Innovations To Help Our Country Grow

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This Manual on Wheat Production in Ethiopia is intended to service mainly the grass root extension staff that are tasked to work directly with smallholder farmers.

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The information herein presented was assembled by combining research data and empirical experience by the author who has been a wheat breeder-pathologist cum commercial wheat grower for over 30 years.

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DISCLAIMER: Any mistakes, inaccuracies or omissions are solely the responsibility of the author.
1. INTRODUCTION

The cultivated wheats (*Triticum aestivum* L. and *T. turgidum* L.), have the broadest adaptation amongst all cereals species. They are the world’s most important crops in terms of area planted (more than 240 million ha) and volume of grain produced that is, more than 600 million tonnes (Cimmyt Wheat Facts and Futures, 2009).

Wheat is a cool season crop and can be grown in many different agro-ecologies from sea-level to altitudes of around 3,000 meters above sea level (masl), or between latitudes 30° and 60° N and 40° S.

According to Briggle (1980) the minimum temperature for growth is about 3° to 4° Celsius with optimum temperature around 25 °C and the maximum around 30° to 32 °C. However, this author has successfully grown wheat in the Sudan (Gezira Scheme, 1987-1989) under minimum night temperatures of 14 °C and maximum day temperatures of 40 °C with grain yield above 6,000 kg/ha under irrigation. The crop can be grown in most locations where annual rainfall ranges from 250 mm to above 1700 mm provided the temperatures are right as pointed above. About 75 percent of all wheat grown receives on average between 375 mm to 875 mm of rain annually. The seasonal distribution of precipitation is critical for optimum production.

On a global basis, wheat provides more nourishment for people than any other food source. The wheat grain contains easily digestible carbohydrates and moderate amounts of proteins, minerals and vitamins, as well as fats (Briggle & Curtis 1987). The main uses of wheat are in the bread-making industry, pastas and pastries. On a kilogram for kilogram basis, wheat is about equal to maize, barley or sorghum when used as a feed grain during fattening of beef. After milling, about 25 percent of the whole grain ends up as by-product (bran) which is a good source of feed for the feed manufacturing industry. Other minor uses of wheat are starch for alcohol production, although cheaper sources such as potatoes and maize are usually preferred.

Wheat (*Triticum spp.*) is widely produced in the highlands and mid-altitudes of Ethiopia. Out of 18 major agro-ecological zones (AEZ) in the country, it is grown in more than eight AEZ. The major wheat growing areas include Arsi and Bale in the south-eastern, Hadiya and Kambata in the south, Shewa in the central highlands, and Gojam, Gondar, Wello and Tigray in the northwest and north. There are also several secondary areas of wheat production in the country.

There are the two major species of wheat grown in Ethiopia: bread wheat (*Triticum. aestivum* L.) and durum wheat (*Triticum turgidum var durum* L.). Durum wheat is traditionally grown on heavy black clay soils (vertisols) of the highlands. The productivity of wheat in Ethiopia is low compared to other wheat producing countries of the world. Reasons for this are: (1) the use of traditional production systems; (2) the influence of biotic (e.g. diseases particularly rust) and abiotic factors; and
(3) the lack of production inputs (e.g. improved seeds) and/or suboptimal use of recommended packages. Since the inception of bread wheat research in Ethiopia, a number of improved bread and durum wheat cultivars have been released to farmers. Besides, associated improved agronomic and crop management technologies of wheat production have been recommended. Generally, it is wise to recommend here that the potential areas of cultivation described for each wheat variety supported by pre-extension demonstration trials conducted at every and each of the respective regions. In this respect, the recommendations provided here could vary from place to place depending on differences in the agro-ecology where the technology is to be adopted.

2. VEGETATIVE DEVELOPMENT

2.1. Germination and Seedling Emergence

The wheat is an ungerminated kernel (seed) which possesses three to six seminal roots primordium. Usually bigger kernels produce more seminal roots as compared to smaller kernels. The embryo may also have initiated tiller bud primordium in the axils of the coleoptile and the first true leaf during its development on the mother plant (Stern and Kirby 1979).

The dormant seed will absorb approximately 35 to 45 percent of its own kernel dry weight before the germination process begins. Minimum soil temperature at seed depth for germination to start is 4 °C and maximum is 37 °C, with 12 to 25 °C being considered as optimum. Some of these parameters may change with seed age and lower soil moisture availability. Once the germination process is set, seedling emergence may take less than a week, or up to three weeks depending on soil temperature, moisture availability and seeding depth.

A seeding depth of 2 to 5 cm is nearly universally optimum for wheat when soil moisture is adequate for stand establishment. Beyond 8 to 10 cm, seedling emergence is poor. Extremely shallow or deep seeding reduces stand establishment. Shallow seeding depth leads to poor crown root and tillering formation and lodging, while deep seeding produces uneven stand and low plant population.

During germination, the radicle and seminal roots extend first, followed by enlargement of the coleoptile (Simons et al 1995. Fig.1). When the coleoptile emerges from the soil, its growth ceases and the first true leaf pushes through its tip. The initial root system serves to anchor the seedling and provides moisture to the growing plant. Eventually it also will absorb nutrients for the developing plant. Before the new seedling becomes photosynthetically functional, the small plantule depends on energy and nutrients provided by the reserves in the kernel. Accordingly, bigger kernels produce healthier, vigorous seedlings since they store more N nutrients.
The growing point will be located below the soil surface immediately above the coleoptile node (crown) and the first shoots (tillers) and main culm will be initiated from there. The number of leaves per culm (shoot) varies from 7 to 15; the final number being influenced by the genotype, temperature, light intensity and nutritional status of the plant. The rate of leaf initiation is about one leaf every 3 days for spring wheat when temperatures fluctuate between 17/12 °C day and night respectively. Rate of leaf initiation increases with higher light intensity and temperature, while delayed (late) planting of wheat results in an increased rate of leaf initiation, thus, shorter vegetative cycle. This in turn, leads to reduced yields.

2.2. Root Development

The first internode is usually located below the soil surface and it is called mesocotyl. The mesocotyl terminates in a node from where the coleoptile begins. This node is called crown or coleoptile node. From the coleoptile node or crown node, a diffuse root system will begin to emerge soon after seedling emergence. Usually only one node will form below the ground, but with very deep sowing, more than one node may develop and each one bearing roots. The total number of roots formed is associated with the number of leaves on a culm and the number of tillers per plant. Roots developed from new tillers, usually will appear after the first three leaves have appeared.

2.3. TILLERING

The tillering stage begins with the emergence of lateral shoots (tillers) from the axis of true leaves at the base of the main shoot. The first tillers to be formed appear from the primary tiller bud (meristem) primordium at the base of the main shoot. Tillers can form in the axils of the first four true leaves of the main shoot (Poole, N. 2005. Fig
2). In addition, subtillers can develop from primary or secondary tillers, particularly in spaced plants.

Fig 2. Tillering

Fewer total numbers of leaves are produced by tillers as compared to the main shoot, which serves to help synchronize the onset of spike initiation amongst shoots on the plant.

Usually the main shoot and earlier-formed tillers are most likely to complete development and form grain. Later formed tillers usually senescence and die prematurely in a crop community environment, mainly due to light competition, since they are overshadowed by the older tillers. Tiller senescence is commonly associated with the beginning of stem elongation, but can also happen beyond this stage.

The senescence of tillers is considered by most scientists to have a negative value for optimizing grain yield. Tillers destined to senesce, may translocate a portion of their current photoassimilate directly to surviving shoots, even before visible signs of senescence are apparent. Water consumption by unproductive tillers has adverse consequences in dry areas. Water consumed by sterile tillers in such circumstances likely reduces the productive capacity of surviving shoots. Thus, row planting of wheat and other cereal crops such as barley, under reduced seed rates may help in eliminating light competition, boosting tiller survival and enhancing grain yields.

Most spring wheats growing under normal conditions will go through the tillering phase from the time of first shoot emergence until 45-50 days. During that time,
usually 8-10 tillers may develop from one seedling, but eventually only one or two may survive and produce grain. The rest will start to senesce and die before stem elongation. Under spaced or row planting, larger number of tillers may form and the rate of survival is also greater.

2.4. STEM ELONGATION

Stem elongation begins when most florets on the developing spike have initiated stamen primordium, which corresponds closely with the formation of the terminal spikelet (Kirby and Appleyard; 1981). This stage usually coincides when the plant is about 45-50 days old from seedling emergence. Stem elongation is parallel with the growth of leaves, tillers, roots and the inflorescence. At this stage it is extremely important that the plant should not suffer any stress from limited supply of nutrients and moisture.

The lower internodes of the stem remain short, with the fourth internode elongating first. When an internode has elongated to about half of its full length, the internode above it begins to elongate. This sequence continues until stem elongation is complete, usually near anthesis (the period of which the inflorescence becomes fully functional, that is ovaries are receptive and grain pollen mature). Each succeeding stem internode is progressively longer, the final internode (known as peduncle), can account for as much as half of the total stem length (Poole, N., 2005. Fig.3)

Fig 3. Stem elongation

The height of the wheat plant ranges from between 30 to 200 cm and it is influenced by both, the genotype and the environmental growing conditions. Some wheat possesses dwarfing genes, classified as Rh genes. Several Rh genes have been identified within the wheat germplasm. Plants possessing more than one dwarfing gene are shorter than those possessing only one gene, which in turn are shorter than those possessing none. As a rule, variation in height is due more to differences in internode length, than internode number.

2.5. SPIKE DEVELOPMENT

The shift from vegetative to reproductive development in spring wheat occurs at very early stage. Spikelet initiation occurs when the main shoot has about three full leaves.
On secondary tillers, spikelet initiation occurs even earlier, for example, the first tiller formed after the main shoot, begins initiating spikelets when it has only one or two leaves.

The rate of spikelet initiation is about two to three times faster than that for the leaf primordium. Spikelet initiation rate on tillers exceeds that of the main shoot, which helps to synchronize more closely the time for terminal spikelet formation and spike emergence among shoots on a plant (Stern and Kirby 1979).

Photoperiod, temperature and nutrient availability have greater influence in determining the number of spikelets per head, than any other factor. Genotypes may differ in their response to all or some of the above factors.

Near the end of spikelet initiation, floret differentiation within spikelets begins in the central-lower portion of the spike and proceeds both upward and downward the spike. Initiation of the terminal spikelet marks the end of the spikelet formation. A spikelet can initiate as many as 12 floret primordia; however, only five or fewer florets will bear a kernel. The same factors that influence spikelet number also influence the number of florets per spikelet. Since floret differentiation begins later at basal and terminal ends, these form fewer florets. Light enhancement or shading during the period of floret development, greatly affects the number of florets at anthesis and the number of kernels per spikelet. These effects are greater in the basal or distant spikelets of the spike than in the central ones.

2.6. GRAIN DEVELOPMENT

Anthesis: Florets at anthesis are forced open by the swelling of two lodicules located at the base of the ovary. By this swelling, the anthers are extruded and exposed. After a few minutes, the anthers dehisce along a longitudinal line and pollen is shed. Pollen falls on the stigmas and after 20-30 minutes the lemma and palea (modified leaves that protect the inflorescence) close the flower and anthesis is completed. Pollen grains are viable for only 15-30 minutes under best conditions, while stigmas are receptive for 4-13 days.

Wheat is normally self-pollinated. Pollen grains after their release from the anthers quickly become extremely desiccated. Because the stigma branches are not sticky, pollen is probably attracted by electrostatic force and once the pollen is in contact with the stigma it absorbs water and germinates on the stigma. Pollen may germinate within one minute and only one grows to produce a tube. If additional grains germinate, they soon swell and burst and only one tube continues to grow. Eventually, the pollen tube reaches the embryo sac and one nucleus fuses with the egg cell to produce a zygote (the first cell of the embryo). The other nucleus from the pollen tube migrates and fuses with the polar nuclei to initiate the endosperm.
Starch deposition begins 1-2 weeks after anthesis and initiates a period of linear increase in kernel dry weight. The duration of this growth period varies depending on temperature, water stress and genotypes, but usually lasts for about 35-40 days. During this period, the grain goes through several developmental stages from 1) grain formation, 2) milk stage, 3) dough stage, 4) hard dough stage and finally 5) physiological maturity. At physiological maturity, the kernel contains about 30-40 percent moisture and has reached its final dry weight.

3. SUITABLE AGRO-ECOLOGY

Wheat can be grown at altitude between 1500-3200 meters above sea level (masl). However, areas with mean temperature from 15-25°C and altitude of 1800-2800 masl are more suitable. It requires an average of 500-1200 mm rainfall, well distributed during the growing season. It performs well on black clay, red clay and brown clay soils. Waterlogged vertisols are not generally suitable for wheat production. But with special soil management practices (broad bed and furrow or BBF), such soils can become more productive. The soil pH should be higher than 5.5.

4. IMPORTANT PRINCIPLES ON WHEAT MANAGEMENT

Specific cultural practices vary greatly between areas and amongst individual farmers within the same region. Therefore, only the general production practices that are known for optimizing grain yield production are presented.

Improved management practices are aimed at integrating all important cultural practices into a complete management package in order to increase efficiency on production.

4.1. SOIL MANAGEMENT

In the past, tilling the soil was recommended in order to accomplish several tasks, namely; 1) to incorporate plant residues in the soil to allow for residue decomposition and release of nutrients as well as building up soil organic matter, 2) improve soil aeration, 3) improve water infiltration, 4) destroy and bury weeds that may have germinated during the fallow period, 5) to workout the soil with several passes of a disk harrow or equivalent farm implement in order to pulverize the soil to produce a fine seed bed for uniform seeding depth placement and even germination, and in general, 6) improve the physical, chemical and biological properties that collectively govern the root environment of crops. Some of these assumptions still are valid today, but also, some others have been challenged as we learn more about soil management and new agricultural practices. For example, with the advent of conservation
agriculture practices, we now know that cereals in general can be successfully grown under no soil disturbance referred to as “no till” or minimum soil disturbance (minimum till) practices. This however, may require the use of herbicides such as glyphosate in order to kill the weeds prior to planting.

One of the problems that result from tilling the land many times and pulverizing the soil before sowing is that it can accelerate soil erosion under heavy rains. Also, it has been amply demonstrated that under no till agriculture coupled with mulching or crop residue management, there is higher rain water infiltration, organic matter accumulation, and better aeration by increasing porosity and enhancing on the biological properties of the soil. Soil clods also are important to reduce soil water erosion on sloppy fields by allowing the rain water to penetrate and prevent runoffs. Soil aggregation will decrease as the number of tilling operations increase. Excessive tillage degrades soil structure stability, which renders the soil more susceptible to particle dispersion by rain drops, water runoff, and surface sealing or soil crusting. Also, wind can easily transport finely pulverized soil.

4.2. SEED BED PREPARATION

4.2.1. TILLAGE

Soil should be prepared to allow for optimum germination and crop growth. Also, ensuring that nutrients and moisture are available within the first 30-40 cm of the top soil, since 95 percent of the wheat nodal or crown roots will grow within this soil profile.

Seed bed preparation must be rather location specific and compatible with specific soil-site characteristics since the number of tilling operations is directly influenced by soil types, the quantity of crop residue present at the time of the tilling operations, type and level of weed infestation, as well as the degree of the slope on the land. For example, excessive tilling operations that destroy soil aggregates (clods) on bare unprotected soils may be counterproductive to soil protection. Soils protected by crop residues will help in increasing dry aggregate size and stability; reduce water erosion by slowing runoff and increase water storage by enhancing water infiltration.

Prior to sowing during the last tilling operation, the soil should be worked out to smaller aggregates, not big clods, neither totally pulverized. Depending on the above local situations, if land has to be prepared by tillage, frequency of tilling may be limited to 2-4 times and 1-2 times for oxen and tractor ploughing, respectively with an interval of 21-28 days, the first being immediately after the harvest of the previous crop when the soil is not dry. In vertisol, where water logging is a problem BBM having 8-12 cm width and allows a drainage furrow of 15-20 cm between beds have to be used. As much as possible, land should be levelled, with good drainage in order to avoid
water logging. Land should be worked out in furrows before planting. Make contour furrowing of the land at about 2-5% gradient when sloppy in order to avoid soil erosion and ensure good drainage. The distance between furrows for planting, should be done at 30 cm between furrows. Never make furrows following the slope.

### 4.2.2. CONSERVATION AGRICULTURE

Under conservation agriculture, it has been amply demonstrated that under no till agriculture coupled with mulching or crop residue management, there is higher rain water infiltration, organic matter accumulation, and better aeration by increasing porosity and enhancing on the biological properties of the soil. From the many options that conservation agriculture (CA) affords, minimum till is perhaps the most appropriate for smallholder farmers. CA has three important pillars:

- Minimum tillage
- Crop-residue application
- Crop rotation.

In addition, amongst the benefits that CA delivers, the following can be highlighted:

- Stopping/minimizing soil erosion,
- Greater rain water infiltration and soil moisture retention,
- Creation of soil organic matter,
- Control of weed infestation,
- Beneficial to women-headed households since it reduces labour constraints.
- One area of concern which can be addressed by research is about residue/nutrient management since some of the N nutrient can be diverted by soil microbial for decomposing crop residues.

If and when farmers are practicing CA, the first operation to remember is that the soil should not be disturbed. On mountainous or hilly areas where farming is practiced, it is important to protect the soil from erosion. On these areas, CA can be practiced in combination with agroforestry, the growth of hedge rows made of trees and grass such as Vetiver or Napier grasses as well as in association with some degree of terracing. In situations where tall and woody perennial weeds or shrubs are grown on the farm land, they should be slashed with a cutlass in order to promote new growth. Wait for the first heavy rain (usually accumulation of up to 20mm of rain in 10 consecutive days will be enough) to promote weed growth. Apply glyphosate (preferably the original Round up since generics are not equally effective) at a rate of 3 lt/ha if weeds are moderate to high in numbers and are actively growing; or 4 lt/ha if weed population is very high. Use 200 lt/ha of clean water (not muddy or silty). After herbicide application, wait for 10-12 days to allow weeds to die out and plant the intended crop. In drier areas where there is a time constraint and planting the crop
needs to take place as soon as enough moisture from the rains has fallen, broad leaf herbicides can be applied instead of glyphosate which allows for immediate planting of the crop after herbicide application. If tractor-driven seed and fertilizer application can be used on the same operation, place the fertilizer in band, at about 10-15 cm away from the seed drill, in order to avoid the N in the basal fertilizer from burning the germinating embryo. When planting with oxen, two shallow furrows need to be made one close to the other. In one place the fertilizer by drilling it along the center of the furrow, and on the other drill the seed.

4.3. PLANTING

4.3.1. PLANTING METHOD AND SEED RATE

Wheat must be planted in rows at a distance of 30 cm apart. The reason for this is that 30 cm allows for ease when hand weeding, side dressing of Urea and implementing other agronomic management practices. Planting at 20 cm between rows is considered too narrow for optimum management. Plant the wheat by drilling 80-100 kg/ha of seed possessing a minimum of 90 % germination. This seed rate is equivalent at placing one seed every cm. or 100 seeds/meter or 300 seeds/m²

In Ethiopia, smallholder farmers do not use farm implements for sowing the wheat crop. Usually, before the last pass with the traditional plow or maresha, farmers will hand broadcast the DAP fertilizer (100 kg/ha) followed by hand broadcasting the seed (130-150 kg/ha). Then, the plow will make the last pass burying seed and fertilizer. This operation is not very efficient and as the result, seed is placed at uneven soil depths leading to irregular germination across the field. To reduce this problem, on the last pass, the maresha should be coupled with a small metal bar or medium-heavy wooden log attached at the end of the maresha to produce a flattening or land leveling effect that will place all the seed at more even seed depth.

4.3.2. SEEDING DEPTH

On most soils, seeds should be planted at uniform soil depth of 2-4 cm to promote uniform and optimum germination. Deep seeding tends to reduce seedling emergence and can produce uneven stands. Shallow seeding reduces tillering and enhances lodging due to poor crown root development.

Preferably, seeds should be covered with soil by foot operation in place of maresha, since this equipment is not reliable on uniformly covering the seed, thus, resulting in uneven and lower germination. When a seed drill is used for planting, adjust the planter to deliver the seed at 2-4 soil depth.
4.3.3. PLANTING TIME

As a rain fed crop, wheat is planted when the main rainy season is well established. Usually, before the establishment of the main season, farmers may experience some irregular rains that will help the seeds of weeds to germinate. This normally happens during late May-June. This is the time when farmers start plowing the land and eradicating weeds at the same time. Generally, planting time depends on location, soil type, onset and distribution of rainfall and the variety to be used. It is important that farmers use as much of the moisture provided by the rains and do not necessarily delay the planting of the crop. The onset of the rainy season usually is signalled by a precipitation of at least 20 mm of rain fallen during a period of 10 days. Plastic rain gauges installed at FTCs can inform farmers in order to sow the crop as early as possible.

Ideally, wheat is planted from last week of June to mid-July. The early planting should always be preferred over late planting in order to maximize grain yield. Even in low rainfall areas, early planting at onset of the rains is highly recommended. The wheat crop usually suffers from terminal drought stress at maturity due to late planting. In fact, the milling industry do not like to purchase wheat grain produced in Ethiopia, because during the milling operation, the flour yield usually is below the standard 75% yield due to terminal moisture stress during grain filling. On vertisol, planting needs to be completed early while the soil is at friable condition and this will provide sufficient time to exercise double cropping. The extension recommendation for farmers to plant is when the accumulated rain on the land, has reached at least 20 mm that can ensure good seed germination.

4.4. FERTILIZER

4.4.1. FERTILIZER TYPE

Crops on most soils in Ethiopia are responding to applications of three basic nutrient elements, namely: Nitrogen (N), Phosphorous (P), and Sulphur (S). Nowadays, farmers can use these three nutrients by applying two basic fertilizers; Urea for N and NPS which contains N, P and S. If NPS is not readily available, farmers can continue applying the same old DAP as before.

The application of chemical fertilizers can be reinforced with application of compost which normally is produced by farmers. Simultaneous application of compost, manure or other nutrient rich organic resources improves fertilizer use efficiency and supplies nutrients. These organic manures are an important source of macro- and micro nutrients and contribute to improvement of soil structure and water infiltration. Addition of these resources is complementary to fertilizer addition and, depending on dose, allows for a partial reduction in fertilizer input.
4.4.2. FERTILIZER RATE

Depending on location and research on soil information, dosage of NPS may vary from one quintal up to one and half quintal/ha. Fertilizer recommendations can be fine-tuned based on soil fertility maps developed by EthioSIS. However, a minimum application of DAP or NPS: Urea, should be in the ratio of 1:1 with an application rate of one quintal of each/ha.

4.4.3. METHOD AND TIME OF APPLICATION

When NPS and Urea are used; the whole of NPS should be applied basal at time of planting in a mix with 1/3 of the Urea. Apply the mix by drilling at 7-10 cm depth in the soil, along furrows of the wheat seeds and cover the fertilizer with soil. The remaining 2/3 of the Urea has to be applied at mid-tillering (35-40 days after planting) as side application 3-5 cm far from the row at 3-5 cm soil depth. Side dressing of Urea should be done immediately following the second weeding operation. If DAP is used in place of NPS, the method of application of DAP and Urea is the same to that of NPS and Urea. At FTC and ATVET pre-extension demonstration, Urea can be applied as a spot application on alternate rows of the wheat crop at 60 cm between alternate rows and 40 cm within the same row.

In all cases; concerning the type, rate, method and time of application if research recommendations that are different from what have been described above exist, location specific recommendation can be used.

4.5. LIMING ON ACIDIC SOILS

It has been estimated that over 40% of Ethiopian agriculture soils are affected by various degrees of soil acidity. To address the issue of soil acidity, it is important to get the proper information from the different soil laboratories in order to estimate the volume of lime application for each specific situation. If applying the lime for whole field at a time is not possible, divide the farm land and apply in rotation one after the other.

4.6. CROP ROTATION

Rotation of wheat with non-cereal crops is extremely beneficial for several reasons: Nitrogen fixation by legumes, add organic matter, improvement in soil-structure, the interruption of weed, disease and insect cycles and crop diversification. The soil fertility level could be enhanced if the preceding crop is a nodulating leguminous crop, which could make a symbiotic association with Rhizobium bacteria that fix atmospheric nitrogen.
In areas where wheat is produced, many other pulses and oil crops such as faba bean, field pea, grass pea, chick pea, linseed, rapeseed and noug are produced. These crops are important rotational or precursor crops in a wheat-based production system. Wheat plot provides more yield when rotated with faba bean compared to continuous wheat after wheat plantation. Research result also showed that growing wheat following faba bean and rapeseed increased grain yield of wheat by 13 and 6 quintals, respectively. In general, wheat should be rotated with these crops every two years in order to attain sustainable wheat production.

To encourage wheat growing farmers to adopt crop rotation mainly with pulses, the productivity of the rotational crops need to be enhanced by using bio-fertilizers (selected strains of nitrogen fixing bacteria) on pulses.

### 5. WHEAT VARIETIES RELEASED

Currently there are several bread and durum wheat varieties released (Tables 1 and 2). However, most of them were released over 10 years ago and have become susceptible to rust diseases. Due to their susceptibility, the continuous use of these varieties poses a serious threat to wheat growers since the risk of a devastating wheat rust epidemic (such as stripe rust in 2010 and stem rust in Bale in 2010), by any of the three rusts, is always very high. In light of this, it becomes of utmost importance that extension staffs are prepared to guide farmers on selecting the variety (es) most adapted to the agro-ecology and appropriate fungicide. A brief description of each variety is presented below.

**Table 1. Bread wheat varieties with their recommended environmental domains**

<table>
<thead>
<tr>
<th>No.</th>
<th>Variety</th>
<th>Year of release</th>
<th>Maturity (days)</th>
<th>Rainfall (mm)</th>
<th>Altitude (m)</th>
<th>Yield (Qt/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jefferson</td>
<td>2012</td>
<td>90</td>
<td>500</td>
<td>1200-1900</td>
<td>20-30</td>
</tr>
<tr>
<td>2</td>
<td>Huluka (ETBW5496)</td>
<td>2012</td>
<td>133</td>
<td>500-800</td>
<td>2200-2600</td>
<td>44-70</td>
</tr>
<tr>
<td>3</td>
<td>Hidase(ETBW5795)</td>
<td>2012</td>
<td>121</td>
<td>500-800</td>
<td>2200-2600</td>
<td>45-70</td>
</tr>
<tr>
<td>4</td>
<td>Ogolcho (ETBW5520)</td>
<td>2012</td>
<td>102</td>
<td>400-500</td>
<td>1600-2100</td>
<td>33-50</td>
</tr>
<tr>
<td>5</td>
<td>Gambo=Quaiu # 2</td>
<td>2011</td>
<td>90-145</td>
<td>Irrigated +rain fed</td>
<td>650-2400</td>
<td>37-55</td>
</tr>
<tr>
<td>6</td>
<td>Shorima(ETBW5483)</td>
<td>2011</td>
<td>105-150</td>
<td>600-900</td>
<td>1900-2600</td>
<td>44-63</td>
</tr>
<tr>
<td>7</td>
<td>Hoggana(ETBW5780)</td>
<td>2011</td>
<td>121-170</td>
<td>800-1200</td>
<td>2200-2900</td>
<td>46-60</td>
</tr>
<tr>
<td>8</td>
<td>Danda’a (Danphe#)</td>
<td>2010</td>
<td>110-145</td>
<td>&gt;600</td>
<td>2000-2600</td>
<td>35-55</td>
</tr>
<tr>
<td>9</td>
<td>Kakaba (Picaflor#1)</td>
<td>2010</td>
<td>90-120</td>
<td>500-800</td>
<td>1500-2200</td>
<td>33-52</td>
</tr>
<tr>
<td>10</td>
<td>Inseno-1 (BWPRAW 03/26)</td>
<td>2009</td>
<td>100</td>
<td>500-800</td>
<td>1600-2000</td>
<td>35</td>
</tr>
<tr>
<td>11</td>
<td>Alidoro (HK-14-R251)</td>
<td>2007</td>
<td>118-180</td>
<td>&gt;500</td>
<td>2200-2900</td>
<td>26-52</td>
</tr>
<tr>
<td>12</td>
<td>Gasay (Gasay (HA-3730))</td>
<td>2007</td>
<td>118-127</td>
<td>&gt;700</td>
<td>1890-2800</td>
<td>44-50</td>
</tr>
<tr>
<td>No.</td>
<td>Variety</td>
<td>Year of release</td>
<td>Maturity (days)</td>
<td>Rainfall (mm)</td>
<td>Altitude (m)</td>
<td>Yield (Qt/ha)</td>
</tr>
<tr>
<td>-----</td>
<td>--------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>---------------</td>
<td>--------------</td>
<td>---------------</td>
</tr>
<tr>
<td>13</td>
<td>Menze/HAR 3008/</td>
<td>2007</td>
<td>154</td>
<td>&lt;900</td>
<td>2800-3100</td>
<td>19-33</td>
</tr>
<tr>
<td>14</td>
<td>Digelu (HAR 3646)</td>
<td>2005</td>
<td>100-120</td>
<td>&gt;600</td>
<td>2000-2600</td>
<td>40</td>
</tr>
<tr>
<td>15</td>
<td>Tay (ET-12 D4/HAR604 (1))</td>
<td>2005</td>
<td>104-130</td>
<td>&gt;700</td>
<td>1900-2800</td>
<td>25-61</td>
</tr>
<tr>
<td>16</td>
<td>Simba/HAR 2536/</td>
<td>2000</td>
<td>100-150</td>
<td>&gt;600</td>
<td>2000-2600</td>
<td>30-50</td>
</tr>
<tr>
<td>17</td>
<td>Hawi/HAR 2501/</td>
<td>2000</td>
<td>105-125</td>
<td>&gt;500</td>
<td>1800-2200</td>
<td>40</td>
</tr>
<tr>
<td>18</td>
<td>Sofumar/HAR 1889</td>
<td>2000</td>
<td>125-150</td>
<td>&gt;600</td>
<td>2300-2800</td>
<td>40-50</td>
</tr>
<tr>
<td>19</td>
<td>Mada-Walabu</td>
<td>2000</td>
<td>100-125</td>
<td>&gt;600</td>
<td>2300-2800</td>
<td>35-45</td>
</tr>
<tr>
<td>20</td>
<td>Tusie/HAR 140/</td>
<td>1997</td>
<td>125-130</td>
<td>&gt;600</td>
<td>2000-2500</td>
<td>40-65</td>
</tr>
<tr>
<td>21</td>
<td>Pavon-76</td>
<td>1982</td>
<td>120-135</td>
<td>&gt;500</td>
<td>750-2500</td>
<td>30-60</td>
</tr>
<tr>
<td>22</td>
<td>ET-13 A2</td>
<td>1981</td>
<td>127-149</td>
<td>&gt;700</td>
<td>2200-2900</td>
<td>30-60</td>
</tr>
</tbody>
</table>

- **Jefferson**: Released by Fedis Research Center in 2012. It is recommended for dry land moisture stress areas such as Harer and Rift valley Areas.
- **Kakaba**: Released by Kulumsa Research Center in 2010. It is a midland altitude and shows some fair level of tolerance to the three rusts. This variety can be promoted as replacement for Kubsa as low land varieties.
- **Danda’a**: It is a highland type and released as replacement to Galama. Released during 2010 by the Kulumsa Research Center and still possess some degree of resistance/tolerance to the rusts.
  - **Mada-Walabu (HAR 1480)**: This variety was released by Sinana Research Center in Bale in 2000. Although it is moderately susceptible to the three rusts, still it can be grown on the high lands of Arsi and Bale. It is not recommended for low altitudes due to stem rust susceptibility.
  - **Digelu**: This variety was released by the Kulumsa Research Center in 2006. It was recommended for mid to high altitudes in Arsi-Bale of Oromia region, wheat areas of Amhara and SNNPR. This variety used to have some degree of resistance or tolerance to the three rusts. Currently, latest information has been released that its resistance has been broken down by a new race of stem rust. Therefore, till other alternative solution is recommended, production of this variety has to be supported by chemical control with proper supervision and recommendation of crop pathologist.
- **Inseno-1**: This variety was released by Awassa Agricultural Research Center for moisture deficit areas such as Halaba, Inseno, Hawassa and similar areas.
- **Pavon-76**: This bread wheat variety was released by Werer Research Center in 1982. Pavon-76 has a pearl-white color grain with excellent bread making quality. It is a popular variety in mid to low altitudes such as the Central Rift Valley. It is not recommended to be planted in higher altitudes due to its susceptibility to yellow rust.
After Kakaba and Danda’a, six more varieties (Shorima, Hoggana and Ga’ambo in 2011 and Huluka, Hidase and Ogolcho in 2012) were released by Kulumsa Research Center and the availability of seed and promotion is in progress. Hoggana, Huluka and Hidase can be considered highland to midland types; Shorima midland type; Ogolcho midland to lowland type, and Ga’ambo irrigated type. These are rough classifications; preferences of the farmers and its adaptability to wider areas as will be verified at ATVET and FTCs pre-extension demos will determine appropriate agro-ecologies of these varieties in the near future.

Table 2. Durum wheat varieties with their recommended environmental domains

<table>
<thead>
<tr>
<th>No.</th>
<th>Variety</th>
<th>Year of release</th>
<th>Maturity (days)</th>
<th>Rainfall (mm)</th>
<th>Altitude (m)</th>
<th>Color</th>
<th>Yield (Q/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flakit (EN-25)</td>
<td>2007</td>
<td>140</td>
<td>900 - 1200</td>
<td>2400 – 3000</td>
<td>White</td>
<td>21.5</td>
</tr>
<tr>
<td>2</td>
<td>OBSA</td>
<td>2006</td>
<td>131</td>
<td>750 - 1000</td>
<td>2300 – 2600</td>
<td>Amber</td>
<td>68</td>
</tr>
<tr>
<td>4</td>
<td>Kokate (DZ-2016-1BZR-10 205-OAK-2AK9(23))</td>
<td>2005</td>
<td>110 - 120</td>
<td>&gt;700</td>
<td>1900 – 2800</td>
<td>Amber</td>
<td>30 - 50</td>
</tr>
<tr>
<td>5</td>
<td>Bakalcha</td>
<td>2005</td>
<td>133</td>
<td>750 - 1000</td>
<td>2300 – 2600</td>
<td>Amber</td>
<td>67</td>
</tr>
<tr>
<td>6</td>
<td>EJERSA LABUD</td>
<td>2005</td>
<td>134</td>
<td>750 - 1000</td>
<td>2300 – 2600</td>
<td>Amber</td>
<td>62</td>
</tr>
<tr>
<td>7</td>
<td>Selam (DZ-1666-2)</td>
<td>2004</td>
<td>107 - 135</td>
<td>&gt;700</td>
<td>1900 – 2800</td>
<td>Amber</td>
<td>22 - 36</td>
</tr>
<tr>
<td>8</td>
<td>Metaya (DZ-2212)</td>
<td>2004</td>
<td>113 - 139</td>
<td>&gt;600</td>
<td>2000 – 2800</td>
<td>Amber</td>
<td>21 - 35</td>
</tr>
<tr>
<td>9</td>
<td>Mosobo (DZ-2178)</td>
<td>2004</td>
<td>102 - 132</td>
<td>&gt;700</td>
<td>1900 – 2800</td>
<td>Amber</td>
<td>20 - 40</td>
</tr>
<tr>
<td>10</td>
<td>Megenagna (DZ-2023)</td>
<td>2004</td>
<td>99 - 128</td>
<td>&gt;700</td>
<td>1900 – 2800</td>
<td>Amber</td>
<td>20 - 40</td>
</tr>
<tr>
<td>11</td>
<td>Ilani (DZ-2234)</td>
<td>2004</td>
<td>135</td>
<td>750 - 1000</td>
<td>2300 – 2600</td>
<td>Amber-pale</td>
<td>35 - 55</td>
</tr>
<tr>
<td>12</td>
<td>Ude (CD 95294-2Y)</td>
<td>2002</td>
<td>111 - 132</td>
<td></td>
<td></td>
<td>Amber-White</td>
<td>35</td>
</tr>
<tr>
<td>13</td>
<td>Yerer (CD 94026-4Y)</td>
<td>2002</td>
<td>109 - 134</td>
<td></td>
<td></td>
<td>Amber-white</td>
<td>37</td>
</tr>
<tr>
<td>14</td>
<td>Oda (DZ-2227)</td>
<td>2004</td>
<td>137</td>
<td>750 - 1000</td>
<td>2300 – 2600</td>
<td>Pale-red</td>
<td>38 - 53</td>
</tr>
</tbody>
</table>


6. CROP PROTECTION

6.1. WEED CONTROL

Weeds can cause heavy grain yield loses due to competition with the crop for light, moisture and soil nutrients, or by allelopathy (suppressing of growth by one plant on another plant through the release of toxic chemicals, usually through the root system).

Weeds can be detrimental in several ways in addition of yield reduction. Grain contaminated with weeds brings lower market price. Some weeds and their seeds such as Allium vineale L. or wild garlic which is widespread in Ethiopia, produce an off-flavor to the flour during milling and thus low quality flour which is rejected by the milling industry.

In spring wheats such as those grown in Ethiopia, the most severe competition from weeds, occurs during the early part of the crop cycle. Thus early weed control is required. Ideally, the crop should be free from weed competition from the time of seedling emergence until the beginning of stem elongation. That is, during the first 40-50 days.

In Ethiopia, where labor cost is low, hand weeding is widely practiced. This method is seldom used in wheat growing countries elsewhere, however, hand weeding may be practical approach when weed densities are low, and the wheat plot is not very large. However, hand weeding is only applicable for removing broad leaves weeds, but not for grass weeds, which normally are undistinguishable from the wheat crop during the early stages of plant development. Hand weeding for grass weeds can easily be done on row planted wheat by removing any growing plant that may be present in between the lines of the planted crop.

Weed infestation can be kept low through common sense farming practices. In fact, before the advent of chemical herbicides, farmers had to rely almost entirely on cultural practices to keep the weeds to a minimum. The first piece of advice and most economical is to use weed-free seed. Purchasing or using weed contaminated seed, can result in a poor economic investment, especially if new (not known) weed species are introduce into new farmers’ fields.

Reduction in weed infestation can also be accomplished by, for example; destroying all the weeds that appear on the field during fallow, before they set any seed. Also, sowing the crop may be delayed to allow as many weeds as possible to germinate and be destroyed by tillage before sowing the crop. However, one has to be careful not to recommend sowing the crop beyond the optimum planting date because of reduction
on the yield potential of the crop.

The reduction in the buildup and the control of weeds can also be accomplished by crop rotation. Weeds that have the same cycle as wheat tend to create the most severe problem. For example, wild oats (Avena spp) are amongst the world’s most noxious weeds in cereals. When crop rotation is practiced, the new crop should have different life cycle or different cultural practices to allow for the destruction of the weed population. For example, wheat can be grown in rotation with faba beans, chickpeas, maize, even sorghum, etc. all of them can be planted in rows to allow for mechanical or hand weeding.

When using fertilizers, weeds usually respond as much as the crop does, leading to reduce grain yield from the crop unless weeds are controlled timely and appropriately.

Wide row planting may be one way to control weeds by cultural practices. Wheat can be planted at spacing between rows of 35-40 cm on a solid drill by hand or machine operation. After seedling emergence, all the weeds that may germinate in the inter row spacing can easily be removed by hand hoeing. It has been amply demonstrated that grain yield it is not affected by wide row planting when other appropriate husbandry practices remain equal.

Chemical control of weeds is another option. It was during the early 1940’s when 2-4-D, MCPA and other phenoxy compounds were discovered that led to the production of selective herbicides. These compounds have the ability to translocate within the plant and can kill not only annual weeds, but also some perennial weeds. However, chemical control of weeds should be viewed as an additional tool, not as a panacea. The efficiency of herbicides often leads to heavy dependence on chemicals alone, to the exclusion of mechanical and cultural methods for weed control. Also, one drawback on the continued use of the same herbicide is that the same weeds the herbicide is used to control, will build up some tolerance to the chemical and a more resistant weed population will become established. This problem can be eliminated by crop rotations and using a mixtures of herbicides or alternating different herbicides from one season to the next, and by hand weeding when economically viable.

6.1.1. BROADLEAF WEED CONTROL

Some herbicides used for broadleaf control such as Dicamba, Picloran, 2-4-D and MCPA are growth regulators type chemicals. They are applied to the foliage of plants and can translocate to the roots. The least injury to the crop is obtained by applying after wheat is well tillered but before stem elongation (between 35-40 days after sowing). All the above mentioned herbicides are already banned in developed country agricultural systems and replaced by new formulations which are not growth regulators. However, in Ethiopia, 2-4D Amine still is widely used since long time ago
due to its low cost. One of the drawbacks is that broadleaf population has shifted and those weeds which are tolerant to the chemical have become established. Also sometimes, herbicides may need to be applied earlier, before 2-4D can be applied. When such situations arise, there are a wide array of other non hormonal herbicides in the market such as Brittox, Starene M, Basagran, Granstar, etc (all commercial names). Dosages vary according to the weed population, time of application, and specific weeds to be targeted. Always the indications on the label should be read before use.

<table>
<thead>
<tr>
<th>Type</th>
<th>Herbicide</th>
<th>Rate (lit/ha)</th>
<th>Growth stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad leaf killer</td>
<td>Starane-M</td>
<td>1</td>
<td>2-5 leaves</td>
</tr>
<tr>
<td></td>
<td>Banvel P</td>
<td>3.25</td>
<td>2-5 leaves</td>
</tr>
<tr>
<td></td>
<td>Gran Star</td>
<td>20 gram</td>
<td>2-5 leaves</td>
</tr>
<tr>
<td></td>
<td>Derbi</td>
<td>100 CC</td>
<td>2-5 leaves</td>
</tr>
<tr>
<td>Grass weeds killer</td>
<td>Puma Super</td>
<td>1</td>
<td>2 leaves to 1 node</td>
</tr>
<tr>
<td></td>
<td>Topic</td>
<td>1</td>
<td>3-6 leaves</td>
</tr>
<tr>
<td></td>
<td>Pallas</td>
<td>0.45</td>
<td>3-6 leaves</td>
</tr>
<tr>
<td>Non-selective</td>
<td>Round up</td>
<td>2</td>
<td>10-15 days before planting when the weed is highly emerged</td>
</tr>
</tbody>
</table>

### 6.1.2. GRASS WEED CONTROL AND ROW PLANTING

The wheat crop in Ethiopia (mainly Arsi and Bale) has been planted as a monocrop for a long period of time. As the result, over time, there has been an unintended selection of noxious weeds growing in association with the crop due to two reasons, namely:

a) On broad leaves weeds, the continued use of 2-4D herbicide by the farmers has selected out the prevalence of 2-4D tolerant weeds which are not killed by the herbicide even when using higher dosages.

b) Narrow leaves or grass weeds such as wild oats (Avena spp), Agropyron spp, fox tail weed Phalaris spp) and other grasses have become a real challenge threatening wheat yields, since on some farmers’ fields these weeds are more prevalent that the wheat crop proper. There are two different specific herbicides for control of these weeds, Pallas and Topic.
Due to high cost of selective herbicides for narrow leaves control, farmers have restrained on the use of chemical control and prefer to do hand weeding instead. However, during the early stage of crop development, farmers are unable to differentiate the grass weed from the wheat crop proper and they often delay the weeding operation until too late when weeds are distinguishable, but the damage is already done to the crop.

6.1.3. WHEAT ROW PLANTING AS A SOLUTION TO GRASS WEED CONTROL

The technology for row planting on wheat in Ethiopia initially was conceived with the objective of controlling grass weeds by mechanical weeding (cultivation with small tractors or oxen driven equipment) or hand weeding. In Mexico where this technology was first introduced to farmers by this author in 1974, more than 700,000 ha of the wheat crop are currently planted in rows. This technology was first introduced by this author through SG 2000 in Ethiopia (in Hitosa) during the late 1990s.

Moreover, as the technology has been progressively adopted by many farmers, some other advantages (in addition of weed control) became evident, particularly for smallholder wheat farmers in Ethiopia. Amongst the additional advantages, the following are important to mention:

i) Wheat should ideally be planted in rows at a distance of 40 cm apart. This spacing gives the crop the replication of the “border effect” all along the length on each one of the rows. As the result of this border effect, competition for light is removed and there is a higher tiller survival when compared with the traditional sowing method by broadcasting. All the plants in the field exhibit the same strong and healthier growth pattern. All the heads produced within the row are uniform with the same number of spikelet, and similar number of grains/spikelet. Also with much more grains per head than those from the traditional broadcasting sowing method.

ii). The amount of seed needed to plant one hectare can be significantly reduced. Currently farmers in Ethiopia use around 150 kg/ha of seed and even sometimes more. With row planting, the seed rate can be reduced to 80-100 kg/ha. Since all seeds are drilled on the row, germination and plant establishment does not become a problem. Also, because seeds are placed very close one from the other, there is no space for weeds to germinate and develop within the row.

iii). All the weeds which germinate on the intra-row spacing can easily be removed by hand hoe at an early stage, thus eliminating weed competition. Particularly the grass weeds can be removed much earlier than before, because anything which
grows outside of the line planting can be considered as weed, thus, candidate to be removed. Family labor such as youngsters after school hours can do the weeding since there is no need for special expertise to distinguish the grass weeds from the crop.

iv). This technology is particularly suited for seed production since the spaces between rows are ample enough to permit a person walking inside the crop to do removal of off types and volunteers without damaging the crop (Fig 4)

v). Grain yield on row planting is usually equal or better than the traditional method of broadcasting provided enough nutrient and moisture are available. This is because each head produces more grains than the traditional sowing by broadcasting method. In Mexico farmers can harvest up to 100 Qt/ha on row planting under irrigation. In Ethiopia many farmers already are harvesting 70-80 qts/ha under rain fed.

vi). Wheat row planting for the future, will also be very much suited for the application of slow release N as urea super granules. This is a new technology in process of testing, which can allow farmers to reduce by 50% urea application as super granules and still get the same yield as applying 100% urea traditional.

Fig. 4. Commercial Wheat Row Planting in Mexico (all the heads are of same size with increased no. of grains due to the border effect).
The absence of row planting in Ethiopia, contributes to the most serious grass weed problem in wheat cultivation caused by wild oats (Avena spp). In some localized areas, other grass weeds may also become important, such as Phalaris spp, Lolium spp, Snodonia spp Agropyron spp amongst others. Until now, only grass herbicides which are highly selective can be used for grass weed control and because of this, not all the grass weeds are controlled by the same chemical. Also, the wheat crop may show some damage due to phytotoxicity from the chemical. As a general rule, the best way to control grass weeds is either by applying the herbicide as pre-emergence herbicide such as Iloxi 6 for the control of Phalaris spp or wild oats, or controlling the weeds at the two to three leaf stage such as when using Puma super for the control of wild oats. However, grass weed herbicides have a more ample window for application, from early tillering up to the joint stage of the weeds. Later applications usually are not recommended since the crop already has sustained some damage due to weed competition.

When grass weed population becomes too high and unmanageable, it is preferable to use crop rotation for a year or two in order to reduce or eliminate the weed challenge.

6.2. WHEAT DISEASES

Crop diseases have been of major concern throughout the history of agriculture. This is corroborated by the fact that many disease-producing microbial organisms are as old as the crop itself. In the case of wheat, the host (the wheat plant) and pathogen (the disease-causing organism) have evolved parallel during the evolution of the wheat genus.

Most of the wheat breeding programs anywhere in the world are directed towards the control of wheat diseases and yield stability as the major concerns. This production manual will not address all the different diseases in wheat, however; a wheat identification brochure has been produced in combination with this manual and the reader is directed to consult it for more information. Herein the major wheat diseases are briefly documented.

6.2.1. DISEASES OF ROOTS AND LOWER STEMS.

There are many micro-organisms that can attack both the roots and the lower part of the wheat plant that is closest to the soil. The unique feature of all these microorganisms is that they spend at least part of their life cycle in intimate contact with the soil. These pathogens can be divided further into two groups, namely; 1) those that can persist in the soil for many years, in the absence of the wheat plant, and 2) those that cannot and are introduced into wheat field from elsewhere. They may come from other crops, or from nearby wheat fields and are usually dispersed by wind, farm machinery, or living organisms such as cattle and man himself.
In general, plants that are attacked by rot-producing pathogens appear stunted, with poor or not tillering, chlorotic, premature death of tillers (whiteheads) and shriveled grain. Affected plants may occur scattered across the field, but most commonly in clear patches. Mature plants may show a discolored rotted internal crown area. In order to confirm the causal micro-organism, a laboratory test to isolate the pathogen becomes necessary. Several fungi may be involved in producing root and lower stem rot; the most important are: Phytium spp, Rhizoctonia spp, Cephalosporium spp, Fusarium spp and nematodes. Some of the control measures include using resistant varieties, chemical seed treatment with correct fungicides and crop rotations.

6.2.2. BACTERIAL AND FUNGAL BLIGHT OF THE FOLIAGE AND HEADS OF WHEAT

Another important group of micro-organisms are those that cause leaf and head blight diseases. The most important in Ethiopia are Septoria spp that produces leaf blotch and head blight. The development of the disease requires optimum temperatures between 20-25 °Celsius and humid conditions. Usually the symptoms first appear on the lower leaves and progresses to reach the head as the season advances. Persistent overcast weather and rain can disseminate the inoculum very rapidly. The problem caused from septoria attack can increase where continuous monocropping is practiced since the pathogen can remain on the wheat stubble until the next cropping season. Wheat varieties differ in their susceptibility to the attack from these fungi and the use of resistant cultivars and crop rotations are the most economic means of protection (Fig 5 and 6)

Fig. 5. Septoria avenae
Fig. 6. Septoria nodorum
Sometimes wheat can also be attacked by bacterial pathogens that cause leaf streaks or blights. The initial inoculum is seed-borne, but the organism can survive on wheat debris until the next cropping cycle. Bacterial cells can be dispersed from one plant to another by rain splash, but insects and wind also are important dispersing mechanisms. The bacterium enters the plant through natural openings such as the stomata and wounds. The lesions at the beginning appear as very narrow, water-soaked streaks that may elongate to the entire length of the leaf blade. During rainy days or heavy dew, a bacterial exudate is produced at the lesion site. This exudate dries out to form a flaky coating on the leaves. The lesions can also be found on the wheat heads.

Some wheat varieties are more resistant than others and the use of clean treated seed and resistant cultivars are the best means of protection against this pathogen.

The most important bacteria pathogens are Xanthomonas campestris, Pseudomonas syringae, P. atrofaciens and Corynebacterium tritici.

6.2.3. RUSTS ፥፥, SMUTS ኣምርም እና POWDERY MILDEW

Rusts, smuts and mildews are the most important wheat diseases worldwide. The causal fungi organisms are highly specialized obligate parasitic on their living host plant. These fungi possess great capacity to vary through mutation and other mechanisms, as a result; previously resistant cultivars can be rendered susceptible by new strains of the pathogen in a relatively short period of time.

6.2.3.1. STEM RUST

Wheat rusts have undoubtedly been present throughout the development and evolution of the wheat and related grass species. Even Bible reports about wheat diseases clearly refer to stem rust. Archeological evidence has been found concerning stem rust dating back to 1400 BC on fragments of wheat heads (Kislev 1982).

The causal agent of stem rust (Puccinia graminis f.sp tritici) produces reddish brown elongated lesions (pustules) which are more evident on the stems, leaf sheaths and peduncles of the plant, thus the name of stem rust. The pustules usually erupt on both sides of the leaf surface when occurring on leaf blades. This rust can cause great grain loses, sometimes amounting to 100 percent when the disease turns into epidemics that begin early during the crop cycle.

Wheat stem rust can be controlled either by the use of fungicides on early application or by growing genetically resistant cultivars. When a variety whose resistance has been eroded, it should immediately be withdrawn from cultivation in order to prevent heavy losses by farmers (Fig.7).
6.2.3.2. LEAF RUST

The lesions caused by leaf rust are nearly as identical as those of stem rusts, but the color is lighter, more orange or brown, leading to the names of brown rust or orange rust. Another distinctive characteristic of leaf rust is that the pustules it produces erupt only on one side (usually the upper side) of the leaf sheath, in contrast to stem rust, which ruptures both sides when occurring on the leaf blades. The fungus that causes leaf rust Puccinia recondita f. sp. tritici has a broader climatic adaptation and widespread occurrence than the other two wheat rusts. It requires intermediate temperature, thus most wheat growing areas around the world may be subjected to leaf rust attack.

There are some fungicides described below that can successfully be applied for the control of leaf rust. However, the use of genetic resistant cultivars still continues to be the best option (Fig. 8).
6.2.3.3. STRIPE RUST

Lesions are present in linear arrangement and are yellow in color. Thus the names of stripe rust or yellow rust as it is also known. Stripe rust is caused by the fungus Puccinia striiformis var. striiformis. The lesions or pustules can be seen on the leaf blades and spikes of susceptible varieties. Sometimes yield losses due to stripe rust attack can be as high as 100 percent when a variety is susceptible.

The control measure can be accomplished by spraying systemic fungicides (the same fungicides applied for controlling stem and leaf rust also work for stripe rust control) under the threat of an epidemic, but the longer term strategy should rest on the use of genetic resistant cultivars as the most economic choice (Fig. 9).
6.3. FUNGICIDES AVAILABLE FOR RUST CONTROL IN WHEAT

Although the use of fungicides for rust control should be viewed as a last resort measure, it is important to assemble a list on the names of fungicides that could be resorted to in a situation of emergency. The following are the most important current products in the market for controlling the three rusts in wheat (Tables 4 and 5):
Table 4. List of Important Fungicides for the Control of Wheat Ruts

<table>
<thead>
<tr>
<th>No.</th>
<th>Commercial Name of Product and Active Ingredient</th>
<th>Manufacturer</th>
<th>Main Diseases Controlled</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rex Duo (Epoxiconazole + thiophanate-methyl)</td>
<td>BASF</td>
<td>controls septoria including head scab, fusarium, powdery mildew and rusts fungi in wheat and sugar beets; Apply at jointing stage when disease symptoms appear.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Folicur (Tebuconazole)</td>
<td>BAYER</td>
<td>controls yellow rusts in wheat and barley, additionally it controls leaf blights on barley produced by Pyrenophora teres, and Rhynchosporium secalis; on Banana for the control of black sigatoka (Mycosphaerella fijiensis var. difformis) yellow sigatoka (Mycosphaerella musicola) and Cladosporium (Cladosporium musae); in Sorghum for the control of Ergot (Sphacelia sorghi), in Vid for controlling powdery mildew (Uncinula necator); and in Garlic for controlling white rot caused by Sclerotium cepivorum. Can be used as seed dressing or foliar spray. Application at early stage of disease development.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Alto [(Cyproconazole: 2-(4-Clorofenil)-3-ciclopropil-1-(1H-1.2.4-triazol-l-il) butano-2-lo]</td>
<td>SYNGENTA</td>
<td>this fungicide is highly specific for the control of rusts in wheat and barley. Can be applied during jointing stage at first detection of disease. Highly effective fungicide.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Opus 125 (Epoxiconazole)</td>
<td>BASF</td>
<td>fungicide for the control of leaf rust, yellow rust, septoria leaf blotch, and septoria leaf scab (Phaeosphaeria nodorum), and powdery mildew (Blumeria graminis f. sp. tritici) in wheat; leaf rust (Puccinia recondita f. sp. hordei), yellow rust rusts (P. striiformis f. sp. hordei), net blotch (Pyrenophora teres f. sp. teres) leaf scald (Rhynchosporium secalis), and powdery mildew (Blumeria graminis f. sp. hordei) in barley. Broad spectrum fungicide.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Sico 25EC (Difenoconazole)</td>
<td>SYNGENTA</td>
<td>Provides long-lasting preventive and curative activity against Ascomycetes, Basidiomycetes and Deuteromycetes including Alternaria, Ascochyta, Cercospora, Cercosporidium, Colletotrichum, Guignardia, Mycosphaerella, Phoma, Ramularia, Rhizoctonia, Septoria, Uncinula, Venturia spp., Erysiphaceae (powdery mildews), Uredinales (rusts) and several seed-borne pathogens. Used against disease complexes in grapes, pome fruit, stone fruit, potatoes, sugar beet, oilseed rape, banana, cereals, rice, soya beans, ornamentals and various vegetable crops.</td>
<td>Broad spectrum fungicide with long residual effect</td>
</tr>
<tr>
<td>6</td>
<td>Quadris (Azoxystrobin)</td>
<td>SYNGENTA</td>
<td>For use in controlling diseases in Canola, Legume Vegetables including soybeans, Seed Corn, Potatoes, Tomatoes, Ginseng, Hazelnuts, Sugar beets, Coriander, Ferns of Asparagus, Spinach, Sweet and Field Corn, Carrots, Radish, Horseradish, Rutabaga, Turnip, Garden Beet, Tobacco, Cereals and Ground Cherries. In wheat it controls both leaf and yellow rusts.</td>
<td>Mostly used on vegetable crops</td>
</tr>
<tr>
<td>7</td>
<td>Stratego (propiconazole + trifloxystrobin).</td>
<td>SYNGENTA</td>
<td>It is a broad-spectrum fungicide for the control of certain diseases in barley, corn, oats, peanuts, pecans, rice, soybeans and wheat (leaf and yellow rusts). Stratego®, contains two fungicides, and works by interfering with respiration in plant pathogenic fungi, inhibition of spore germination, and by blocking fungal growth;</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Quilt (Azoxystrobin+propiconazole).</td>
<td>SYNGENTA</td>
<td>For the control of barley and oat net blotch (Pyrenophora teres), barley scab (Ryncchosporium secalis), barley leaf rust (P. recondita f. sp. hordei); wheat scab (septoria sp), wheat tan spot (Pyrenophora tritici repentis), leaf and yellow rusts.</td>
<td></td>
</tr>
</tbody>
</table>
The above are commercial product names of formulations that use different active ingredients for controlling the three rusts in wheat. As a general rule, farmers should avoid using the same product or active ingredient repeatedly in order to avoid the fungus building up resistance or tolerance to the product. The best recommendation is to use alternate fungicides (different active ingredients) in order to prevent building resistance. Research should be in charge of periodically revise the list of new products to test and eventually register for use on Ethiopia.

Table 5. Commonly used fungicides and rate of application for the control of wheat rust

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Rate (litre or kg/ha)</th>
<th>Water (litre/ha)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillt 250 EC</td>
<td>0.5 litre</td>
<td></td>
<td>If the diseases occur earlier and there is an increasing trend, second application should be done 3-4 weeks after the first application.</td>
</tr>
<tr>
<td>Bumper 25EC</td>
<td>0.5 litre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baylton 25 WP</td>
<td>0.5 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noble 25 WP</td>
<td>0.5 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orius 25 EW</td>
<td>1 litre</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.4. WHEAT SMUTS

Wheat smuts were once a devastating disease worldwide, until the use of chemical seed treatment was discovered by Tillet in 1775 in France. Since then, seed treatment and use of resistant cultivars provided the best example of controlling plant diseases. With the persistent use of farmer-saved seed or seed exchange from farmer-to-farmer, seed is not routinely treated and the disease is becoming an issue of concern, since literally on all wheat fields, some smut infected wheat heads are commonly observed. This is one area where plant quarantine should offer advice and regulate the use of untreated seed.

There are four different smut diseases of wheat, namely: 1) Bunt or stinking smut, 2) loose smut, 3) flag smut and 4) karnal smut. Three of them directly affect the grain, while flag smut is found on the leaves of susceptible plants.

Stinking bunt may be produced by either of two related fungal species and it is also named as common bunt. The causal pathogen can be either Tilletia caries or T. foetida. When an infected head is observed, all the kernels are replaced by the spores of the fungus enclosed on the grain pericarp (grain coat). Affected plants may grow stunted and usually all the heads on the same plant may be affected, but not always. The mass of spores release a fish-like smell that can be detected at a distance. The contamination of sound, healthy grain with bunt spores reduces the quality of the grain during milling or for feed use. The problem of common bunt has been practically eradicated from most wheat growing areas of the world by the use of PCNB seed treatment. It is only in areas where seed treatment it is not practiced that the challenge persist (Fig 10 and 11).
Fig. 10 Stinking Smut of Wheat

Fig. 11. Stinking Smut of Wheat
Another disease that it is common in Ethiopia is loose smut produced by Ustilago tritici. The pathogen is carried internally by infected seeds. As the infected seed germinate, the fungal mycelium grows and becomes systemic in the plant. That is, every cell is infected during cell division of the plant as the fungus becomes established. At the time of heading, the entire spike is usually replaced by the fungus. The spores can easily by blown away by the wind and rain and infect new flowers of nearby plants to repeat the disease cycle. Loose smut can easily be controlled by using systemic fungicides as seed treatment. The most widely used fungicides are carboxyl and benomyl (Fig. 12).

Fig. 12. Loose Smut on Wheat

6.5. OTHER DISEASES OF WHEAT

Although not important in Ethiopia, there are other pathogenic organisms that may appear sporadically. Among them, the mildews and virus diseases are worth mentioning.

Powdery mildew is an important disease in Northern Europe, Russia and cooler parts of USA and Canada. Winter wheats appear to be more susceptible than spring wheats. Spores of the causal agent may be imported into Ethiopia on commercial grain shipments and may sporadically infect the wheat crop under unusually wet climate.

As for virus, at least two types of diseases can be mentioned, namely; Barley Yellow Dwarf Virus (BYDV) and Wheat Streak Mosaic Virus (WSMV). Both attack wheat and a range of other grass cereals and cultivated crops. Fortunately, these diseases are not considered to be of economic importance in Ethiopia.
6.6. INSECT PEST

- Diagnosis – scouting, matching symptoms to pest. Usually shoot fly can become a challenge when germination of seedlings is followed by a dry spell. If chemical control is required, use of Pyrethroids is recommended because they are environmentally friendly and offer good control. Consult nearby research centre or bureau of agriculture office for more information.
- Occasionally migratory pests such as army worms could become present and need immediate control since the wheat crop has very little biomass at early growth stages and can be devastated by the pest. Normally, government agencies at federal and regional level are responsible for the control of migratory pests.
- During later stages of wheat developmental stages, usually at booting, aphid infestations can become a problem under dry spells. These insects usually are controlled by rain, but if chemical control may become necessary, they can be controlled by application of ½ litre/ha of a Pyrethroids dissolved in 100 litre/ha of clean water.
- Consult your nearby research centre or bureau of agriculture for advice. Some of the herbicides recommended for insect The following herbicides are recommended for control of insects are mentioned below.

**Armyworm:** Spray 2-3 liters of Malathion 50 EC or 1.5 kg of Carbaryl powder in 250-400 liters of water/ha. 1 liter Fenetrithion 98% ULV or 1.5 liter Malathion 95% ULV may be applied on one hectare of crop land.

**Aphids:** 1 kg of Primor 50% WP or 1.5 litre of Chlorimyphos 50% EC in 300-500 litres water for one hectare.
Barley shoot fly: Diptrex 95 SP 1 kg/ha mixed with 200-300 liter water for one hectare. Grasshoppers: 250 g Carbaryl 85% WP mixed with 25-30 kg barley bran or wheat bran and spread on one hectare, or 0.75 liter of Fenethrithion 98% ULV for one hectare, or 1.5 liters of Malathion 95% ULV for one hectare.

### 7. HARVESTING AND THRESHING

It is advisable to harvest the wheat crop soon after maturity when its color is changed yellowish at a moisture level of 16-18% to avoid or minimize losses from shattering and sprouting, in case of unexpected strong wind and showers of rain. Traditionally, wheat is harvested manually and threshed on the ground using animal power. Farmers use the force of wind for winnowing and cleaning. Modern harvesting and threshing methods, however, involve use of combine harvesters and/or motor mounted threshers for stationary threshing.

There are various threshers in the market which can efficiently thresh the wheat crop. The Regional Bureaus of Agriculture should identify the most appropriate thresher for the region and target the FTCs in the wheat growing areas to operate at least one as a demonstration. Use of threshers is recommended to reduce broken grain damage and grain cracking which enhances insect pest proliferation.

### 8. STORAGE

Different storage pests can attack the wheat grain in the store. Proper drying of grains to about 12.5% moisture level is necessary before putting grains in storage facilities. Grain store should be constructed in a way that, it is rodent and bird proof and must be free of weevils before storing grain. It is advisable that the storage facility is placed in a well-ventilated area. When available, use new bags to keep the grain sound and safe. If grain is to be stored for more than 3 months, it should be treated before bagging with Actellic Supper or Malathion 5% dust and be kept on a place that is moisture free. Metal silos (hermetic) and insect proof bags are highly recommended to use when available.

### 9. SOIL FERTILITY AND WHEAT PRODUCTIVITY

Soil fertility and crop productivity are not the same. The fertility of a soil depends on many properties that can be classified as: 1) physical, 2) chemical and 3) biological

#### 9.1 PHYSICAL; WHAT IS SOIL?

- Soil is the top layer of the earth in which plants grow. A dark brown or black mixture usually of mineral and organic constituents, clay and rock particles,
living organisms and porosity that can be occupied by air and water.

- On Average, soil is made of 45% minerals (sand, clay, silt), 25% Water, 25% Air and 5% Organic Matter.

- Soil consists of all different minerals, mixed in different particle sizes such as sand, silt, clay and gravel in varying ratios. Higher amounts of each are termed as different types of soil. One with high amounts of sand would be sandy soil, silt soil, and clay soil respectively.

The physical properties of a soil encompass soil density, water holding capacity and rooting depth. By comparison, shallow soils, light textured soils and sandy soils will possess lower yield potential as those classified as heavier textured and deep soils mainly because of reduced water holding capacity and nutrient retention. When yield potential is reduced, the amount of nutrients to be added should also be reduced. The management of available moisture becomes critical and may require water-harvesting techniques such as tied ridges to enhance water infiltration and reduce soil erosion.

9.2. CHEMICALS; PLANTS REQUIRE 16 ELEMENTS FOR A HEALTHY GROWTH

The most important chemical properties refer to soil pH, P and K status and the level of soil organic matter content. The availability of other secondary major nutrients or micro nutrients may also affect soil fertility, but cannot be easily identified until the P and K levels are adequate. Most plant nutrients are readily available at pH range fluctuating around 6.2 to 7.2.

Plants require at least 16 elements for normal growth and for completion of their life cycle. Those used in the largest amounts, carbon, hydrogen and oxygen, are non-mineral elements supplied by air and water. The other 13 elements are taken up by plants only in mineral form from the soil or must be added as fertilizers (Fig 13).
Fig 13. Crops require macro, secondary and micro …

... NUTRIENTS

Crops (Plants) Require Essential Nutrients

Role of Nutrients

1. Structure
   Role of Nutrients involved in:

2. Energy Storage and Transfer

   Nitrogen : -NO₃, NH₄⁺ (nitrate, ammonium) amino acids, proteins, nucleic acids

   Sulfur : -SO₄²⁻ (sulfate); amino acids, proteins, enzyme activation

   Phosphorous : H₂PO₄⁻ (orthophosphate) ; ATP, ADP, NADPH, DNA, RNA,
   ................................................................................................................ Membranes

3. Charge Balance

   Potassium : K⁺ (potassium ion) enzyme activator, maintenance of osmotic
   potential; balance of charges; stomatal opening.

   Calcium : Ca²⁺ (calcium ion) component of cell walls; cell division and
   elongation; meristem function.

   Magnesium : Mg²⁺ (magnesium ion) center of chlorophyll molecule; .........................
   ................................................ important in enzymatic reactions....................
   .................................
Role of micro-nutrients

4. Enzyme activation + electron transport

Fe

Mn

Zn

B (H₃BO₃ - Boric Acid)

Cu

MoO₄⁻⁻ (molybdate)

Cl

9.2.1. NITROGEN CHARACTERIZATION

- Soil nitrogen is the most difficult nutrient to characterize: it occurs in organic and inorganic forms, in solution and as a gas, and as cation and an anion. Plant roots absorb only the inorganic forms.
- Common forms of N contained in fertilizers and fresh manures include ammonia, urea, ammonium and nitrate.
- Ammonia (NH₃), a gas, reacts rapidly with soil water to form the positively charged ammonium (NH₄⁺) cation.
- Urea -CO (NH₂)₂ - is rapidly converted from the solid or liquid form by the urease enzyme to the ammonia form. When urea or fresh manure is applied to the soil surface, N loss as gaseous ammonia is possible, especially with warm, dry conditions and a soil high pH. If incorporated or watered into the soil, urea is changed in rapid succession to ammonia and on to ammonium. The positive charged ammonium ion is held by the negative charges of the soil. This prevents ammonium leaching except in low CEC soils.

9.2.2. P, K NUTRIENTS

Much research has been done in understanding the soil processes involving phosphorous and potassium in relation to plant nutrition. It is well known that when adding P and K as water soluble fertilizers, a portion of that fertilizer will become fixed in the soil, thus, not immediately available to the plant roots. However, these nutrients
are not lost forever; the soil will release them back in small amounts over a prolonged period of time (Johnston 1994).

If P and K residual in the soil are beneficial, then, to what extent should residues be increased economically? Most crop plants exhibit predictable P and K demand for every ton/ha produced on above the ground biomass. Table 6 gives an indication for spring wheat. Once the critical levels of P and K have been attained, farmers should add every year an amount equivalent to the level removed by the crop they grow (nutrient level maintenance). If nutrients are not restored, yield will fall.

Table 6. Nutrient Up Take/Removed by the Wheat Crop*

<table>
<thead>
<tr>
<th>Type</th>
<th>Yield Ton/ha</th>
<th>Kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Spring Wheat</td>
<td>Biomass 9.0</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Grain 4.5</td>
<td>100</td>
</tr>
</tbody>
</table>

*= IFA World Fertilizer Use Manual 1992

Potassium the same as ammonium have a single positive electromagnetic charge. The remaining cations have two or more positive charges. The higher the charge of a cation, the more strongly it is attracted to the negative charge sites of the soil. This means that K⁺ and NH₄⁺ can be displaced from their electromagnetic linkage with the soil by Ca⁺⁺, Mg⁺⁺ etc, which have more than one positive electromagnetic charge. When the sum of the positively charged nutrients exceeds the soil’s capacity to hold nutrients, K⁺ and NH₄⁺ will leach before nutrients such as Ca⁺⁺ and Mg⁺⁺.

9.2.3. SECONDARY NUTRIENTS AND TRACE ELEMENTS

Once major nutrient deficiencies are corrected, other secondary elements such as Calcium, Magnesium, and trace elements such as Manganese, Zinc, Iron Copper and Boron may show deficiency which was masked before by the major nutrients. It is not easy to identify such deficiencies when the other major nutrients are limiting.

In soil science, cation-exchange capacity (CEC) is the maximum quantity of total cations, of any class, that a soil is capable of holding, at a given pH value, for exchanging with the soil solution.

- CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination.
• It is expressed as milliequivalent of hydrogen per 100 g (meq+/100g), or the SI unit centi-mol per kg (cmol+/kg). The numeric expression is coincident in both units.

• Clay and humus (which are of colloidal size) have electrostatic surface charges that attract the solution ions, and hold them. This holding capacity varies for the different clay types and clay-blends present in soil, and is very dependent of the proportion of clay + humus that is present in a particular soil. A way to increase CEC is to favor the formation of humus. In general, the higher the CEC, the higher the soil fertility.

9.3. BIOLOGICAL PROPERTIES

Soil pH plays the greatest role in determining the biological properties of the soil by allowing the population of soil micro-organisms (bacteria and fungi) to prosper or diminish depending on pH levels. Soil microbia are responsible for the nitrification process. Generally, the highest population of these micro-organisms occurs at soil pH that ranges around 6.2 to 7.2. As soils become more acidic or alkaline, the microbial population diminishes and nitrification becomes impaired. Fig 14 presents one example to show how bacterial population tends to become reduced under pH below 5 (upper circle) and molybdenum becomes insoluble (lower circle), thus stopping the nitrogen fixation of Rhyzobium. That is the reason why legumes do not normally prosper under very acidic soils. Also, Fig 15 shows the effect of soil pH on N nitrification.

In particular N biological fixation becomes no longer possible in acidic soils

Fig 14. On Soil Biological Life
The more acidic the soil... the more difficult the nitrification process

When smallholder farmers, such as in sub-Saharan Africa remove nutrients during harvest, this brings down soil pH and impairs nutrient uptake. Cultivation removes from the fields Ca, Mg; K..., lowers the soil content and so lowers the soil pH. What we do not replace, we mine. When farmers remove more minerals than what they replace, the system becomes an extractive system where soil acidification jeopardizes the yield, the quality and the future of cultivation.

Conversely, when farmers allow the crop residues to be incorporated in the soil as well as organic manures, the soil microbial population will use them as food source and its activity will produce soil organic matter or humus. Humus can assist in increasing the water holding capacity as well as the cation exchange capacity of the soil which in turn allow the retention of P, K, and other nutrients to be available for the plants.

**9.4. CROP PRODUCTIVITY**

Once soil fertility is brought to near optimum level, crop productivity may still be limited by other constraints such as climatic, nitrogen level and crop management. Farmers can do nothing about climate, but they can do a lot to improve N status in the soil and good husbandry practices such as timely weed, disease and insect control.

Nitrogen is required by plants in readily assimilable forms. This nitrogen is taken up by the roots of the plants either as nitrate (NO$_3^-$) or ammonium (NH$_4^+$). When the supply of N in the soil is too small, yields are very low. In order to increase the
yield, N needs to be supplemented either by organic manures or chemical fertilizers.

Most of the N in the soil is stored as organic compound in the humus fraction and as this, it is not readily available when needed. Also, some is stored as organic compound in the compost or manures the farmer may apply. Microbial activity in the soil will decompose these organic N to produce first NH$_3$ (ammonia gas), then NH$_4^+$ (ammonium) and then NO$_3^-$ nitrate ions. NO$_3^-$ is very soluble in water and whenever excess rain leads to drainage, NO$_3^-$ will leach out with the water.

Adding organic matter to soils rarely provides enough N to meet the need for high grain yield. Usually, the optimum soil conditions for decomposition of organic matter do not match with the crop N demand, thus; most of the NO$_3^-$ from organic sources will remain mobile in the soil and at risk of leaching. For this reason, N fertilizer applied at correct time and in the right amount to an actively growing crop will achieve optimum yield and very little NO$_3^-$ will remain in the soil after harvest.
10. REFERENCES


