleoptile penetrates the soil and results in emergence of the seedling, usually within 5 to 7 days after planting. If the seed is planted too deeply, beyond the elongation distance of the coleoptile, seedlings cannot emerge and a poor stand will occur. Semi-dwarf wheat varieties form short coleoptiles as well as short plants, and planting depth is particularly critical for them.

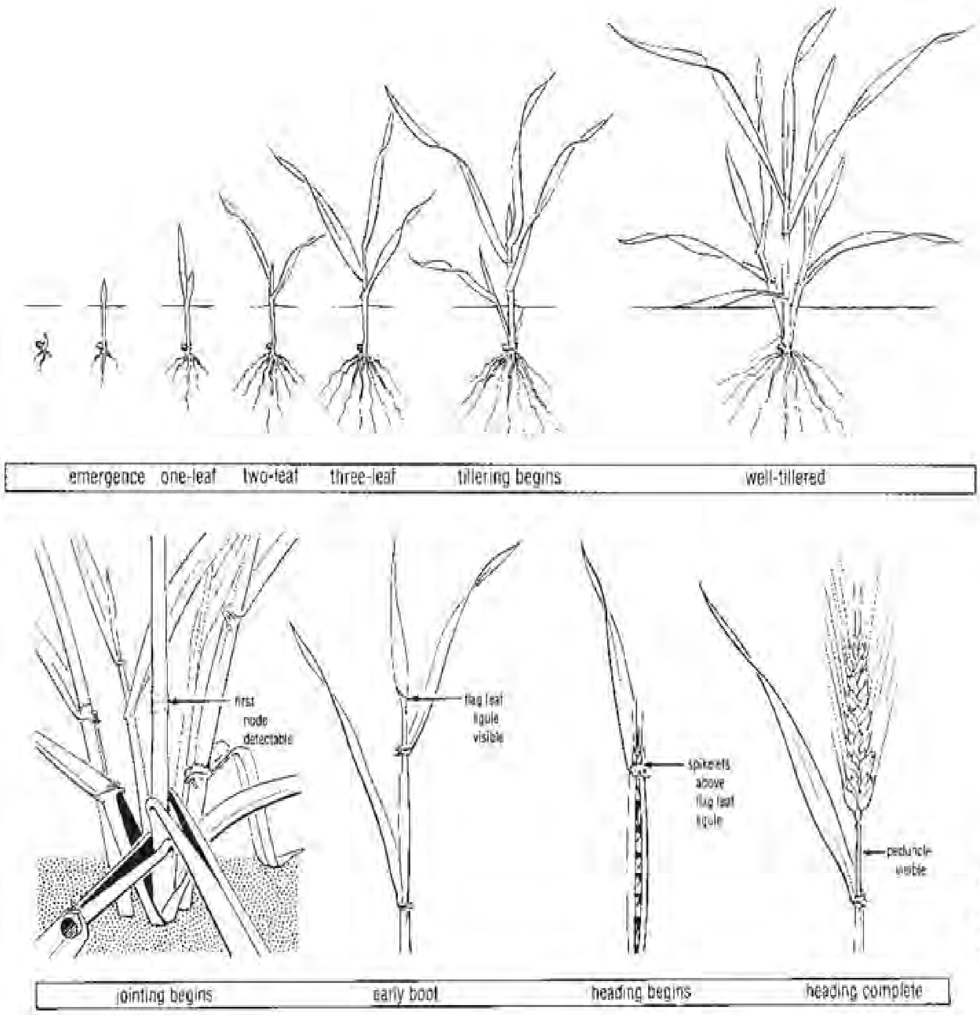


Figure 1. Small grain developmental stages. *Source:* Flint 2002.

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 drying of the soil and resume growth when moisture reoccurs, but seedlings that are 4 or 5 days old probably will not tolerate drying.

- **Tillering and Vegetative 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 such as 2, 4-D stop development of the tillers and should not be applied at this stage. Farmers should consult their Agriculture Extension Specialist for herbicide recommendations for Iraq.

- **Stem Elongation and Heading**

  Stem elongation, or jointing, occurs when stem internodes increase in length and bring the nodes above ground. The uppermost five or six internodes elongate, begin-ning with the lowest of these. The appearance of the first node above ground marks the beginning of jointing. Jointing begins about the time all spikelet primordia have formed. The flowering structure (inflorescence) of wheat, triticale, and barley is called a spike; Inflorescences are composed of spikelet's, each consisting of one or more flowers, called florets, at nodes along the spike.

One spikelet forms at each node of the wheat and triticale spike, but each spikelet consists of threeo six potentially fertile florets.

During stem elongation the spike or panicle increases in length from about 3 mm to its final size, and individual florets mature. All stages of spikelet development in wheat, triticale, and barley begin near the middle of the spike and proceed toward the base and tip. Development of oat florets begins at the tip of the panicle branches and proceeds toward the base. The last leaf of the small grain plant to emerge is called the flag leaf. When the flag leaf blade has completely emerged, the appearance of its ligule (a short membrane on the inside of the leaf at the junction of the blade and sheath) marks the beginning of the boot stage. During boot stage the enlarging spike swells and splits the sheath of the flag leaf. Heading begins when the spike begins emerging through the flag leaf collar and is complete when the base of the spike is visible.

- **Flowering and Grain Filling**

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.

Wheat is highly self-pollinated and quite resistant to most stresses except frost during flowering. Temperatures only slightly below freezing quickly kill the male flower parts, sterilizing the florets so no grain is formed. However, only part of the spike might be sterilized because of the variation in flowering, so grain might form on the center or ends but not on the other parts.

The flowers of wheat, triticale, barley, and oat are self-pollinated; most of the pol-len is shed before the anthers emerge from the florets. Flowering (anthesis, or pollen shed) usually occurs within 2 to 4 days after spikes have completely emerged from the boot (barley often flowers prior to emerging from the boot). If emergence occurs dur-ing hot weather, flowering may occur while spikes are still in the boot. Most cells of the grain endosperm are formed during a period of rapid cell division following pollination. These cells enlarge and accumulate starch during grain filling. Most of the carbohydrate used for grain filling comes from the photo-synthetic output of the flag leaf. Developing spikelets compete for limited supplies of pho-tosynthate and nitrogen. The smallest, slow-est-growing florets, which occur at the tip of the barley spike and at the tip of each wheat spikelet, are often unable to obtain enough nutrients to keep growing. Some spikelets at the base of the wheat or barley spike also may fail to develop. The stages of grain ripening are called milk, soft dough, hard dough, hard kernel, Figure 2. Stages of grain ripening in wheat. *Source:* Flint 1990, and harvest ripe (for wheat, see fig. 2). Dry matter begins accumulating in the kernel.

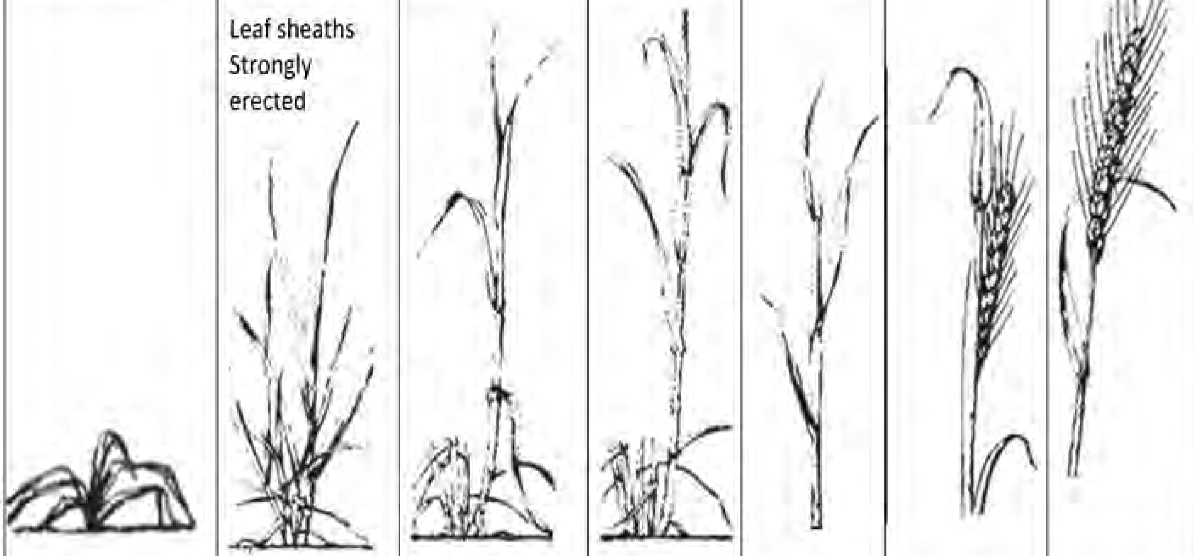
- **Yield Components for Wheat**

  Components for 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 seed-lings that emerge and survive. Tiller number per plant depends on plant density, culti-var, planting 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 reduc-es the number of spikelets that are formed. Florets are initiated during the stem elonga-tion stage. The small grain plant is not able to produce enough photosynthetic 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 maxi-mum number of florets. The cells of the endosperm accumulate starch and protein dur-ing 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.

- **Timing of Field Activities**

Table 2 gives approximate dates when important crop growth stages occur for wheat produced in key growing regions of Iraq. The dates and corresponding growth stages are for common wheat cultivars planted at optimal planting dates with sufficient soil moisture to initiate germination. Seasonal weather conditions are considered average. Depending on the cultivar selected, crop development may vary seven days on either side of the dates specified. Similarly, even under the most variable weather conditions, crop development will be within about seven days of the dates specified. Herbicides for early-season weed control should be applied prior to the onset of tillering, when weeds are small (follow the label). Herbicide applications for later-season weed control should be made when the crop is fully tillered. Fertilizer top-dressing should be made at the mid-tillering stage. Nitrogen top dressing to improve grain protein should be made at heading or flowering in conjunction with an irrigation. If fungicide applications to control foliar diseases are planned, they should be applied to protect the flagleaf and penultimate leaf (the leaf that emerges prior to the flagleaf), and thus should be made just prior to boot stage. Farmers should consult their Agriculture Extension Specialist for herbicide recommendations for Iraq.

January	February	March	April	May	June	June
Stage 3 Winter dormancy Prostrate growth	Stage 3, 4 tillering continues Leaf sheaths Strongly erected	Stage 5,6 Jointing First node of steam visible	Stage 6, 7, 8 Second node visible	Stage 9, 10 Boot heading flowering	Maturation Ripening Harvest	Harvest



January	February	March	April	May	June	June
Top-dress Nitrogen						Summer tillage
					Selected varieties	
						Soil test
					Harvest	
		Green bugs				
			Hessian Fly			
	Cutworms and Armyworms					
				Tanspot, leaf rust & Speckled Leaf Blotch		
			Monitor Wheat Streak Mosaic			
				Monitor for Take-all, Loose Smut		Monitor Grain for Bunt
			Monitor for Foliar Disease	Make Decision Whether to apply fungicide		

Figure 2. This calendar reflects average dates for Iraq. Harvest may occur somewhat later in the extreme north and somewhat earlier in the extreme south.

Fertilization of Wheat

- **Soil and Soil Fertility**

  Soils and small grain crops are grown on many soil types. Crop rooting depths vary with soil texture, soil profile development, drainage, and the presence of restricting layers. Roots of small grains can penetrate 2.1 meters deep on well-drained deep soils if there are no restricting layers, but penetration of 0.9 to 1.5 meters at maturity is more common. Soils in many rainfed areas are shallow clay-pans or hardpans types. Nitrogen loss can be very high on these soils during high-rainfall years since de-nitrification occurs under waterlogged soil conditions. Nitrogen losses can be minimized on shallow or coarse-textured soils by making split applications of nitrogen.

- **Nitrogen**

  Nitrogen is the element most frequently lacking for optimum wheat production. Nitrogen recommendations are based on expected yield, cropping system, soil texture, and available profile nitrogen.

- **Role of Nitrogen in the Plant**

  Adequate nitrogen stimulates vegetative growth and increases yield and protein con-tent. Excessive nitrogen increases lodging, delays maturity, increases the severity of some diseases, contributes to groundwater pollution, and causes rainfed crops to deplete available moisture too early in the season. The nitrogen requirement of the crop is directly related to the final grain yield. Plants obtain nitrogen from residual nitrogen in the soil, from nitrogen released from decaying organic matter (including the residue of the previous crop), and from applied fertilizer. On most soils 28 to 55 kg/donum of nitrogen may produce 1.7 to 1.95 metric tons per donum 6.7 to 7.8 t/ha of wheat grain, depending on the previous crop, winter soil moisture, and rainfall conditions. Durum wheat may require higher rates of nitrogen, up to 68 kg/donum (269 kg/ha).

- **Deficiency Symptoms**

  Nitrogen deficiency symptoms are characterized by an overall yellowing of leaves, begin-ning with the bottom (older) leaves. Younger leaves remain green and appear healthy. Plants are smaller and produce fewer tillers than plants with adequate nitrogen.

- **Nitrogen Requirements and Rates**

  The amount of nitrogen required by the crop depends on the type of small grain, the previous crop in the rotation, the soil type, and weather conditions and cultural practices during the growing season. Barley, oat, triticale, and wheat require different amounts of nitrogen; the amount depends on the yield potential of the crop and the intended use (grain production requires higher nitrogen levels than forage produc-tion). More nitrogen is required when wheat follows crops such as rice, cotton, or wheat than when wheat follows vegetable crops, since more residual nitrogen normally remains after the harvest of vegetables. Large amounts of residue from any previous crop may require more nitrogen at sowing to provide enough available nitrogen for small grain growth and residue breakdown. Nitrogen may be lost on gravelly or sandy soils due to leaching below the root zone. Losses can occur from waterlogged soils when nitrogen is lost to the atmosphere as nitrogen gas (N2) or nitrogen dioxide (N2O) through a biological process called de-nitrification. Waterlogging is likely on heavy soils and/or soils with a hardpan or clay-pan. Excessive winter rains and excess irriga-tion can cause nitrogen loss from any soil. Sowing on raised beds rather than on flat ground provides better drainage, reduces nitrogen loss, and provides better soil condi -tions for root growth.

If the crop is sown in late fall and makes little growth before the onset of cold weather, little nitrogen uptake will occur during winter. A sub-stantial amount of nitrogen uptake normally occurs beginning in late January to early February. The rate of accumulation increases through winter, peaking at about flowering and then decreasing as the crop reaches maturity.

A soil test for available Nitrogen profile is very helpful in evaluating the amount of residual nitrogen. The test measures the quantity of available nitrogen in the soil at the time the sample is collected. The soil sample for available nitrogen test should be taken after September /October for pre-plant and after January for top dress applications.

Rain-fed Production of Wheat

Three types of cropping are common in rainfed small grain production in other areas in the world: 3-year or lon-ger rotations (pasture-fallow-small grain), 2-year rotations (fallow-small grain), and annual cropping. Less nitrogen is applied under 3-year rotations than under annual cropping because nitrogen accumulates in soils during pasture and fallow years. Fields that produce abundant annual clovers require less applied nitrogen if annual clovers are pastured and plowed under as green manure crops. As little as 11.2 to 22.4 kg/ha of nitrogen at sowing is sufficient if legumes are plowed under as a summer fallow. If the fallow green manure crop consists entirely of grasses or broadleaf weeds, an application of 22.4 to 44.8 kg/ha of nitrogen is recommended at sowing. Residual soil fertility is adequate for optimal yield for some long-term rainfed rotation acreage.

Since moisture is generally the limiting factor for rainfed yield, nitrogen rates should be adjusted for lower yield potential, rainfall patterns, and soil moisture hold-ing capacities. All nitrogen normally is applied pre-plant for rain-fed production.

- **Split Application**

  Split applications of nitrogen are usually beneficial for irrigated production, although all nitrogen can be applied at once during sowing on well-drained soils not normally subject to leaching and waterlogging. When splitting the nitrogen on heavy or claypan soils, apply one-half to two-thirds of the nitrogen at sowing and apply the remainder as a topdressing. On extremely gravelly or sandy soils or on poorly drained soils of high clay content, split the nitrogen application with half applied pre-plant and half top-dressed to reduce nitrogen losses. On peat soils, apply about half the amount of nitro-gen normally used on mineral soils; no pre-plant nitrogen is required, but a low rate of nitrogen should be part of the starter fertilizer (high phosphorus content) at sowing.

- **Topdressing for Yield**

  When topdressing, make one or two applications of

8.4 to 14 kg/donum (33.6 to 56 kg/ha) of nitrogen, depending on the amount of rain during the winter. Nitrogen applications made during the tillering stage, followed by rain or an irrigation, are most effective for attaining maximum grain yield; applications made as late as boot stage are less effective, while applications made at heading or later have little effect on grain yield. If rain or irrigation occurs within a few days after application, little nitrogen is lost to the air. If conditions are dry and cold (typical during tillering), losses are mini-mal if rain or irrigation occurs within two weeks. Volatilization of nitrogen to the air is greatest under warm, moist conditions. Stem nitrate-nitrogen (NO3-N) tissue tests are an effective way to monitor the nitrogen status of the crop. Table 1 provides critical stem NO3-N levels for wheat and barley as the crop develops from the third and fourth leaf stage to boot stage.

Table 1. Critical stem NO3-N levels during vegetative growth for wheat and barley

Growth Stage	NO_3-N (ppm dry weight)		
	Deficient	Adequate	Excessive
3 to 4 Leaf	< 7,000	7,000 - 12,000	> 12,000
Tillering	< 6,000	6,000 - 11,000	> 11,000
Jointing	< 5,000	5,000 - 10,000	> 10,000
Boot	< 4,000	4,000 - 9,000	> 9,000

tests are not effective for managing nitrogen fertility after heading when the goal is to achieve high grain protein. Proper tissue sampling is important to attain a valid, informative analysis. Collect 20 to 40 stems at random from typical areas of the field. Cut off the roots and plant tops and send the bottom 1 to 2 inches (2.5 to 5 cm) of the stems to the laboratory for analysis. Be certain the stem tissue sample is not contaminated with soil or leaves. Submit the tissue samples for analysis the same day they are collected.

- **Application to Improve Grain Quality**

Wheat grown for bread flour should be managed to attain high kilogram per hectoliter and a grain protein content above 13 percent, as well as maximum grain yield. An irrigated wheat crop with high yield potential should receive 28 to 51 kilograms per donum (112 to 201.6 kg/ha) of nitrogen in a combination of pre-plant and top-dressed (during tiller-ing) applications. After heading, wheat may require one more nitrogen application of 5.7 to 14 kilograms per donum (22.4 to 56 kg/ha) to produce a high protein content in the grain. Nitrogen can best be applied during the 3 weeks after the spikes have emerged from the flag leaf sheath to about two weeks after flowering. An application is effective only when coordinated with an irrigation or rainfall. Low rates are appropri-ate for low-yielding crops, while higher rates are best suited for yields above 1.8 tons per donum (6.7 t/ha).

Late-season application of nitrogen may not be needed to attain high grain pro-tein content if the wheat grain yield potential is less than about 1.4 tons per donum (5.0 t/ha), and if nitrogen was applied pre-plant and top-dressed during the tillering stage. Cool, dry weather during grain filling generally results in higher grain yields; manage-ment for protein is more critical under those conditions.

Farmers undertaking a fertilization program for high protein must combine the practice with a marketing program to receive a protein premium to pay for the additional nitrogen. Additional nitrogen applied as a topdress above the recommended rate will favor higher protein. However, many climatic and genetic factors also are involved. 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.

Nitrogen application near the boot stage (before heading) typically increases the grain protein content about 0.5 to 1.0 percent. The increase is not as large as when nitrogen is applied at flowering, when nitrogen applications usually increase grain pro-tein content by 1.0 to 1.5 percent or more.

Water-run applications of anhydrous ammonia, UAN -32, aqua ammonia, or urea applied at the beginning of an irrigation set are preferred for late-season fertilization. This provides an effective means of applying the necessary nitrogen and water for maximum yields. Foliar nitrogen applications are also effective at raising grain protein content but are usually more expensive and may damage the leaves under many conditions.

- **Forms and Costs of Nitrogen Fertilizers**

The choice of fertilizer material depends on current weather conditions, weather fore-casts, and fertilizer costs. Urea (46-0-0) is the highest-analysis nitrogen fertilizer avail-able and is usually the least expensive dry form of nitrogen. It is particularly effective when broadcast and followed by at least 2.5 cm of rain within 5 days after application. Urea is converted to ammonium nitrogen and then to nitrate nitrogen by soil microbial processes, so it is released over a longer period of time and is less prone to leaching from the root zone than are some other forms of nitrogen. Urea is relatively unstable when broadcast onto the soil surface, however, and volatilization (loss to the air) can occur.

Ammonium nitrate (34-0-0) is an alternative to urea, if it is available, but it is more expensive and not generally available in Iraq. It is preferable to urea when the crop is severely deficient because both the nitrate and ammonium forms of nitrogen are readily taken up by the crop and recovery is more rapid. Ammonium sulfate (21-0-0) containing 24 percent sulfur is desirable if there is a likelihood of sulfur deficiency, but this material is usually more expensive than urea. A blend of mostly urea with some ammonium sulfate is available in some areas.

Phosphorus

- Role of Phosphorus

Phosphorus is a component of cell membranes and plays a role in the transfer and storage of energy within plant cells. It makes up part of the structure of key molecules, including DNA. 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.

- Deficiency Symptoms

Phosphorus deficiency is most likely on shallow upland (terrace and foothill) soils. Symptoms of phosphorus deficiency include slow early growth, lack of tillering, and sometimes a slight purpling of plants. 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.

- Requirements and Rates

Small grains are generally grown when soil temperatures are low and phosphorus availability is reduced. If phosphorus is needed, placement with or near the seed is best. On mineral soils a soil test (sodium bicarbonate extraction method) on samples taken to plow-layer depth can serve as a guide for phosphorus fertilization. Responses to phosphorus application are likely if phosphorus levels are less than 6 ppm, variable if phosphorus levels are from 6 to 15 ppm, and unlikely if phosphorus levels are above 15 ppm. Many growers apply a low-nitrogen, high-phosphorus fertilizer, such as 11-48-0, 11-52-0, 10-50-0, or liquid 10-34-0, at planting time with or near the seed. Mono-ammoniun phosphate, with an approximate 1:4 to 1:5 nitrogen to phosphorus ratio, is more desirable than a diammoniun phosphate (1:3 ratio) because little, if any, toxic ammonia is released. Urea, urea phosphate, or diammonium phosphate (18-46-0) are more hazardous because the initial reaction in the soil releases ammonia that can kill seedlings.

If a soil test indicates phosphorus deficiency, apply 8.4 Kg to 11.2 kg per donum (33.6 to 44.8 kg/ha) of P2O5 drilled with seed for irrigated crops, and 5.6 to 7.5 kg per donum (22.4 to 33.6 kg/ha) of P2O5 for dryland crops. To avoid injuring seed, no more than 7 to 8.4 kg per donum (28 to 33.6 kg/ha) of nitrogen should be drilled. If phosphorus is broadcast, use higher rates, up to 22.4 kg per donum (89.6 kg/ha) of P2O5. Application of nitrogen at rates greater than 2.8 to 3.75 per donum (11.2 to 16.8 kg/ha) combined with the higher rates of phosphorus stimulates the growth of grassy weeds.

The bicarbonate extraction method and phosphorus levels cited above are not reli-able if small grains are sown directly after a crop of rice. An increased yield response to phosphorus is nearly always expected following rice, particularly if rice has been grown for several seasons.

Phosphorus applications are often needed on heavy soils because phospho-rus becomes unavailable when soil pH is low, which is typical in peat soils. Wheat yield increases of up to 224 kg per donum (896 kg/ha) can often be obtained by applying 14 kg per donum (56 kg/ha soils; application rates on high-pH soils should be increased to 8.4 to 14 kg per donum (33.6 to 56 kg/ha) of P2O5 and drilled with the seed.

Sulfur

- <u>Role of Sulfur</u>

  Sulfur is an essential constituent of the amino acids cysteine, methionine (required for protein synthesis), several coenzymes (e.g., biotin, co-enzyme A, thiamine pyrophos-phate, and lipoic acid), thioredoxins, and sulfolipids. 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.

- <u>Deficiency Symptoms</u>

  Sulfur-deficient plants become spindly and develop a pale yellow color. The symptoms are very similar to nitrogen deficiency. Sulfur deficiency reduces the number of grains per spike; the number of tillers and grain weight are less affected unless the deficiency is severe.

- <u>Requirements and Rates</u>

  Sulfur deficiency most often occurs on gravelly or sandy soils. It is more common dur-ing 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. Nitrogen metabolism and sul-fur metabolism are strongly interdependent: when sulfur is deficient relative to nitrogen, nonprotein compounds such as amines accumulate, resulting in a nitrogen to sulfur (N:S) ratio of greater than 15:1. Wheat is likely to be sulfur deficient if it has a total sulfur of less than 0.20 percent and a N:S ratio greater than 17:1 in the upper fully developed leaves at flag leaf to anthesis. The concentration of sulfur in grain and the N:S ratio have been used to retrospectively diagnose sulfur deficiency, with critical values of 0.12 per-cent and 17:1 N:S.

Small grains have a lower sulfur requirement, 2.8 to 8.4kg per donum (11.2 to 33.6 kg/ha), than many other crops, but an adequate level of sulfur is necessary for sat-isfactory crop growth and for optimal levels of S-containing amino acids in grain. Sulfur deficiency is best corrected by planting-time application of fertilizer that has nitrogen and sulfate-sulfur, such as ammonium sulfate (21-0-0). Applications of relatively low rates of readily available sulfate-sulfur sources can be effective corrective treatments dur-ing the active early spring growth period; elemental sulfur is much less effective. If ele-mental sulfur is used, applications must precede the growing season by sufficient time (probably several months) to allow conversion of sulfur to the sulfate form for plant use. Moisture is also required for this process. Gypsum is also an immediately available but slow releasing form of sulfur. Sulfur deficiency symptoms disappear in most instanc-es as soil temperatures warm, moisture levels drop below saturation, and plant growth progresses.

Potassium

- <u>Role of Potassium</u>

  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, winter-kill, and root diseases. It also helps develop strong stems and decreases lodging.

- <u>Deficiency Symptoms</u>

  Potassium deficiency symptoms generally appear on the older leaves first. Depending on the severity of the deficiency, the entire plant may be affected, and 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. An "arrow" of green tissue remains from the base upward to the center of the leaf. Complete death of older leaves is common, and plants appear to have dried prematurely, as with drought stress.

Table 2. Potassium sufficiency in wheat for selected growth stages

Growth Stage	Plant Part	Sufficiency Range (Low to High)
3 to 4 Leaf	Undergound Stem	2.0 - 3.0 %
	Whole Plant	2.4 - 4.0 %
Tillering	Aboveground Stem, Lower 2 inches (5 cm)	2.0 - 3.0 %
	Top 4 Leaves	2.4 - 4.0 %
Jointing	Aboveground Stem, Lower 2 inches (5 cm)	1.5 - 2.7 %
	Top 4 Leaves	2.0 - 3.0 %
Boot	Aboveground Stem, Lower 2 inches (5 cm)	1.0 - 2.4 %
	Top 4 Leaves	1.5 - 2.7 %

Sources: California Plant Health Association 2002.

- Requirements and Rates

In many areas yield responses to applications of potassium are highly unusual and occur only on the most deficient soils, such as soils with ammonium acetate extractable potassium levels of less than 60 ppm. Plants need as much potassium as nitrogen during rapid growth periods. Potassium sufficiency in wheat depends on the stage of growth (table 2). Several sources of potas-sium (potash) are used as commercial fertilizers (table 3). Potassium is rapidly absorbed and very mobile, making it a food additive to foliar fertilizers.

Table 3. Commercial fertilizer sources of potash potassium is rapidly absorbed and very mobile, making it a good additive to foliar fertilizers. The crop response to foliar nutrition depends on the soil, the crop, and environmental conditions.

Fertilizer Material	Formula	Water-Soluble Potash (K_2O) %	Other Nutrients
Monopotassium Phosphate	KH_2PO_4	32 - 34	50 - 52 % P_2O_3
Potassium Chloride (MOP)	KCl	60 - 62	——
Potassium Magnesium Sulfate	K_2SO_4- $2MgSO_4$	22	18 % S, 11 % Mg, 0.1 % Ca
Potassium Nitrate	KNO_3	44 - 46	13 % N
Potassium Sulfate (SOP)	K_2SO_4	50 - 53	18 % S
Potassium Thiosulfate	$K_2S_2O_3$	25	17 % S
Sources: California Plant Health Association 2002			

Zinc

- Role of Zinc

Zinc is an essential micronutrient for crop growth of shoots. A critical level of zinc is required in the soil for roots to grow and function effectively.

- Zinc Deficiencies

Zinc deficiency is probably the most widespread micronutrient deficiency in small grains. 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. Although most mineral soils contain 80 to 300 ppm of total zinc, DTPA extractable zinc is usually less than 1 ppm; the remainder is fixed in an unavailable form. The unavailability of zinc can be attributed to soil alkalinity: when the soil pH is above 7.0, zinc availability is generally reduced. Zinc availability is low in some soils with high organic matter, in some clay soils with high magnesium content (these soils fix zinc in an unavailable form by strong adsorption on the clay minerals in place of magnesium), and in soils high in phosphorus. Low zinc levels combined with high phosphorus levels enhance accumula-tion of phosphorus in old leaves to concentrations that are toxic; this enhances necrotic symptoms in old leaves. Yield responses to applications of zinc occur only on the most deficient soils, such as soils with zinc DTPA extractable levels below 0.3 ppm.

Irrigation and Water

- **Planting 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 grower 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 pro-vides soil moisture for rapid seedling emergence and growth. Pre-irrigation a month or so before planting (depending on soil type and cropping sequence) is often used in low-rainfall areas, where soil moisture is likely to be low at planting time. However, pre-irrigation followed by extensive rainfall can result in inefficient water use, less efficient nitrogen uptake, and higher irrigation costs. If extensive rainfall follows pre-irrigation, soils may become waterlogged and anaerobic and in turn reduce seedling establishment. In a worst-case scenario, farmlands pre-irrigated late in the fall and then followed by extensive rainfall may require delayed planting past optimal dates or not be able to be planted at all. Planting to a dry seedbed and then irrigating risks poor germination and crop loss, particularly on slow -draining soils and if irrigation is followed by an extended period of rainfall. Irrigation can saturate and cool the seedbed to the extent that seed will not germinate and may rot. Where sprinkler irrigation is used and amounts of applied water are more easily controlled, there is less risk of oversaturat-ing the soil. If irrigation is used to germinate the seed, it should be timed for when the chance of rainfall occurring for several days after irrigation is low, thereby giving the soils a chance to drain, aerate, and warm. In general, sowing seed into a dry seedbed and relying on rainfall for germination is more commonly practiced than pre-irrigation or irrigating immediately after planting. Optimal planting dates in late November and December coincide with a time frame when it is reasonable to expect enough rainfall to germinate shallow planted seed and establish sufficiently rooted seedling plants that can then be irrigated in January or February with less risk to crop health. The great-est risk to this approach is that in severe drought years, germination may be substan-tially delayed and result in a shorter growing season and reduced yields.

- **Moisture Stress**

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 spikelets that can grow into mature kernels has been determined. Plants at this stage are sensitive to moisture stress. Plants under moisture stress during stem extension form fewer florets. Plants sacrifice tillers, spikelets, and/or florets 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, spikelets, or florets are sacrificed first. Small grains are 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 develop-ment 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
  - slight rolling or cupping of leaves

  More severe symptoms include:
  - a deep blue-green canopy
  - dead tissue along leaf margins
  - leaf rolling

- shortened and spindly stems
- 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. Among the most common methods for checking soil moisture in the root zone are:

- soil feel and appearance
- gravimetric sampling
- tensiometers
- resistance blocks
- neutron scattering
- time domain reflectometry

- **Patterns of Seasonal Water Consumption**

Understanding general patterns of crop water consumption is important for anticipat-ing when to irrigate and avoiding moisture stress. Small grain water consumption varies depending on grain type, cultivar, geographic production region and climate, and end use for the crop. Utilizing historic averages they are typically within 20 per-cent of the actual crop water use in a given year. Despite the in-exactness, these estimates represent important patterns of water consumption from germination through harvest/ maturity and can assist with irrigation decisions, especially if rainfall is monitored and consider- the water holding capacity of the soil. Crop water consumption also is referred to as crop evapotranspiration. Crop water consumption is lower than the irrigation requirements because more irrigation water must be applied to ensure that all parts of the field are adequately irrigated. Typically, an efficiently designed and managed flood, furrow, or sprinkler irrigation system applies about 15 to 35 percent more water than the estimate of crop water consumption.

Root Zone of Wheat

Small grains have a fibrous root system. Most roots in a fully developed small grain plant's root system are in the top 0.6 m of soil. Under ideal conditions, small grains can root to 2.1 m deep by the end of the season. Generally, rooting depths will be deeper in uniform soils than in soils with distinctly different soil layers. The soil layers are physical barriers to both root growth and drainage of water and aer-ation. Digging backhoe pits to evaluate soil uniformity, soil textures, and evidence of roots following a small grain crop is an effective way to characterize root zone depths for specific fields. Soil texture and structure and the depth of the root zone influence irrigation frequency and the ability to irrigate efficiently. Crops with deeper root zones and finer soil textures require less-frequent irrigation and sometimes less total applied water. Less-frequent irrigation is needed because these conditions provide more stored water for crop consumption between irrigations. Irrigation efficiency is generally great-er on deep, fine-textured soils because less of the applied water is lost to percolation. More rainfall can be stored within the root zone and can contribute to the seasonal water consumption, postponing the first irrigation and enabling earlier irrigation.

- **Timing of First Irrigation**

  As discussed earlier, the first irrigation may have to be applied before or near the time of sowing to ensure timely seed germina-tion 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. Since one growing season is seldom like the next, what is appropriate tim-ing one year may not be for another. 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. Using a rain gauge to monitor rainfall and a soil sampling tube or auger to estimate soil moisture content (soil moisture depletion), understanding crop water consumption patterns and root development, and rec-ognizing how soils feel as they dry can be used to time the first crop irrigation and avoid crop stress.

- **Determining Irrigation Frequency**

  The small grain 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 in most areas. Once the root zone is fully developed, the interval between irrigations is fairly consistent up to irrigation cutoff. Depending on soil texture and water-holding capacity, there are 7.5 to 25.5 cm of available stored water in a root zone 0.6 to 1.2 m deep. About 4 to 12.5 cm of soil moisture is available to sustain the crop between irrigations since about one-half of the stored water can be consumed from the crop root zone before moisture stress occurs. This amount is enough to sustain an irriga-tion frequency ranging from about 7 to 10 days for sandy and sandy loam soils, 12 to 18 days for loam soils, and up to 25 days for silt loams, clay loams, and clays. Warm, windy days deplete soil moisture quickly, so it should be replenished more frequently under such conditions, especially if the crop was previously exposed to wet soil conditions that limited root development. Irrigation frequency should be verified by checking soil moisture and watching for the earliest signs of crop stress, possibly in a particularly sensitive area of a field.

- **Irrigation Methods**

Several methods are used to irrigate wheat:
1. Flood (border check)
2. Furrow
3. Sprinkler systems. (overhead)

For border check irrigation, the optimal strip width and check length depend on soil type and slope of the field. Shorter and narrower strips with steeper slopes are used on light-textured soils, while longer and wider strips with lesser slopes are used on heavy-textured soils. The check length can range from 61 m for a sandy soil with a slope of about 1 percent to more than 366 m for a clay soil with a 0.3 percent slope. Strip width can range from 6 to 30 m for the above soil types and slopes, respectively. Borders or furrows should be made at planting time. When border flood or furrow irrigation systems are used, extra irrigation water is usually applied near the head of the field to prevent under-irrigation in the middle and the tail end of the field.

Irrigation practices that ensure ample soil water storage during early stages of crop development promote a deep, extensive root system. In general, flood or furrow irriga-tion should bring the upper 1mt. of the soil profile to field capacity. Usually about 10 to 20 cm of water is applied per flood or furrow irrigation event. Less water, usually 5 to 10 cm, may be applied per sprinkler irri-gation. Table 3 provides a general guide for the amount of water needed to bring soil moisture to field capacity for different soil types.

Table 4. Approximate amount of water needed to bring selected soil textures to field capacity

Available Soil Water Remain-ing	Inches of Water Needed for Soil Texture (in/ft)*				
	Loamy Sand	Sandy Loam	Silt Loam and Clay Loam	Sandy Clay and Silty Clay	Peats and Mucks
0 - 25	0.9 - 0.7	1.4 - 1.1	2.2 - 1.7	2.3 - 1.7	2.5 - 1.9
25 - 50	0.7 - 0.5	1.1 - 0.7	1.7 - 1.1	1.7 - 1.2	1.9 - 1.3
50 - 75	0.5 - 0.2	0.7 - 0.4	1.1 - 0.6	1.2 - 0.6	1.3 - 0.6
75 - 100	0.2 - 0	0.4 - 0	0.6 - 0	0.6 - 0	0.6 - 0
At Field Capacity	0.9	1.4	2.2	2.3	2.5
Note: * 1 in/ft = 8.33 cm/m					

- **Determining the Date of Irrigation Cut-Off**

Timely irrigation cutoff prevents yield losses and assures adequate kernel weight. It also helps minimize irrigation costs and prevents irrigating too late, avoiding problems with field access by heavy combines. Irrigation that continues too late in the season results in more severe lodging and black point disease, stimulates late-season weed growth, causes yield reductions, slows harvest, and delays ground preparation for the subsequent crop. The appropriate irrigation cutoff date depends on the soil water-holding capacity and root zone depth. The optimal irrigation cutoff is determined by patterns of dry matter accumulation in the grain after heading, crop water consumption during grain filling, and weather. Sufficient moisture must be available from the last irrigation to carry the crop through the late dough stage (the end of dry matter accumulation). For sandier soils and crops with shallow root zones, this period may be 7 to 10 days before the late stages of dough development. For finer-textured uniform soils and crops with deeper root systems, the irrigation cutoff may be 14 to 21 days or more before the late stages of dough development.

Integrated Pest Management

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 pro-duction system. The most reliable way to do this is to anticipate pest problems and prevent them whenever possible. When pesticides are needed, materials and applica-tion 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
- Field sanitation
- Residue management
- Proper cultural practices (timing and amounts of irrigation, fertilization,

- **Crop Rotation**

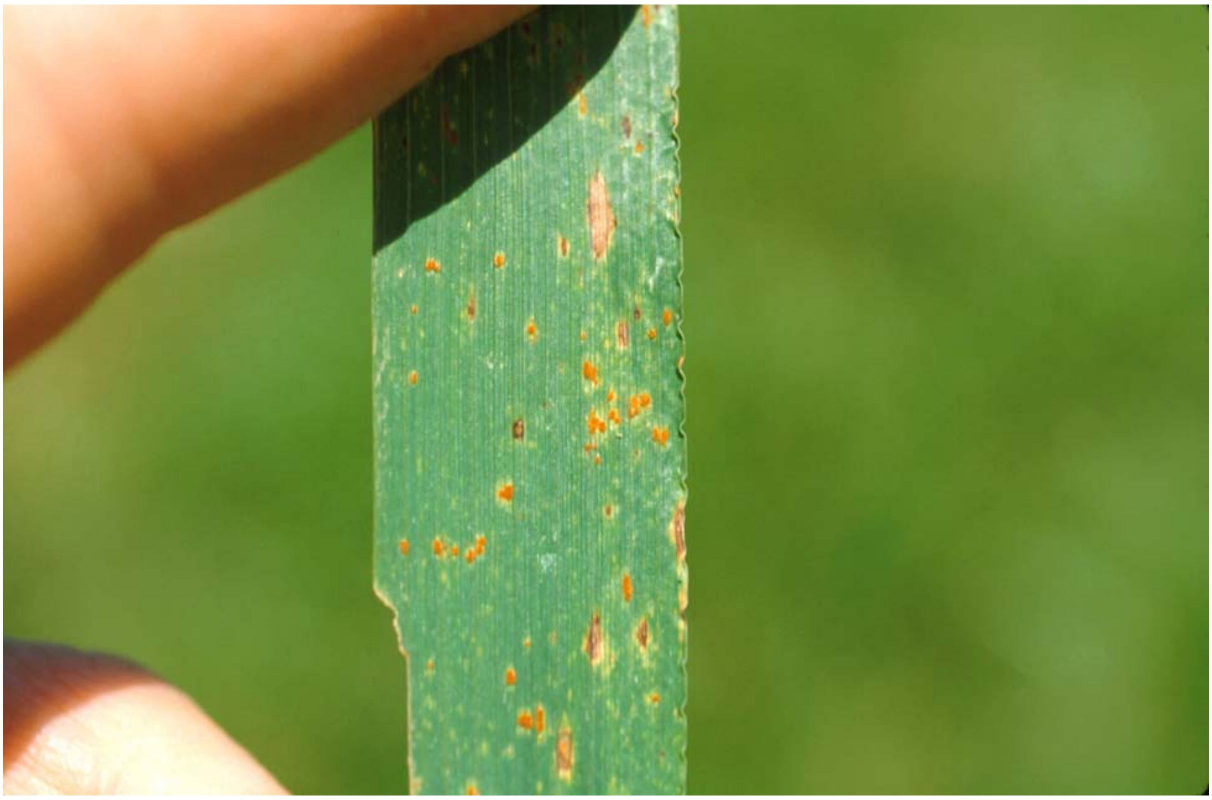
  Crop rotation is a "best management practice" because it reduces the carryover of diseases, insects, and weeds between crops. It is very effective for controlling tan spot, dryland root rot, eyespot, Cephalosporium stripe, and take-all root rot. Crop rotation may reduce severity of scab, seedling blight, Septoria leaf blotch, Stagonospora leaf blotch, glume blotch, and sharp eyespot. One year of rotation or fallow is enough to break the cycle for most diseases. A few pathogens can crossover between different crops. The take-all fungus can build up on barley, smooth brome, and weedy brome grasses. The scab fungus builds up on corn and survives in surface corn residue. Therefore, avoid planting wheat after barley or brome, or into heavy corn residue.

- **Diseases of Wheat**

Disease	Pathogen	Primary Hosts	Alternate Hosts	Symptoms
Leaf Rust	Puccinia Triticina	Bread and durum wheat, triticale	Thalictrum, Anchusa, Isopyrum, Clematis	Isolated uredinia on upper leaf surface and rarely on leaf sheaths
Leaf Rust Duri Type	Puccinia Triticiduri	Durum and bread wheat in traditional agriculture	Anchusa Italica	Isolated uredinia on lower leaf surface; fast teliospore development
Stem Rust	Puccinia Graminis F. SP. Tritici	Bread and durum wheat, barley, triticale	Berberis Vulgaris	Isolated uredinia on upper and lower leaf surface, stem and spikes
Stipe Rust	Puccinia Striiformis F. SP. Tritici	Bread and durum wheat, triticale, a few barley cultivars	Unknown	Systemic uredinia on leaves and spikes and rarely o nleaf sheaths
Roelfs, A.P., Huerta-Espino, J. & Marshall, D. 1992. Barley stripe rust in Texas				

The rust disease of wheat, their primary and alternate hosts and symptoms

Leaf Rust



The only time identification is a problem is when leaves are flecked. Usually you will find at least a couple of lesions to indicate that the flecking is due to rust, if not it is probably genetic flecking, which is very common. Leaf rusts, caused by the fungi *Puccinia triticina* (wheat), *P. hordei* (barley), and *P. coro-nata* (oat), are late-season diseases that are most severe in years with lower than normal temperatures and high humidity. The fungi grow only on living host plants and have narrow host ranges (wheat leaf rust does not affect barley; barley leaf rust does not affect wheat). Symptoms on wheat, barley, and oat are similar. Pustules on barley are small, round, and yellowish brown (fig. 4). Pustules on wheat are reddish orange and are scattered or clustered on the upper leaf surface (fig. 5). Pustules on oat are oblong and orange colored (fig. 6). As the plants mature, the pustules turn dark and shiny, indicating the formation of teleospores.

Volunteer small grain plants and distant small grain fields are the sources of pri-mary inoculum. Spores (urediospores) produced in pustules on leaves are dispersed over long distances - hundreds of miles - by wind and cause initial infections. Urediospores from initial infections are windblown to initiate secondary cycles at 7to 10-day inter-vals. Leaf rust is most severe when temperatures are 16° to 22°C and humidity is high or rainfall is intermittent. It causes the greatest reductions in yield if infections occur prior to spike emergence and continue for 30 to 40 days during the grain fill period.

Strip Rust

About half of Soft Red Winter Wheat varieties are susceptible to this disease. So we are concerned. The fungus grows only on living host plants and survives between seasons on volunteer wheat or barley, some wild grasses, and distant small grain fields. Spores (urediospores) produced in pustules are spread over long distances by wind to initi- ate infections. Disease development is most rapid at cool tem-peratures of 10° to 16°C with intermittent rain and dew; secondary cycles occur at 7 to 10-day intervals. The disease can continue to develop where daytime temperatures are higher than this as long as nighttime temperatures are not higher than about 16°C.

Control is through the use of resistant cultivars. If new races develop that render current resistant cultivars ineffective, fungicides can be used for control. Applications should be made between tillering and heading to protect the flag leaf from infection.

Stem (Black) Rust Puccinia araminis f.sp. tritici pqt -UG 99

- Stems
- Leaves and sheaths
- Glumes
- Peduncles
- Lodging
- Premature Deat
- Serious yield loss, ofter on large scale

Genes with resistance to UG 99
Sr 36 in many Spring Red Wheat
Lr 34 enhances stem rust effectiveness
Lines with Sr 26 + Sr 36 + Sr/A.1R completely resistant to stem rust
Moderately effective: Sh 22, Sr TMP, Sr 26, Sr 32, Sr 35, Sr 39, Sr 42, SrCad, Sr Web.

Ergot (Clavicepts Jourpura)

Ergot sclerotia are large (1/4 to 1/2 inch long) purple-black fungal structures that replace the developing grain and protrude from the head. They could be confused with bunt balls, but ergots are larger than

bunt. Ergot sclerotia are hard with a solid white or gray interior, while bunt balls are fragile and filled with smelly, dark spores. Ergot is rare in wheat but fairly common in triticale and rye.

Loose Smut (Ustilago Tritici)

Loose smut, a flower-infecting disease, is caused by different species of the fungus *Ustilago: U. tritici* infects wheat, triticale, and rye; *U. nuda* infects barley; and *U. nigra* infects barley and oat. Symptoms are most visible at heading, but before heading infected plants show dark green erect leaves, sometimes with chlorotic streaks. Infected spikes emerge slightly earlier than healthy spikes. Normal spike tissue is replaced by olive -black masses of spores (teliospores) that are enclosed in a fragile gray membrane (fig. 10) that ruptures near flowering time, releasing the spores and leaving only a bare rachis at maturity.

The fungus survives as dormant mycelium inside infected seed (the black loose smut fungus, however, survives as teliospores on the surface of contaminated seed). When infected seed germinates, the previously dormant mycelium resumes growth and becomes systemic in the plant. When smutted spikes emerge at heading, the fun-gal membrane soon ruptures, and windborne spores land on healthy plants, where they infect developing kernels (no symptoms are visible). Infection is most likely during cool, moist conditions. Plants are most vulnerable to infection from flowering to about eight days later.

Control is through seed treatment with systemic fungicides and/or certified smut-free seed. Hot water treatment can eliminate smut fungi from contaminated seed, but it must be used carefully to avoid reducing seed vitality.

Loose Smut

Covered Smut (Tilletia Caries & T Foetido)

The normal head tissue of plants infected by loose smut is completely replaced with dark masses of fungal spores, giving the heads a black powdery appearance. It is possible to see heads damaged by loose smut while much of the head is still inside the boot. Only the central stem of the head is left after the spores are released.

Management: Fungicide seed treatment, disease free seed sources.

Covered Smut

Root Rots (Helminthosporium Sativum, Fusarium Culmornum & Fusarium Graminearum)

Common root rot causes premature death of wheat, resulting in patches of white heads scattered throughout a field. Infected plants are often dark at the base and have poor root development. A key diagnostic feature of common root rot, however, is dark-brown lesions on the thin stem extending from the base of the plant to the remnant of the seed. This thin stem is known as the "subcrown internode". Healthy subcrown internodes should be cream colored and firm.

Management: Crop rotation, control grassy weeds.

Fusarium Root, Crown, and Foot Rots

Fusarium root, crown, and foot rots cause patches of wheat to die prematurely, resulting in areas of white heads within a field. Infected plants are typically brown at the base and have poor root development. During advanced stages of the disease, the *Fusarium* fungus often produces a pink, cottony growth inside the lower portions of the stem. Often, the disease is most severe after prolonged periods of dry weather.

Management: Crop rotation, control grassy weeds.

Insect Pests of Wheat

Sunn Pest or Corn Bug (Eurygaster Integriceps Puton - Eurygaster Integriceps)

(*Eurygaster integriceps* Puton) is a very damaging insect pest of wheat and barley in countries of West Asia, including Afghanistan, Iran, Iraq, Lebanon, Syria and Turkey, as well as in the Central Asian republics (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan), and Bulgaria and Romania. Sunn pest infestations spread over 15 million ha in the affected area. Both nymphs and adults cause damage by feeding on leaves, stems and grains. Yield loss is commonly estimated at 20 to 30 percent in barley and 50 to 90 percent in wheat. Apart from the direct reduction in yield, the insects also inject chemicals that greatly reduce the baking quality of the dough.

Wheat is the most important food crop in the Central and West Asia region. It provides a substantial component of the human diet: wheat products provide over 40 percent of the per capita dietary supply of calories and protein in most of the countries mentioned above, and substantially more in some of the Central Asian Countries. Control of Sunn pest by chemical insecticides is expensive, costing more than $40 million annually in the countries concerned, and poses a risk to human health, water quality and the environment as a whole. The present insecticide-based strategies for control of Sunn pest must be replaced with multi-dimensional integrated pest management (IPM) approaches. The proposed research addresses an urgent need of farmers in the West and Central Asian region in their effort to grow an abundance of high-quality grain.

Shield and Stinkbug

Acanthosoma Labiduroides Female

The nymphs and adults have piercing mouthparts, which most use to suck sap from plants, although some eat other insects. When they group in large numbers, they can become significant pests.

Wheat Leaf Miner

The leaf minor *Syringopais temperatella* Led. Has a great significant for wheat and barley in the north of Iraq. Some earliest studies of the biology and ecology of this pest were conducted in Iran and Turkey. There was one generation per year. It attacks the leaves of the plants. Where larvae mine through leaves of wheat and barley Adults usually appeared in the field during the second half of April. Each female laid 29.2 eggs. After hatching the larvae formed cysts in which they aestivated during summer, fall and part of winter as first- instar larvae. They resumed activity at the second half of January. The larvae moulted three times (4 instars). The larval period lasted for 315.46 days. By the first half of April the full-fed larvae entered the soil and constructed cocoons crevices at a depth of about o.3 to 4 cm. The pupal period averaged 13.96 days.

European Wheat Stem Sawfly

The adult is a slow flying, brightly colored yellow and black insect, between 7 and 12 mm in length. Adult coloration is highly variable within and between populations. The head is large, with two prominent compound eyes. The wings are transparent, the costal margin is yellow and veins are brown. The egg is shiny, reniform in shape and about one mm long. Full grown larvae are 10 to14 mm long and yellow-green in color. The species is a serious pest throughout its range in

Europe. Damage varies, depending on the year, locality, host plant and cultivar. In Europe losses of up to 56 percent (in wheat) and 50 percent (in barley) have been recorded. Typical symptom is wheat lodging, because of stem cutting, and decreasing of grain weight.

Preventive Methods:

early stubble breaking and following fall-plowing
using resistant wheat varieties will reduce the severity of sawfly damage

Control:

There are many egg and larval hymenopterous parasitoids known to reduce sawfly populations. Cultivated hosts are wheat, barley, rye, and oats. Wild hosts include variety of wild grasses.

Shield Bug (Carpocoris Podigus)

This species is widespread in most of central and southern Europe (Albania, Austria Bulgaria Croatia, Czech Republic, France, Germany, Greece, Italy, Macedonia, Romania, Northwestern Russia, Slovakia, Slovenia, Switzerland and the former Yugoslavia.

Wheat Stem Borer

The damage was usually confined to a single tiller per plant at a relatively low incidence through fields. Infected tillers seemed to have flowered normally, but soon after flowering the stem upwards from the last node (and including the head) died and was white in color with no grain in the head. From a distance, these symptoms appeared to be the same as those of crown rot. However, infected tillers were green and apparently healthy from the last node (including the flag leaf) down.

Soft Scale (Exaeretopus Tritici)

Soft Brown Scale insects are a bit like miniature turtles in shape and are about 2 to 4 mm long. The older females are dark brown and are usually found along the centre vein on the under side of a leaf where they suck the sap. They excrete 'honeydew' which is full of sugars and drops onto the lower leaves or anything below - it attracts other insects such as ants and wasps to feed on it. Also you may find nymphs, known as crawlers as they are able to move around, the older females lose their mobility and eventually die, but their shell remains to protect the eggs.

Beetle

Cereal leaf beetle (pictured below) is a widely distributed pest of small grains in Europe and the Middle East

This pest will occur from about mid-April until wheat maturity. The beetles over-winter as adults, and re-enter fields when warm-up occurs. After mating, females deposit small clusters of eggs usually on the upper surface of the leaf. These eggs are bright yellow just after they are laid but darken to almost black, just before hatch. They are shaped like cylinders with rounded ends. Insecticidal control of CLB is not particularly difficult.

Nematode

Nematodes are roundworms with complex organ systems. They occur worldwide in all environments. Most species benefit agriculture by contributing to decomposition of organic matter and are important members of the food chain. Some species are parasitic to plants or animals. More than 2,000 of the 20,000 identified nematode species are plant parasites. The plant-parasitic species cause estimated annual crop losses of $8 billion in the United States and $78 billion worldwide. Most plant-parasitic species live in the soil and are so tiny they can be seen only with the aid of a microscope. Round worms parasitize agricultural crops in every part of the world. Two species of root lesion nematode, *Pratylenchus thornei* and *Pratylenchus neglectus,* are damaging to wheat.

Unthrifty plants appearing in patches across a field may indicate a nematode infestation. Early damage signs to look for are yellow lower leaves and loss of secondary branching in the root system. Since populations of nematodes occur in ‘hotspots', extensive soil sampling is required in order to accurately evaluate nematode populations. Soil testing for root lesion nematodes can only be performed by a laboratory.

Weed Control for Wheat

Weed control is important in small grains because weeds compete with developing plants, reducing grain or forage yield; green weeds that emerge late in the season can impede harvest operations and reduce grain quality; and weed seeds can contaminate the grain, making extra cleaning necessary. Effective weed control in small grains also helps reduce weed infestations in subsequent crops. Many weeds are more economi-cal to control in small grains than in other crops. The distinction between winter and spring small grains and among different classes of cereal crops is important because some herbicide labels give different application rates or crop injury potentials for dif-ferent small grains or cereal crops. Labels should be checked before an application is made and all label instructions must be followed.

Broad Leaf Weeds

A wide range of broadleaf weeds infest small grains. The more common weeds are mustards (*Brassica* spp., especially black mustard, *B. nigra)*, wild radish *(Raphanus raphanistrum)*, London rocket *(Sisymbrium irio)*, shepherd's purse *(Capsella bursa-pastoris)*, coast fiddleneck *(Amsinckia intermedia)*, annual sowthistle *(Sonchus oleraceus)*, prickly lettuce *(Latuca serriola)*, burning nettle *(Urtica urens)*, pineapple-weed *(Matricaria matricariodes)*, miner's lettuce *(Claytonia perfoliata)*, common chick-weed *(Stellaria media)*, field bindweed *(Convolvulus arvensis)*, swamp smartweed *(Polygonum coccineum)*, common lambsquarters *(Chenopodium album)*, and yellow starthistle *(Centaurea solstitialis)*. Broadleaf weeds vary in their ability to compete with small grains. For example, an average of one wild radish plant per square foot (10 per sq m), when established at the same time a wheat crop emerges, can reduce yield by as much as 66 percent by completely overtopping the wheat canopy and competing for light. Low-growing weeds such as common chickweed, henbit *(Lamium amplexicaule)*, and miner's lettuce are generally less competitive, but even high populations of com-mon chickweed can smother small plants, reduce yield, and remove soil nutrients and moisture. Poor weed management also causes weed problems in succeeding crops.

Grasses

Grass weeds are difficult to control in small grains because they mimic the growing cycle and growth habit of the crop. Many grass weeds germinate at the same time as small grains and mature slightly before or at the same time as the crop, assuring an ample sup-ply of seed for next year's weed crop. These weeds compete for light and space and also remove soil moisture and nutrients needed for crop growth. Winter annual grassy weeds that are found in small grains include wild oat *(Avena fatua)*, Italian, or annual, ryegrass *(Lolium multiflorum)*, ripgut brome *(Bromus diandrus)* and downy brome *(B. tectorum)*, hare barley *(Hordeum leporinum)*, rabbits foot grass *(Polypogon monspeliensis)*, and hood canary-grass *(Phalaris paradoxa)* and littleseed canarygrass *(P. minor)*.

Wild oat emerges throughout the cool season from autumn through spring. In small grains it causes lodging, slows harvest, clogs harvester screens, and lowers yields. An average of (70 per sq m can reduce wheat yields by 840 kg./donum (3,360 kg/ha) in a crop with a yield potential of 1,680 kg/donum (6,720 kg/ha). Ripgut brome is a particular problem in rainfed production areas. The weed reduces yield by competing with the crop, and its seed can contaminate the grain and reduce its marketability. Infestation of hood and little-seed canary-grass can reduce yields by more than 50 percent. Canary-grass is a prolific seed producer, and populations of canary -grass in fields continuously cropped to small grains often exceed 1,000 plants per sq m.

Cultural Practices that Reduce Weed Pressure

An integrated weed management system combines crop rotation, fertilization, irriga-tion, tillage, herbicide applications, and high plant populations to help control weeds. Field sanitation is a prerequisite for weed control. Planting and tillage implements should be free of weed seeds and other plant properties to avoid spreading weeds from field to field. Field perimeters should be kept free of weeds because they serve as a reservoir for seed to infest the field.

A properly prepared seedbed can increase yield and reduce weed pressure. Plant high-quality, vigorous, weed-free certified seed. Using noncertified seed risks the introduction of new weed infestations. The sowing date can influence weed competition. Late sow-ing produces shorter small grain plants that have fewer tillers and are less competi-tive with weeds. Lower seeding rates also can intensify weed pressure. Studies have shown that higher seeding rates are very effec-tive at reducing competition by swamp smartweed, Johnson grass, mustard, wild oat, canary grass, and common chickweed. Row spacing should be as narrow as feasible to promote early development of a solid, competitive crop canopy.

Mulch planting can give a small grain crop a head start over weeds. In mulch planting, a shallow cultivation is done following rainfall or irrigation, when weed seeds germinate before planting. The crop seed is then sown into moist soil below the mulch layer of dry soil that resulted from the cultivation. Because the crop seed is

placed into moist soil, it germinates quickly, ahead of weeds.
Fertilization is essential to maximize small grain vigor and health and is an excellent weed suppression practice. Starter fertilizer (low nitrogen and high phosphorus content) may be required in some areas. Place starter fertilizer near the seed to provide early availability to the crop, not to weeds. Broadcast-applied starter fertilizer enhances weed growth, especially for wild oat and canary grass; broadcast applications are less efficient and should be avoided.

Irrigation and proper drainage keep small grains in a vigorous growing condition for maximum competition with weeds In areas where flooding and high water tables occur, small grains should be sown on 0.75 to 1.5-m raised beds. For rainfed production systems, fields can be fallowed every other year to prevent weed seed buildup and to conserve moisture for maximum small grain growth. Weeds should not be permitted to produce seed dur-ing the fallow period. Tillage operations before planting should be delayed until the first fall rains germinate the weed seeds so that tillage can kill the first flush of weeds before sowing. Weeds may also be treated with an herbicide during the fallow period (chemical fallow).
Rotating small grain crops with other crops reduces infestations of Johnson grass, wild oat, Italian ryegrass, and other weeds that are important in small grains

(see part 12, *Small Grains in Crop Rotations*). Crop rotation allows weed populations to be reduced chemically, mechanically, and physically in the alternate crop. Growing dif-ferent crops at different times of the year helps break the reproduction cycle of some problem weeds. Small grains are often grown so that weeds important in higher-value crops can be controlled. For example, small grains grown in rotation with vegetable crops allow post-emergent broadleaf herbicides to be used to control nightshades and sow thistle, major problems in vegetable crops.

Crop Rotation and Wheat

Crop rotations differ depending on the relative importance of specific crops in different regions. In low -rainfall areas small grains may be grown in a summer-fallow system with or without tillage or chemical fallow, or they may be cropped annually with minimum tillage. Rain fed production in higher-rainfall areas occurs in rotation with pasture (sometimes with three or more years of pasture). Under irrigation, small grains are rotated with a wide assortment of crops, including cotton, tomato, potato, sugar beet, rice, safflower, sunflower, melons, lettuce, onions, and alfalfa. Small grains can be double-cropped with a summer crop of corn, grain sor-ghum, or beans. Small grain rotations can help reduce pest problems in other crops and provide agronomic benefits that improve the long-term stability and performance of agricultural systems. Weeds, pathogens, and nematodes are the pests most commonly affected by wheat rotations. Wheat helps improve soil structure, aid water penetration and retention, and reduce erosion on sloping land. They may also help retain residual soil nitrogen in the root zone by decreasing the potential for leaching losses of nitrogen during the rainy season.

Barley can be grown in some cases to reduce salt levels in saline soils so that other crops less tolerant of salt can be grown. This is an important part of a reclamation program for saline and sodic soils. If irrigation water is not high in salts, irriga-tion can leach excess salt from the upper portion of the soil profile, and a few seasons of barley production to leach salts from the soil may be sufficient to allow other crops to be grown. When water penetration is a problem because of poor water quality, incorporating barley straw into the soil improves water penetration. An amount of residue equal to 10 to 30 percent by volume of the upper 15 cm of soils is recommended.

The deep, fibrous root system of small grains helps build soil structure, improve water penetration, and control soil erosion. Straw residue and roots left after har-vest decompose slowly, which is important for erosion control and for improving soil physical characteristics. Incorporating the residue increases soil organic matter, improving soil tilth. Residue cover on the soil surface also slows runoff and improves water retention, which is particularly important on sloping land. Water penetration to deeper soil layers is improved by the root penetration of small grains and the bio-logical activity associated with decomposition of crop residue. Small grain crops may mobilize potassium and phosphorus from deeper in the soil, making it available to the following crops in the rotation.

Crop rotation helps make weed management easier by changing growing condi-tions that favor the buildup of specific weeds and by allowing the use of different her-bicides according to crop labels. The improvement of soil tilth by the small grain crop allows the rotation crop to grow more vigorously and compete more effectively with weeds. Small grain crops are especially useful for helping control broadleaf weeds that emerge during the small grain crop and perennials that emerge prior to grain harvest. Small grain crops are highly competitive with weeds, and most broadleaf weeds are easily controlled with selective herbicides that can be applied to the small grain. This helps reduce the populations of weeds that are difficult to control in winter broadleaf crops such as cole crops, lettuce, and sugar beets. Sunflower family weeds such as cudweed, common groundsel, mayweed cham-omile, prickly lettuce, and sow thistle are common problems in all broadleaf crops. Available herbicides control these weeds in small grains. Mustard family weeds such as London rocket, kaber mustard, black mustard, shepherd's-purse, and wild radish are common problems throughout California but are easy to control in small grains with available herbicides. Small grains also help reduce infestations of field bindweed, curly dock, Canada thistle, Bermuda grass, Johnson grass, and nutsedges.

Crop rotation is an important tool for managing some diseases. If a pathogen does not survive for more than a few years in the absence of a host plant or host plant residue, rotation to a nonhost crop is effective in reducing disease. Rotating small grain crops with other crops can help reduce diseases of small grain crops such as Septoria tritici blotch of wheat, Fusarium crown and root rot, barley scald, and barley net blotch. Small grain rotations are useful for managing a number of diseases of vegetable crops and broadleaf field crops such as alfalfa, beans, cotton, and sugar beets, and they also can help reduce inoculum of some diseases of tree and vine crops (table 5).

Crop	Disease	Scientific Name	Reduce Inoculum Below Damaging Levels	Reduce Inoculum and/or Keep Inoculum Levels from Building up
Beans	Anthracnose	*Colletotrichum Lindemuthi-anum*	x	
Beets	Leaf Spots	*Cercospora Beticola*	x	

Crop	Disease	Scientific Name	Reduce Inoculum Below Damaging Levels	Reduce Inoculum and/or Keep Inoculum Levels from Building up
Carrots	Foliar Blight	*Alternaria Dauci*	x	
	Leaf Spot	*Cercospora Carotae*	x	
Celery	Late Blight	*Septoria Apicola*	x	
Cole Crops	Bacterial Diseases	*Pseudomonas Syringae PV. Maculicola; Xanthomonas SPP.*	x	
	Black Leg	*Phoma Lingam*	x	
Cotton	Verticillium Wilt	*Verticillium Dahliae*	x	
Lettuce	Anthracnose	*Marssoninia Panattoniniana*	x	
Melons	Damping off, Fruit and Stem Rot, and Sudden Wilt	*Pythium SPP.*		x
	Fusarium Root Rot	*Fusarium Solani F. SP. Cucurbitae*	x	
Peas	Aschochyta Blight	*Aschochyta SPP.*	x	
Potato	Ring Rot, Bacterial Wilt	*Corynebacterium Sepedonicum*		x
	Scab	*Streptomyces Scabies*		x

Crop	Disease	Scientific Name	Reduce Inoculum Below Damaging Levels	Reduce Inoculum and/or Keep Inoculum Levels from Building up
Potato	Stem Rot	*Sclerotium Rolfsii*		x
Sweet Potato	Scab	*Monilochaetes Infuscans*	x	
Tomato	Corky Root	*Pyrenochaeta Lycopersici*		x
	Phytophthora Root Rot, Fruit and Seedling Blight	*Phytophthora SPP.*		x
Trees, Vines, and Canebarries	Crown Gall	*Agrobacteruim Tumefaciens*		x
	Southern Blight	*Sclerotium Rolfsii*		x
Vegetable Crops	Sterm Rot, White Mold, and Lattuce Drop	*Sclerotinia Minor; S. Sclerotiorum*	x	
	Southern Blight	*Sclerotium Rolfsii*		x
	Verticillium Wilt	*Verticillium Dahliae*		x

Small grain crops in a rotation can also reduce populations of several nematode. (table 6)species that can be harmful to trees, vines, or broadleaf crops.

Crop	Nematode	Scientific name	Reduce nematode populations
Cole Crops	sugar beet cyst nematode	*Heterodera schachtii*	x
	cabbage cyst nematode	*Heterodera cruciferae*	x
Spinach	sugar beet cyst nematode	*Heterodera schachtii*	x
Sugar Beets	sugar beet cyst nematode	*Heterodera schachtii*	x
Various Broadleaf Vegetable and Field Crops	root knot nematodes	*Meloidogyne* spp.	x
	root knot nematodes, warm-climate species	*Meloidogyne incognita, M. javanica, M. arenaria*	x
	Northern root-knot nematode	*Meloidogyne hapla*	x
Various Tree and Vine Crops	root-knot nematodes	*Meloidogyne* spp.	x
	lesion nematode	*Pratylenchus vulnus*	x

Harvesting and Storage

Direct Combining

Most small grain crops are harvested when the moisture content of the grain is 8 to 12 percent. Grain is fully developed when its moisture content drops below 35 percent, but it cannot be stored safely until the moisture is below 14 per-cent. A simple test to determine whether grain is dry enough for harvest is to rub a grain head between the palms of your hands. If the kernels do not separate readily from the chaff, or if the kernels separate but are easily dented with your thumbnail, the grain is too moist to harvest. Grain can be harvested at higher moisture content and artificially dried to below 14 percent before storage, but this is usually not cost-effective. Harvesting early and drying the grain may be justified in some cases by the time gained for planting a high-value crop that follows the small grain crop. If green weeds are present when the crop is ready for harvest, herbicides are available to desic-cate the weeds so that normal combining can proceed.

Follow the manufacturer's recommendations for adjusting the combine when you prepare for harvest. Attachments can be added to measure the amount of grain being lost as un-threshed seed or as free seed over the shoe and straw walkers at the rear of the machine. Frequent adjustments are necessary during harvest as conditions change. Use a slower cylinder speed and less air as grain becomes drier; very dry grain kernels crack easily.

Windrowing - Swathing

Windrowing (swathing) instead of direct combining is sometimes done to hasten drying, to dry out late-spring or summer weed growth, or to avoid grain yield losses by cultivars susceptible to grain shattering at maturity. Shattering is the loss of grain when kernels are knocked from the spikes (or panicles in oat) as the spikes move against each other or are whipped about by wind. Losses can vary greatly between cultivars. Cultivars of wheat with the tight glume characteristic do not shatter much but are more difficult to combine than those with loose glumes. Swathing should be done after the grain moisture level is less than about 35 percent (late dough stage) to avoid losses in grain yield due to underdeveloped (immature) kernels. Windrows can be combined after sufficient drying time (1 to 3 days).

Storage

Since prehistoric times grain has been stored to save seed, provide food between har-vest seasons, and supply feed for livestock. Today, grain is harvested over a relatively short period of time during the year and is stored for a variable period (from a few weeks or less to several years) before being distributed to the final destinations as food, feed, seed, or other uses. A simple and affective system of grain handling and storage has been developed.

Today, much of the grain supply is stored in farm on-the-farm grain storage bins/tanks. Grain is also stored in bulk bins, bagged and stored in warehouses, and in commercial grain elevators.

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, plump-ness, color, odor, and test weight; insect-damaged kernels; presence of live insects and foreign material; and proportion of germinated and broken kernels.

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 con-tent from respiration. At average air temperatures weight loss in dry matter is about one 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

Moisture

The average moisture content at harvest ranges from

18 to 26 percent. Grain can be stored safely at a moisture content of below 14 percent. Grain with higher moisture content should be dried. The most economical method to dry grain is delay harvest until the grain reaches the desired moisture content. Low humidity, solar radiation, and windy conditions decrease grain moisture content. Forced unheated air can lower grain moisture if relative humidity is below 70 percent after the grain has dried to 15 to 17 percent moisture. The dry-ing of grain requires airflow of 0.8 to 4.8 liters of air per minute per liter of grain. Using heated air to dry grain is costly, but it is rapid and dependable. Drying should start promptly after harvest and proceed continuously at a rate fast enough to avoid heat damage. For grain intended for seed, 43°C is generally the upper temperature limit; for grain intended for milling, temperatures should not exceed 54°C; for grain intended for feed, temperatures from 62° to 71°C are permissible.

Insect Pests Affecting Storage

Insects destroy as much as 30 percent of the world's supply of stored grain each year. 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 dominic*
- rusty grain beetle *(Cryptolestes ferrugineus)*

These insects are widely distributed in all grains, cereal products, and animal feeds, and are very common where grain is stored (silos, warehouses, storage bins, barns, and houses). Because most insect infestations originate after grain is placed in storage, sanitation offers the most practical means of preventing insect infestations. Grain should be free of infestation before being placed in storage. New grain should not be placed on top of old grain; bins should be completely emptied and cleaned before they are refilled. Extra care should be given to areas of potential insect contami-nation such as broken sacks and small piles of grain around machinery, grain bins, warehouses, and silos. The temperature and moisture of the storage environment can be manipulated to prevent insect problems. As temperature and moisture become lower, the rates of insect activity, feeding, development, and reproduction are reduced. Grain temperature can be lowered by aeration with ambient air or refrigerated air. The goal is to reduce grain temperature to about 14° to 18°C, a level at which most insects either cannot complete development or grow very slowly. Simple temperature aeration controllers can be used to lower air temperatures to cool the grain at night. Insects such as weevils are long-lived at a temperature of about 14°C, and only prolonged exposure to temperatures below 10°C significantly increases mortality; cooling with refrigerated air is an option in such cases. Secondary benefits of aeration include control of moisture migration, preservation of grain quality, and distribution of volatile toxicants. The lower the moisture content of grain, the less susceptible it is to spoilage by insects and mites, as well as by fungi (see below). Mites and fungi are a problem only at moisture contents above 14 percent, and insects cannot reproduce in grain of mois-ture content below about 9 percent. To help prevent losses to insects, mites, and fungi, grain with a high moisture content must be dried either in the field or in storage after it is received using either ambient or heated air.

Corrective treatments are required when grain becomes infested; these treatments can include fumigation and heated air. The role of chemical grain protectants for insect control is in question because of the decreasing tolerances of chemical residues in grain and food products and the increasing incidence of insecticide resistance.

Monitoring is essential for protecting stored grain. Infestations can be detected in bulk grain by taking grain samples, usually with a spatial sampling program, at regular intervals of between 2 and 4 weeks.

Mold (Fungus)

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.,
- "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.

The five agriculturally important fungal toxins include deoxynivalenol, zearale-none, ochratoxin A, fumonisin, and aflatoxin. Worldwide, aflatoxins produced by storage fungi have caused the most severe mycotoxicoses. Factors that affect mycotoxin formation in storage include moisture, temperature, time, mechanical damage to grain, oxygen and carbon dioxide levels, composition of substrate, fungal abundance, prevalence of toxigenic strains, spore load, microbiological interactions, and invertebrate vectors. *Eurotium* spp. (*Penicillium* spp.) xerophilic fungi are often the primary invad-ers of stored grains; once established, their metabolic activity raises the moisture con-tent of the grain, allowing establishment and growth of fungi such as *Aspergillus flavus* and *A. parasiticus*. Mycotoxin production is maximized from about 25° to 35°C.

Field fungi generally do not grow in grain with a moisture content less than 20 percent, and their growth is severely inhibited by low oxygen and high carbon dioxide concentrations. Clean and dry storage conditions combined with low storage temperatures are the best line of defense against fungi (and bacteria) that cause moldy grain. The best ways to prevent mold damage are to avoid storing grain with high moisture content and to cool the grain with aeration (temperatures that limit insect growth also reduce mold growth).

Notes

Notes

Notes

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov