Wollo University

Ecological Organic Agriculture initiative for Africa SDC-BvAT (EOA-Phase II) project -Pillar I.

Guideline for Organic Potato (*Solanum tuberosum* L.) Production in Ethiopia

Prepared

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1. Introduction

1.1 The Potato Crop

Potato (*Solanum tuberosum*), a member of the Solanaceae family of flowering plants, popularly known as 'The king of vegetables', is the fourth most produced food crop and the first non-cereal crop in the world. It is an extremely drought susceptible crop, which has primarily been attributed to its shallow root system (Fig. 1). Potato is a staple food with its high potentiality in fighting malnutrition in the world since potato tubers are known sources of vitamins, proteins, carbohydrates and minerals. When eaten with its skin, a single medium-sized potato of 150 g provides nearly half the daily adult requirement (100 mg) of vitamin C.

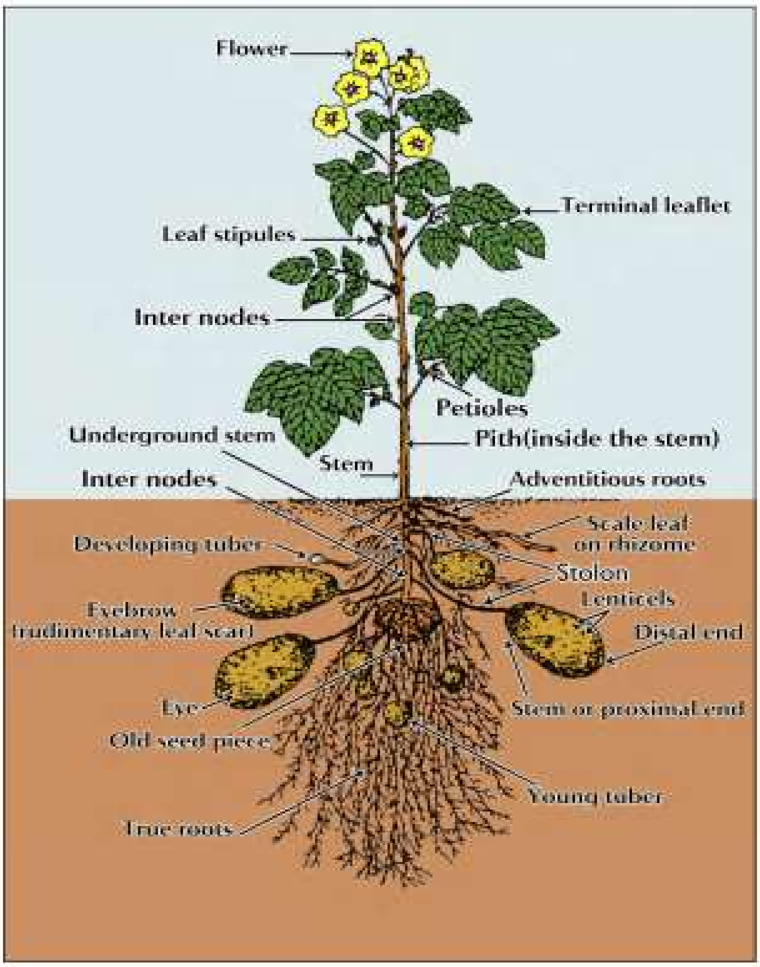

Figure 1. Morphology of the potato crop

It originated and was first domesticated in the Andes Mountains of South America. Potato was introduced to Ethiopia in 1858 by a German Botanist, Wilhelm Schimper, and rapidly adopted by Ethiopian farmers. Ethiopia has possibly the greatest potential for potato production. About 70% of the available agricultural land is located in an altitude of 1800-2500 m.a.s.l. and receives an annual rain fall of more than 600mm which is suitable for potato production. Since the highlands are also home to almost 90 percent of Ethiopia's population, the potato could play a key role in ensuring national food security. It is an extremely important crop for countries such as Ethiopia, where inadequate protein and supplies of calories are apparent nutritional problems. It also provides employment opportunities in the production, processing, and marketing chains.

1.2 Site selection

Criteria for Site Selection:

- Has the site been used for production of potato or crops in the Solanaceae family such as tomato and capsicum for the last 3 seasons and were there serious diseases/pest incidences?
- Is the site prone to run off from fields where potato or crops from Solanaceae family have been cultivated before?
- Is the surface topography gently sloping to allow proper drainage?

Nematodes, Fusarium wilt and Bacterial wilt are serious soil borne potato pests and diseases. The disease and pest infestation may have been from previous potato or related crops. They could also have been washed down to the farm from other infected farmer fields.

When potatoes are planted on infected soil it will lead to high yield losses. This can also result in excessive use of pesticides and fungicides, which is harmful to both humans and beneficial organisms.

1.2.1 Soil

Potato can be grown in a wide range of soil types but well-drained loamy to sandy loam soil is the most recommended. It also grows well with adequate fertilization even in sandy soils. Black soils that have undesirable physical and chemical qualities should be avoided. The pH should range between 5.0 and 7.0 but the ideal pH should be 5.5. The soil should be deep, light, loose and well drained but able to retain moisture. It should also be free from pests and diseases such as bacterial wilt, nematodes and blight. Blight requires a living host to survive between seasons. Partially decomposed tubers, which give rise to plants known as ‘volunteers’, infected with late blight, are a major source of blight infestation in subsequent potato crops. Poultry can be used to remove the partially decomposed tubers from the field after the crop has been harvested.

1.2.2 Altitude and Topography

Potatoes are grown mainly in the high altitude areas between 1,500 and 3,000 meters a.s.l. The low lying areas which are likely to be drained with surface run offs from other higher potato growing zones should be avoided. This is because other than carrying away soil nutrients, run off may contain soil borne disease caused by pathogens such as bacterial wilt, Fusarium wilt, blights and soil borne pests like nematodes.

1.2.3 Temperature

Potatoes require an average daily temperature of between 15 to 18^0 C. Temperatures above 21^0 C have adverse effects on growth of potato as it leads to sharp decline in tuberization. Above 29^0C there is little or no tuber formation. The cooler the soil temperature, the more rapid the initiation of tubers and the greater the number of tubers formed. Optimum soil temperature for tuber formation is 15-24^0C. Higher temperatures reduce tuber formation.

One way of avoiding high soil temperatures is timely ridging and adequate ridge volumes. It is common practice for small holder farmers to mulch their potato garden with maize stovers to reduce soil temperature. This is done mostly when the potatoes are planted before the onset of rains. Moist and cloudy conditions, high temperatures and humidity lead to insect pest, foliar disease and virus epidemics.

1.2.4 Soil moisture and irrigation requirement

Potatoes require a good supply of soil moisture to maximize the yields and quality. They require between 400 and 800 mm of rains during the growth period. Whenever the roots have inadequate water, consequently the leaves and stems are subjected to moisture stress; the growth rate is reduced affecting yields and quality of tubers. The soil moisture content can be enhanced by:

- Addition of manure to the seed bed
- Cutting furrows along the contours to harvest and conserve surface water
- Deep ploughing to loosen an adequate amount of soils for water storage
- Mulching with grass species and maize stover after planting
- Hilling and earthling up to increase surface water harvesting in the furrows and reduce chances of surface erosion

It is best to plant potatoes into a soil with sufficient moisture to get the crop started. Irrigating newly planted potatoes will cool the soil, seal the soil to aeration, and get weeds started. Under warm conditions it will permit anaerobic bacteria to start seed breakdown. Unless there has been sufficient rainfall to wet the soil to a depth of 30 cm, it is useful to pre-irrigate. Having sufficient moisture will also make the soil easier to till, prevent clod formation, and assist in early season weed control. Soil moisture of 70% to 80% field capacity is considered ideal for most soils.

Soil moisture from rains can be supplemented by irrigation. The irrigation methods available are drip, sprinkler and furrow. Drip irrigation is more effective; however it is more expensive than sprinkler irrigation and may not contribute to establishment and spread of foliar diseases. Sprinkler irrigation may not cover all parts of the field adequately and may spread foliar diseases like late blights by extending the duration of availability of moisture in the canopy. Infections in the upper leaves can be spread to the lower leaves as water drains down the crop. Furrow irrigation can also be used but if the drainage along the furrows is not well maintained, this may lead to water logging, inducing anaerobic conditions and spread of soil borne disease caused by pathogens in the field.

The most critical stages for water requirements are: emergence, tuber setting and tuber bulking. Potatoes are sensitive to moisture stress especially after tuber initiation which occurs during flowering; lack of water during this stage leads to misshapen tubers and low yields (Otieno et al., 2015). Depending on the crop growth period, a farmer should plan for irrigation based on these critical periods which should be done either early in the morning or late afternoon to minimize evaporation.

Figure 2. Irrigation methods for potato crop (Furrow, Sprinkler and Drip)

1.3 Nutrient Management

Nutrient management for potatoes starts immediately after site selection. This involves using simple observations to identify symptoms of nutrient deficiency or preferably, sampling soils, conducting chemical analysis to quantify the nutrients, and linking deficiency syndromes and analysis results with what needs to be done to improve nutrients supply. The potato plant has a shallow root system; nonetheless it has a high demand for nutrients.

Organic growers use a variety of fertilizers during the growing season after planting seed Potatoes. Using a cotton meal, bone meal, and green sand increases soil acidity and provides nitrogen, potassium, and phosphorus. In combination, kelp detects small amounts of minerals in food. When the soil is prepared for most vegetable crops, the fertilizer is added to the soil. When the soil is ready from above, the fertilizer settles on top of the soil.

In addition to the essential nutrients, this organic matter is rich in secondary and micronutrients, which significantly increase crop yields, soil fertility, and physical condition. Soil physical condition is improved by water infiltration, water storage capacity, aeration, permeability, soil aggregation, root depth, reduction of soil crusting, bulk density, runoff, and erosion.

In general, soil fertility in a potato farm can be improved and maintained through interventions such as:

- Application of mulches
- Application of Bio-fertilizer (compost and vermicompost)

- Application of Farm Yard Manure (FYM)
- Application of Green manure
- Application of liquid organic fertilizer (Vermiwash, Vermicompost tea)
- Planting of Nitrogen fixing plants like legumes
- Practicing crop rotation and other recommended cultural practices

Note:

- Avoid manure from livestock fed with potato /Solanaceae crop residues
- Organic fertilizers should not be made using potato crop residue

Manure as an organic source of nutrients contains N, P and K if well prepared. Apply manure at the rate of 5-10 tons/ha (2-4 tons/acre). Ensure the manure is well prepared and ready for use by 'feeling' with your hands. It should feel like 'cotton', crumbles easily and when dry it's 'floury'. The best manure has the following characteristics;

- Not made from livestock fed with potato family crop residue. This is to reduce chances of spread of bacterial wilt diseases.
- Not made from compost with crop residue from potato family.
- Well-decomposed manure so as to prevent occurrence of black leg and black scurf diseases.
- Free from potato pests and other diseases.

Steps in applying manure uniformly on a potato farm are as outlined below;

- Divide the land into 4 equal quarters.
- Divide available manure into 4 equal portions.
- Allocate each quarter portion of manure to each quarter portion of land.
- Apply each portion of manure to the allocated portion of land.
- If manure has been placed in ridges or furrows, mix it or cover it lightly with soil before placing fertilizers.

Application of manure by spreading: Manure can be applied on land just after ploughing before harrowing. If the amount required is available, spread 2-4 tons/acre. Then incorporate into the soil during harrowing and furrow preparation. You can also spread it in the field using a fork (Fig.3).

Figure 3. Manure/compost application

1.4. Planting

Planting should coincide with start of the rains so as to maximize water utilization under rained system. There exists different recommendation on planting potatoes which include: planting on ridges or furrows, spacing, manure and fertilizer use, amount of seed needed and depth of covering. The seed should be planted with the sprouts facing up whether in ridges or in furrows. The spacing between plants should be 30cm.

Furrows

Furrows are prepared after harrowing and it should be opened just before planting at the depth of between 8 and 12 cm deep. The soils should be well drained and the area should not be water logged. When potatoes are planted by hand, a range of row/drill spacing options are available.

Three values are typical, 65 cm, 75 cm and 90 cm. Varieties with a short growing season should be planted at 65 cm inter row spacing, since these types generally produce smaller canopies.

Ridges

Prepare ridges after harrowing. Ridges which are raised planting beds are used for planting where there is possibility of water logging. At ridging up, a narrow top on the drill is desirable in wet conditions as it facilitates water to run down the outside allowing the potato crop to grow on elevated beds. In dry conditions, a flatter, wider drill will conserve more moisture(Fig.4).

Figure 4. Planting methods of potato tuber

2. Weeds

Potato yield reductions due to weeds of between 14 and 80% have been recorded □ □ Perennial grass and broad-leaved weeds are a particular problem in potato crops It is important to remove couch before or soon after crop emergence to minimize yield loss. Couch that regenerates after early removal will cause less damage .Tall weeds such as fat-hen are the main annual species that affect potatoes A single weeding at between 3 and 6 weeks after crop planting has been shown to prevent yield losses due to annual weeds. Chitting the potato tubers aids early establishment Potato cultivars that emerge early, grow rapidly and develop a dense leaf canopy suppress weeds better.

Weed management□

The normal cultural practice is to ridge shortly after planting and let the ridges settle. Weed control is then applied ten days after planting using chain harrows, ridgers or purpose built weeders. The number of passes depends on weed density. Where a second harrowing is needed this may be carried out at or shortly before crop emergence. Thermal weed control can also be used to control seedling weeds prior to crop emergence. Cultivation's are best done when weeds are small and unlikely to re-establish Rolling cultivators used by some growers have tines that weed between the rows and rolling star-shaped tines to cultivate the sides of the ridges. The ridges are then rebuilt by ridging bodies that follow the tines .Rotary cultivation are left until just prior to crop emergence. The need for subsequent repeat treatments depends on the timing of the first cultivation and the weed pressure. A harrow can be used to dislodge weeds from the ridge tops unless soil capping is a problem. Later a ridger is used to return the soil to the ridges. Cover-crops inter-seeded at ridging or 3, 4 or 5 weeks after crop planting have given good weed suppression but can reduce crop yield.

3. Potato Diseases

The potato, *Solanum tuberosum* L., is one of the most important and widely distributed food and cash crop in Ethiopia. It plays a key role in contributing towards food and nutrition security, poverty eradication and employment creation. The potato consumption is growing tremendously and this is attributed to urbanization and population growth and changing consumer tastes and preferences towards consuming value added products such as chips and crisps. However, the current productivity levels are low, averaging below 10 tons per ha vis-a-vis 40 tons per ha achievable under recommended agronomic practices. Improvement in production and use of certified seed, optimization of use of inputs, disease control, and improved storage and marketing has the potential to transform the subsector into a more competitive industry.

Lack of proper storage facilities on-farm and after harvest has led to huge losses during marketing. Farmers do not store potatoes due to lack of technical know-how; need for immediate cash and poor quality produce due to pests, diseases or mechanical damage. Potato pests and diseases results into high yield losses both in the field and during storage.

The only option farmers practicing in the medium and long term program are to increase productivity per hectare and to reduce pre- and post-harvesting losses. Important fungus diseases that contribute to this loss are late blight, verticillium wilt, common scab, early blight, and rhizoctonia canker. Blackleg and ring rot are the most serious bacterial diseases. The prevention of disease occurrence and spread is of primary importance to successful potato production. Diseases develop in the field, in storage, in transit, in the market, and in the home. Disease loss has been reduced, however, by the use of resistant varieties. Planting potato varieties that are resistant to one or more diseases is one of the effective means of combating potato-disease losses.

Currently the development of sustainable agricultural systems relies on the implementation of integrated pest management (IPM) practices. Modern pest and disease control goals include not only successful suppression of causal agents, but a reduction in the use of synthetic pesticides and farming methods that negatively impact on the environment and human health. Successful IPM relies heavily on early and accurate detection of pests and diseases and their causal agents. In this way, our hope is that this field guide will contribute to the development and implementation of IPM programs that ensure sustainable agricultural production, healthy soil, water and natural environments, food safety and human health.

Organic farmers are responsible to protect the organic fields from being sprayed with synthetic pesticides. Pest and disease management consists of a range of activities that support each other. Most management practices are long-term activities that aim at preventing pests and diseases from affecting a crop. Management focuses on keeping existing pest populations and diseases low level Control on the other is a short-term activity and focuses on killing pest and disease. The general approach in organic agriculture to deal with the causes of a problem rather than treating the symptoms also applies for pest and diseases. Therefore, management is of a much higher priority than control. This document describes preventive practices, as well as control practices using cultural, mechanical control and natural pesticides.

Prevention practice

Knowledge about plant health and pest and disease ecology helps the farmer to choose effective preventive crop protection measures. As many factors influence the development of pest and disease, it's crucial to step in at the most sensitive points. This can be accomplished through the right timing of management practices, a suitable combination of different methods, or the choice of a selective method. Some important preventive crop protection measures are as follows:

1) **Selection of adapted and resistant varieties:** → Choose varieties which are well adapted to the local environmental conditions (temperature, nutrient supply, pests and disease pressure), as it allows them to grow healthy and makes them stronger against infections of pests and diseases.

2) **Selection of clean seed and planting material: -**Use safe seeds which have been inspected for pathogens and weeds at all stages of production. Use planting material from safe and known sources.
3) **Use of suitable cropping system: -**
    a. Mixed cropping systems: can limit pest and disease pressure as the pest has less host plants to feed on and more beneficial insect life in a diverse system.
    b. Crop rotation: reduces the chances of soil borne diseases and increases soil fertility.
    c. Green manuring and cover crops: increases the biological activity in the soil and can enhance the presence of beneficial organisms (but also of pests; therefore a careful selection of the proper species is needed).
4) **Input of organic matter:-**increases micro-organism density and activity in the soil, thus decreasing population densities of pathogenic and soil borne fungi. Stabilizes soil structure and thus improves aeration and infiltration of water.
5) **Application of suitable soil cultivation methods:** Facilitates the decomposition of infected plant parts, regulates weeds which serve as hosts for pests and diseases and protects the micro-organisms which regulate soil borne diseases.
6) **Use of good water management:** - No water logging: causes stress to the plant, which encourages pathogens infections. And avoid water on the foliage, as water borne disease spread with droplets and fungal disease germinate in water.
7) **Conservation and promotion of natural enemies: -** Provide an ideal habitat for natural enemies to grow and reproduce and avoid using products which harm natural enemies.
8) **Selection of optimum planting time and spacing: -** Most pests or diseases attack the plant only in a certain life stage; therefore it's crucial that this vulnerable life stage doesn't correspond with the period of high pest density and thus that the optimal planting time is chosen.

    Sufficient distance between the plants reduces the spread of a disease and good aeration of the plants allows leaves to dry off faster, which hinders pathogen development and infection.

9) **Use of proper sanitation measures: -** Remove infected plant parts (leaves, fruits) from the ground to prevent the disease from spreading and eliminate residues of infected plants after harvesting.

Potato diseases identification and diagnosis are critical to implementing effective control measures. Luckily, there are many technical aids available to scientists, field scouts, agronomists and farmers to assist identification. In the visual identification of potato pests and diseases, a diagnostician needs a clear indication of symptoms, both written and visual.

This guide line contains good overviews of major potato diseases and disorders widely occurred in Ethiopia. We have attempted to include all the pests, diseases and disorders that are most likely to be encountered in the country. We listed all known pests and diseases and ranked them in order of importance. Those considered of minor importance were omitted.

The guide line has been prepared using a format that will enable quick access to the most relevant information on all of the major diseases, pests and disorders of potatoes. Each pest includes the basic information on symptoms (including photographs), status of the disease, life cycle and conditions that promote disease and management /control methods.

Nine fungal, one root nematode, two bacterial and four viral diseases were recorded on potato in Ethiopia. Early blight (*Alternaria solani*), Bacterial wilt (*Ralstonia solancearum*), late blight (*Phytophthora infestans*) and viruses were the most widely distributed potato diseases in all of the areas. Details of some of important potato diseases are presented as follows.

Late Blight of Potato

Causal organisms – *Phytophthora infestans*

Late blight has the potential to be an extremely destructive disease of potatoes. The fungus attacks all parts of the plant.

Pathogen

The late blight fungus overwinters as mycelium in seed tubers, cull pile tubers or tubers left in the field after harvest. Potato plants originating from infected tubers are the main sources of inoculum during the growing season. Millions of spores, called “sporangia,” are produced on lesions of infected plants. Sporangia are spread mainly by rain or wind to healthy plants.

Oospores are thick-walled, survive in the soil for several years in a dormant state and can initiate late blight infections

Symptoms

Foliage: Symptoms of late blight appear as small light- to dark-green water-soaked spots, often with a chlorotic halo (Fig. 1). Lesions enlarge rapidly and turn brown or purplish black. The lesions are not limited by veins, and they coalesce as new infections occur, blighting and killing the entire leaf within a few days. If the lesions dry out, the leaf becomes very brittle (Fig 5 A & B). Lesions may occur on petioles or stems, making detection difficult because leaves still appear green and healthy. Infected stems turn black with rot but are not as spongy as stems infected with blackleg or soft rot bacteria (Fig. 5 C). During periods of high relative humidity and leaf wetness, lesions may be bordered or totally covered by cotton like white moldy growth on the underside of the leaf or on the stems (Fig. 5 D). High temperature and dry conditions will slow or temporarily stop disease development, but as conditions become moist and cool, the fungus resumes growth and disease development continues.

Figure 5 A .Late blight lesions with chlorotic halo. Figure 5 B.Late blight lesion that has dried and become brittle.

Figure 5 C. Symptoms of late blight on stem sporulation

Figure 5 D. Late blight on stem leaves with

Figure 5 D.Symptoms of late blight on lower surface of leaflets.

Tubers: Exterior surfaces of late blight-infected tubers have irregularly shaped, small to large, slightly sunken areas of leathery, purplish-brown skin. Below the skin, potato tissues are tan or light brown in colour with a dry granular rot extending into the tubers (Fig 6).

Figure 6. External and internal symptoms of late blight on a tuber.

Disease Cycle

The fungus survives between potato crops primarily in infected tubers (as seed, culls, volunteers). When infected tubers sprout the following cropping season, the pathogen can grow from the tubers into the newly formed plants. Under cool, moist conditions, the fungus can sporulate (reproduces) on the foliage of these plants. If the spores become airborne, they can be carried to neighboring plants or nearby fields. As long as spores continue to form on diseased foliage, infections will occur throughout the growing season.

When spores are washed off the foliage by rainfall, tubers can become infected. Tubers also may become infected at harvest through contact with spores on infected vines. Tubers inadequately covered by soil are more likely to be infected than those that are properly hilled. If the fungus sporulates on tubers in storage, any movement of those tubers can cause the sporangia to be disseminated and allow infections to occur on other tubers.

Conditions That Promote Disease

Ideal conditions that promote for late blight are cool nights (50 to 60°F) and warm days (60 to 70°F) accompanied by fog, rain, or long periods of leaf wetness. Conditions must remain moist for 7 to 10 hours for spore production to occur.

Management

- Use high-quality disease-free seed.
- Use resistant cultivars where possible
- Choose fields with good air movement and well-drained soil.
- Rotating potatoes into new areas of the garden every year is a good idea.
- Avoid overhead watering. Avoid working with plants (e.g., staking, suckering, harvesting) when they are wet, since this pathogen can be spread during these types of activities.
- Maintain good air circulation in storage.
- Destroy cull piles and volunteers.
- Do not over fertilize with nitrogen.
- Make sure plants are adequately hilled.
- Scout suspect areas such as low-lying areas, areas near woods, and areas that tend to dry out more slowly.

- Harvest only when vines are dead.
- Avoid harvesting under wet conditions.
- Pull all volunteer potato plants, as well as any Solanaceous weeds that grow in and around the garden.

Early Blight of Potato

Causal Organism – *Alternaria solani*

The early blight fungus is found in most soils where potatoes are grown, and the disease develops every season. The fungus overwinters in the soil on dead leaves, vines or infected tubers

Symptoms

Foliage: Foliar symptoms first appear as small circular dark spots on lower, older leaves (Fig. 7). Lesions are dark brown to black and have concentric rings, resulting in a target like appearance within the dead tissue. As lesions coalesce, they become restricted by large leaf veins and take on an angular shape (Fig. 8). Lesions may be surrounded by a chlorotic border. Infection also may occur on stems, resulting in small dark lesions that do not cause significant injury. s old and new lesions develop, the whole leaf becomes chlorotic, then necrotic (Fig.9), often remaining attached to the stem as a desiccated, brown to black parchment.

Tubers: Circular or irregularly shaped, dark, sunken lesions on tuber surfaces with raised, purple to dark brown borders can be seen at, or after, harvest (Fig. 10). Below the tuber surface, tissues are dry, leathery to corky and dark brown with yellowish, water-soaked borders. The dry rot phase of tuber symptoms develops slowly.

Figure 7. Early blight lesions on leaves.

Figure 8. Early blight lesions on leaves and stem

Figure 9. Severe symptoms of early blight on plant

. Figure 10.*Alternaria*tuber symptoms.

Disease Cycle

The fungus overwinters in soil, plant debris, infected tubers, or other solanaceous hosts. The disease usually occurs along fields adjacent to potato fields from the previous season. Early blight usually occurs late in the season. Spores are produced on the older lesions and are dispersed to other plants by wind, rain, irrigation water, or mechanical means throughout the later part of the growing season. The disease therefore increases more rapidly after the plants flower. Tuber infection occurs during harvesting and is most severe when the tubers are bruised or wounded.

Conditions that Promote Disease

Alternating wet and dry conditions with long periods of high relative humidity and leaf wetness promote disease development. The disease is more severe on potatoes that are stressed from poor nutrition, insect damage, drought, or other stresses. Disease development increases as senescence begins.

Management

- Rotate away from the previous year's potato fields.
- Plant cultivars with some degree of resistance, since early-maturing cultivars are more susceptible than late maturing cultivars.
- Use of resistant cultivar.
- Use cultural practices that promote tuber skin set.
- Use harvesting methods that minimize skinning and bruising.
- Reduction of inoculum sources with proper crop rotation, crop debris disposal, weed management and the use of healthy seed will lessen the occurrence and impact of the disease.
- Proper crop fertilization, water supply, cultivation, disease management and other crop and land management strategies that improve crop health will limit the occurrence and damage due to early blight.

***Verticillium Wilt* (Early Dying)**

Causal Organism – *Verticillium dahliae*

Affects **-** foliage and tuber

Symptoms

Foliage: Verticillium wilt causes early senescence of plants (Fig. 11). Symptoms often are difficult to distinguish from normal senescence, since they are expressed typically during the later part of the season. Foliar symptoms appear as uneven chlorosis and wilting of lower leaves (Fig. 12). Either top leaves, single stems, or leaves on one side of the stem may begin to wilt first (Fig. 13); however, the stem remains erect as the leaves wilt, turn yellow, and eventually die. Tan discoloration of the vascular tissues usually can be seen when the stem is cut in cross section or in a longitudinal section near its base (Fig. 14).

Tubers: Some tubers from infected plants may develop a light brown discoloration in the ascular tissue at the stem end, which usually does not extend through the tuber (Fig. 15)

Figure 11.Verticillium wilt, advanced senescence.

Figure 12. Verticillium wilts with wilting on lower leaves and uneven chlorosis.

Figure 13. Verticillium wilt with chlorosis of one side of plant.

Figure 14. Verticillium wilt with discoloration of vascular tissue

Figure 15. Verticillium wilts with discoloration of tuber vascular tissue.

Disease Cycle

The fungus survives in the soil, on the seed piece, or in infected plant debris, and can persist in the soil for many years. Infection occurs through root hairs, wounds, or sprouts, and then continues into the vascular system. As infected plants die, the fungus grows through all of the dying tissues and forms infective propagules that are released into the soil.

Conditions that Promote Disease

That Promote Disease is elevated temperature and moisture during the early part of the growing season, followed by drought, promote Verticillium. Continuous potato cropping and planting susceptible cultivars (Kennebec and Superior) increase the pathogen population

Management

- Do not plant susceptible cultivars.
- Rotate potatoes with cereals, grasses, or legumes.
- Avoid rotation with highly susceptible Solanaceous crops such as eggplant or tomato.
- Plant resistant cultivars such as Elba or moderately resistant cultivars.
- Control weeds.
- Control nematode populations.
- Avoid over-irrigation.
- Use green manure crops such as corn, oats, peas, rape, rye, and Sudan grass to reduce the pathogen population

Rhizoctonia Canker (Black Scurf)

Causal Organism – *Rhizoctonia solani*

Symptoms

Stems and stolon: Characteristic symptoms of Rhizoctonia are brownish black sunken lesions on underground stems and stolon (Fig. 16). The disease may cause non uniform stands of weak, spindly-looking plants. Early-season infections often result in the pruning of young stolon where lesions girdle them completely. Dark stem lesions occurring below the soil line may girdle the main stem, resulting in yellowish or purplish leaves that curl upwards. On relatively healthy-looking plants, aerial tubers may form (Fig. 17). During midseason, the fungus may develop a white powdery mold growth on the stems that extends just above the soil line (Fig. 18). This often is associated with stem lesions below the ground. Tubers may be misshapen, cracked, or may develop a rust like skin (Fig. 19).

Figure 16. Rhizoctonia cankers girdling the stem.

Figure 17. Rhizoctonia aerial tubers.

Figure 18. Rhizoctonia mycelium growth on lower stem.

Figure 19. Rhizoctonia cracks and russetlike skin.

Disease Cycle

The fungus survives in soil with decomposing plant residue. Sclerotia can survive on infected tubers and persist in the soil for many years. Sclerotia germinate and invade stems or sprouts. Roots and stolons are invaded as they develop throughout the growing season. Sclerotia can form on new tubers at any time, but maximum development occurs as tubers remain in the soil after the death of the vines.

Conditions that Promote Disease

Ideal conditions for Rhizoctonia are cool (55 to 60°F), moist soils. The pathogen population increases with continuous potato cropping.

Management

- Use disease-free seed.
- Warm the seed prior to planting.
- Plant in warm (60°F) soil.
- Any practice that promotes rapid emergence will reduce attack by Rhizoctonia.
- Use proper crop rotation, preferably grasses or cereals

Bacterial Wilt of Potato

Causal organisms – *Ralstonia solanacearum*

The disease is present in the tropics and in the warmer climates throughout the world.

Symptoms

Bacterial wilt on potato and other solanaceous crops appears as a sudden wilt. Infected young plants die rapidly (Fig.20). Older plants first show wilting of the youngest leaves, or one sided wilting and stunting, and finally the plants wilt permanently and die. The vascular tissues of stems, roots, and tubers turn brown, and in cross sections they ooze whitish bacterial exudates (Fig.21). The eyes and the vascular tissue of infected tubers appear greyish-brown. Glistening beads of bacterial slime ooze freely from the vascular tissue of freshly cut stems and tubers. Sticky exudates may form at tuber eyes or at the stem end of the tuber (Fig. 22).

Figure 20. Potato plant showing typical bacterial wilt symptoms

Figure 21. The vascular ring shows a grey-brown discoloration. A pale bacterial slime oozes freely from the diseased tissue.

Figure 22. Rotting of and cavity formation along the ring of vessels in an infected potato tuber

The bacterium can be soil- and seed-borne. *Ralstonia solanacearum* bacteria overwinter in diseased plants or plant debris, in vegetative propagative organs, such as potato tubers, on the seeds of some crops, in wild host plants, and probably in the soil. It survives poorly in the absence of water.

Bacteria are spread through the soil water, through infected or contaminated seeds, tubers, and transplants, by contaminated knives used for cutting tubers or for pruning suckers, and, in some instances, by insect. Contaminated irrigation water may also be a significant source of infection.

Conditions that Promote Disease

High temperatures and high soil moisture favour the development of *Ralstonia solanacearum*. It invades a plant mainly through injured roots. Once inside the plant, the bacteria multiply and move to the vascular tissues. Infection eventually leads to wilting of the plant as the xylem vessels get blocked by the bacterium. The end result is plant death. Bacteria can move from the roots of infected plants to the roots of nearby healthy plants.

Management

The control of bacterial wilt of potato and other solanaceous plants depends mostly on

- The use of resistant varieties, when available, and
- Proper crop rotation or fallow.
- Only bacteria-free propagative material should be used, and
- Tools, such as knives, should be disinfested when moving from one plant to another.

- Infested soils should be kept fallow for about a year and frequently disked during the dry season to accelerate the desiccation of plant material and the death of wilt bacteria.

Blackleg, Aerial Stem Rot and Tuber Soft Rot

Causal organism – *Erwinia* carotovora

Bacterial soft rots occur worldwide and cause serious diseases of crops in the field, in transit, and especially in storage. They cause a greater total loss of produce than any other bacterial disease.

Symptom

Stems infected with blackleg have an inky black decay that usually begins at the decaying seed piece (Figs. 23 - 26). Soft-rot symptoms begin as a small water-soaked lesion, which enlarges rapidly in diameter and in depth. Leaves of infected plants tend to roll upward at the margins, become chlorotic, and wilt (Fig. 27). Plants are often stunted and appear stiff before wilting and eventually dying (Fig. 28). Tubers with soft rot have brown, slightly sunken, water-soaked areas on the surface (Fig. 29). Advanced disease symptoms include slimy, completely rotted tissues with a foul odor (Fig. 30).

Figure 23. Initial lesions on stems first

Figure 24. Eventually, the rotten tissue acquires the typical blackleg colour.

Figure 25. Aerial rot may spread to most of the plant.

Figure 26. Infection has moved down the stem and probably into daughter tubers.

Figure 27.Potato plants in the field showing blackleg symptoms

Figure 28. Older plant wilted and dying as a result of blackleg.

Figure 29.Immature tubers harvested under hot, humid conditions are prone to soft rot.

Figure 30. The infected flesh first appears cream-colored.

Disease Cycle

Soft-rot bacteria may survive in infected tissues, in the soil, and in contaminated equipment and containers. They are spread by direct contact, hands, tools, soil, water, and insects. The primary inoculum for blackleg is on or in seed tubers. Bacteria can be spread during seed cutting and handling. After being planted, the seed pieces decay, releasing bacteria into the soil and sometimes infecting the stem of the host plant. Bacteria may move in soil water and contaminate developing tubers of adjacent plants. Bacteria can enter lenticels, growth cracks, or harvesting injuries.

The primary inoculum for soft rot of tubers comes from decaying seed pieces, infected plants, infested soil and contaminated seed cutting, or harvesting equipment. Infection occurs through lenticels or wounds.

Conditions that Promote Disease

High soil temperature and seed bruising favor pre-emergence blackleg. Cool, wet soil at planting followed by high temperatures after emergence favor post-emergence blackleg. Extremely wet conditions at planting or harvesting promote soft rot. Excessive weeds may harbor the soft rot bacteria. Soft rot infections increase when immature potatoes are harvested or when the temperature is above 70°F during harvesting. Excessive bruising, improper wound healing, or free moisture and poor air circulation in storage increase soft rot incidence.

Management

The control of bacterial soft rots of vegetables is based almost exclusively on sanitary and cultural practices.

- Warm seed pieces to 55 to 60°F before planting.
- Plant clean seed.
- Avoid planting when soil temperature is below 55°F.
- Plant seed in well-drained soil.
- Frequently clean and disinfect seed cutting and handling equipment as well as harvesting equipment.
- Avoid excessive irrigation.
- Remove infected plants as soon as they appear.
- Harvest only dead vines, preferably when the temperature is between 50 and 65°F.
- Avoid harvesting under extremely wet conditions.
- Products to be stored should be dry, and the humidity and temperature of warehouses should be kept low
- All debris should be removed from warehouses, and the walls should be disinfested
- Prevent condensation in the storage pile.

Common Scab of Potato

Causal organism - *Streptomyces scabies*

Common scab of potato is caused by *Streptomyces scabies* and occurs throughout the world. It is most prevalent and important in neutral or slightly alkaline soils, especially during relatively dry years.

Symptoms

Common scab of potato affects mostly the tubers. Infected tubers at first develop small, brownish, raised spots. Later, the spots usually enlarge, coalesce, and become corky. Lesions typically are circular, raised, and tan to brown in color, with corky areas that develop randomly across the tuber (Fig. 31). Lesions may become irregular in shape when they coalesce (Fig. 32). More than one type of symptom may be present on a single tuber. Symptoms usually are not noticeable until late in the growing season.

Figure 31.Typical common scab symptom

Figure 32.Common scab with many scab lesions

Disease Cycle

The pathogen usually is introduced into the soil on seed pieces, and survives indefinitely once the soil is contaminated. The organism can survive on decaying plant debris and spread through soil water, by windblown soil, and on infected potato seed tubers. It penetrates tissues through lenticels, wounds, and stomata and, in young tubers, directly. Young tubers are more susceptible to infection than older ones.

Conditions that Promote Disease

The severity of common scab of potato increases as the pH of the soil increases from pH 5.2 to 8.0 and decreases beyond these limits. Other conditions that promote common scab include continuous cropping with potatoes, coarse soils that dry out quickly, and legumes (especially red clover) that have been cut down and left on the field.

Management

Potato scab incidence is reduced greatly by high soil moisture during the period of tuber initiation and for several weeks afterward. Potato scab is also lower in fields after certain crop rotations and the ploughing under of certain green manure crops, probably as a result of inhibition of the pathogen by antagonistic microorganisms.

- Use of certified scab-free seed potatoes
- Using certain crop rotations,
- Bringing and holding the soil to about pH 5.3
- Avoid over liming the soil
- Maintain soil moisture levels during and after tuber set.
- Irrigating for about six weeks during the early stages of tuber development, and
- Planting resistant or tolerant potato varieties.
- Avoid applying animal manure to fields where potatoes will be planted.

Root Knot Nematode

Causal Organism – *Meloidogyne* spp.

More than 40 nematode species parasitize potatoes, but only a few are of economic importance. Nematodes parasitizing potatoes have either worm-like or sack-like bodies, and range in size from 0.5–4 mm in length. Their bodies are colorless and appear more or less transparent; only the sack-like species (root-knot and cyst nematodes) can be seen with a hand lens in the field.

Causal organisms – *Meloidogyne* spp.

Symptoms

High populations of root-knot nematodes may cause varying degrees of stunting, chlorosis or wilting. Symptoms are more evident under conditions of temperature or moisture stress.

Roots: root-knot nematode causes a general swelling of tubers but no warty galls. Penetration of lenticels results in scab-like lesions. *Meloidogyne* spp. invasion is identified by the presence of knots or galls, usually irregular in shape (Fig. 33). The nematodes also induce the formation of 'giant cells' in the vascular tissue, which are multinucleate with dens cytoplasm and highly invaginated cell walls.

Tubers: The outer layers of tubers are sometimes invaded when large nematode populations are present in soil. Symptoms are not always apparent but may appear as wart-like protuberances (Fig. 34), and thin slices of tuber tissue may reveal adult females below the swelling..

Figure. 33 Knots or galls in roots caused by root-knot nematode.

Figure 34 Wart-like protuberances caused by root-knot nematode.

Management

Local spread can occur in soil on farm machinery, in irrigation water or on animals moving from infested to uninfested fields. Care can be taken to avoid spread in these ways, but once established in an area spread may be difficult to restrict.

Crop rotation can reduce root knot nematode populations, but host ranges differ between species and races, and identification is critical. A weed-free fallow can reduce populations by 80–90%. Biological control methods using some fungi and bacteria could reduce the disease.

Potato Leafroll Virus (PLRV)

Causal organisms - Potato Leaf roll Virus (PLRV), Potato Virus Y (PVY), Potato Virus X (PVX), Potato Virus S (PVS), Potato Virus A (PVA), and others.

Affects - foliage

Symptoms

PLRV: Current-season infections (transmitted by aphids) may have no visible symptoms, although younger leaves may roll up and appear yellowed or slightly pinkish (Fig. 35). On plants that are infected with diseased seed pieces, the lower leaves roll up and have a leathery texture (Fig. 36). The plants may be somewhat stunted and appear upright (Fig. 37). Some varieties develop symptoms in the tubers called net necrosis, an internal browning that fans out from the centre pith area (Fig. 38).

Figure. 35. Leafroll on upper leaf.

Figure. 36. Leafroll from infected seed piece.

Fig. 37. Plant stunted from leaf roll

Fig. 38. Leafroll symptoms in tuber.

Disease Cycle

The potato leafroll virus (PLRV) is introduced into a potato field either by planting infected seed tubers or by aphid transmission. Several species of aphids can transmit PLRV, but the green peach aphid seems to be the most efficient vector of this virus. Winged aphids spread the virus over long distances. Infected seed, sprouted cull potatoes and volunteers are the main sources of PLRV.

Management

- Sanitize equipment and storages.
- Plant only high-quality certified seed.
- Plant resistant cultivars.
- Monitor and manage the aphid and leafhopper population

4. Insect pests

Potato tuber moth: Phthorimaea operculella

Marks of identification:

Potato Moths are small narrow winged greyish brown in colour, measure about 12 mm long. Full grown caterpillars are pinkish white or pale greenish in colour and 14-20 mm long. Adult moths have a narrow, light brown body with grayish-brown wings containing a variety of small dark spots. The moth contains two sets of wings, both having frayed edges.

The damage caused by the larvae is that of mines in the leaves and / or weakening of the stem, which can break. The feeding paths of the caterpillars in the tubers can only be detected when the potato is cut open. The galleries in the tubers makes then unsaleable and also facilitate the entry of pathogens.

Nature of damage by potato tuber moth

- It bores into petioles and terminal shoots
- The main danger is to tubers both in the field and under storage.
- The caterpillars bore the tubers and feed on the pupal as a result of damage the potato tubers rot.
- The presence of black excreta near the eye buds helps to detect its presence in the tubers(Fig. 39& 40).

Figure 39. Larvae

Figure 40. Leaf damage

Figure. 41 Adult

Figure. 42 Tuber damage

Management

- Timely earthing up of the crop to cover the exposed tubers helps in reducing the intensity of infestation.
- Heaps of harvested potatoes should not be kept exposed in the field but covered with straw and infested tubers should be rejected before storage.
- Destroy all infested potatoes immediately and remove all plant residues from the field.
- Caterpillars pupate in the tubers and dry stems left in the field.
- Destroy all volunteer potato plants before planting new potato crops
- Avoid leaving harvested tubers overnight in the field as these potatoes could act as egg laying sites for potato tuber moth.
- Using healthy tubers - Eggs, larvae or pupae can remain present inside affected tubers and damage the following year's crop.
- Manual control - Manually removing and destroying affected tubers or leaves.
- Crop rotation – Rotation can break the chain in the potato tuber moth's life cycle preventing it from attacking the following year's crop.
- Crop maintenance - hilling up soil and covering exposed tubers can prevent adult insects from laying eggs on them.
- The potatoes should be stored in well-ventilated cool and dry places with temperature not exceeding 21^0C.

Potato Cut worm: Agrotis ypsilon

Marks of Identification:

Potato cutworm Moth is medium sized (22-26 mm longer), stout with greyish brown wavy lines and sports on fore wings and creamy white wings. The moths are active at dusk and are attracted by light. Full grown caterpillars are 40-48 mm long dirty black in colour and have habit of coiling at slightest touch.

Nature of damage

- It damage plants and tubers, especially after dark
- They attack young plants by severing their stems, pulling all parts of the plant into the ground and devouring them particularly at 25 – 35 days after planting (DAP)
- Signs of damage on tubers are boreholes, larger than those made by potato tuber moths

Figure 43 Damage during seedling stage

Figure 44 Larvae with symptom of damage

Management of Potato cutworm:

- Heaps of green grasses may be kept at suitable interval in infested field during evening and next day early in the morning along with caterpillars to destroy
- Clean cultivation and mechanical destruction of caterpillars also help in reducing pest infestation
- Irrigation also brings them on the surface and birds shall predate them
- Sanitation and thorough tillage can eradicate pupae present in the soil.
- Irrigation before planting.
- Manual control by turning the soil and killing cutworms present around plants.

Epilachna beetle of Potato: Epilachna viginatioctopunctata

Marks of identification:

The epilachna beetles of potato are special in shape, pale brown in colour and motted with black spots. The grubs are yellow with hairs on their body

Nature of damage by epilachna beetles

- Both grub and beetle eat the chlorophyll of the leaf in between the veins and cause characteristic skeletonised patches on leaves

Figure 45 Epilachna beetle in Potato

Management of epilachna beetles

1. Hand packing of grubs and collection of beetles by hand nets during early stages of attack, helps in reducing the intensity of infestation
2. Conservation and augmentation of natural parasitoids viz.Pediobius foveolatus, Pleunotrogrus faveolatus andTetrastichus sp
3. Application of Neem, Mahua, ground nut cakes are efficient in suppressing the pest population

Aphids in potato: Myzus persicae

Marks of Identification:

Aphids are tiny yellowish soft-bodied insects, the adult is along 1mm long and has two projections called cornicles on the dorsal side of abdomen

Nature of damage by Aphids

Direct damage:

- It puncturing them and sucking their juices.
- They damage the young and soft parts of plants, such as new leaves and shoots.
- Signs of damage are leaves not opening properly and being smaller in size.
- Severe infestation can cause shoots to wilt and dry out.

Indirect damage:

- Aphids have wings and can move from plant to plant spreading viral diseases (potato virus Y and potato leaf roll virus), picked up from infected plants
- Aphids secrete a sugary liquid that stimulates black sooty mold growth. It can cover the surface of leaves which affects the way they absorb sunlight

Figure 46. **Jassids of Potato: Empoasca fabae:**

Marks of Identification:

The adults are greenish yellow with front wings having a black spot on each, at the apical margin and two black spots on the vertex of the head. The nymphs are also green. They walk diagonally.

Nature of damage by Jassids in potato crop

- Both nymphs and adult suck the sap from the lower surface of the leaves
- The damaged leaves curl upwards along the margins and turn yellowish and show burnt patches. This affect adversely plant growth and yield

Figure 47. Hopper burn symptoms – burnt patches

Thrips of potato: Helicothrips indicus:

Marks of Identification:

The adults are minute, delicate insects, less than 1 mm long and are light yellow in colour. Wings have fringe or hairs throughout and hence they are called fringed, winged insects. The nymphs are still smaller, minute and wingless.

Nature of damage by Thrips in potato

Direct damage:

- It damage the undersides of leaves by scrape the epidermis and such the oozing sap
- They damage young and soft parts of plants such as new leaves and shoots
- As a result, leaves curl downwards and change to a blackish- silver color
- Severe infestation causes young leaves to wilt and dry out

Indirect damage:

- It can carry and spread spotted wilt virus diseases

Management of Thrips of potato

1. Sufficient watering – Thrips thrive in dry conditions and watering will increase moisture and inhibit their development.
2. Using black silver mulch – Light reflected from the silvery surface illuminating the undersides of leaves can repel thrips.

White grub of potato:

Marks of Identification:

White grubs are the larval form of beetles. They are large reaching 2-3 cm in length, are shaped like the letter C, and have three pairs of legs on their thorax. Their heads are hard and ruddy-brown in color, and they have strong mandibles.

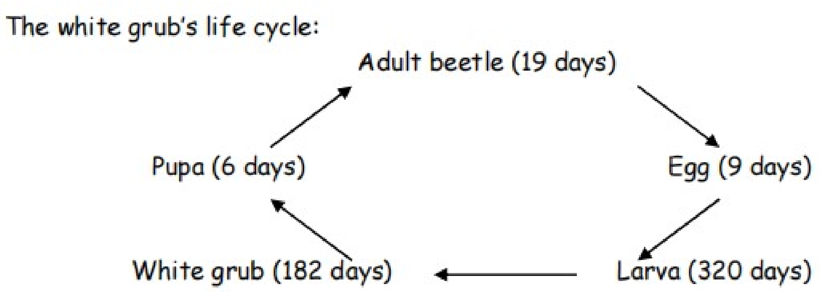

Figure 48. white grub's life cycle

Nature of damage by White grub of potato

Symptoms of white grub damage are abrasions and irregular holes on tubers,

which sometimes become misshapen. This damage can leave tubers vulnerable to

infection from diseases.

- Tubers damaged by irregular holes. More than two holes are often found in one tuber.
- These holes are not so deep, as white grubs do not enter and live inside tubers.
- Severe infestations usually occur in fields previously covered with grasses.

Management of white grub of potato

- Collecting larvae when tilling soil, planting, weeding and hilling up.
- Avoiding using un composted organic fertilizer, as it is a suitable breeding ground for this pest.
- Avoiding to plant potatoes in fields that were previously covered with grasses.
- Flooding field prior to planting, Where possible farmers can consider temporarily flooding fields, particularly on severely infested fields.
- Making use of bird predators to reduce white grub populations.
- catching imago/adult insects.
- using cropping patterns to sever the white grub's life cycle.
- managing manure properly to prevent nesting.
- tilling soil deeply so they are exposed to sunlight. manually removing white grubs.
- flooding fields. making use of bird predators to reduce white grub populations.

5.Harvesting and Post harvest Handling of Potatoes

5.1. Dehaulming

This is the removal or destruction of the haulm (the plant part above the ground level) to allow the skin to harden and reduce damage to the tubers during harvest. It improves the storability of potato tubers and prevents diseases from spreading from the plant stem to tubers especially viral diseases, late blight and stem rot. For plants infected with bacterial wilt, it is too risky to assume that the infection has not spread to the tubers simply by removing the haulm. The infected plants should be removed totally (roots, stems and tubers) and destroyed.

When and how to dehaulm: De-haulm two weeks before harvesting when the crop has attained physiological maturity and at least 50% of the haulms have started to turn yellow. This can be done using hand tools or uprooting the entire stems from the ground or use of herbicides as described below. When the potato crop is dehaulmed it is easier to detach the tubers from the stolons at harvest, resulting in less tuber damage.

5.2. Harvesting

Determine if the plant has matured and is ready for harvesting, by first uprooting some plants at random, examining the tubers and rubbing the ends to see if the skin peels off easily or it has hardened. This technique for determining tuber maturity and skin set is known as the 'Thumb Test"; thumb pressure and lateral force are applied to the skin. When the skin does not slip readily, the tubers are deemed to have achieved skin set and may be safely harvested. The following should also be considered:

- Harvest when the soil is dry.
- Harvest when it is relatively cool with cloud overcasts.
- Do not expose harvested tubers to sunlight for a long time so as to prevent them from drying out too quickly, and avoid greening of the white skin varieties, which would reduce their keeping quality and consumer acceptance.
- Avoid harvesting when the soils are wet in order to avoid pathogens sticking on tubers.
- Shield harvested tubers from rain to avoid the risk of rotting.
- When packaging into bags ensure you fill the bags half way for ease of lifting and transporting from the farm

Figure 49. Harvesting of potato tuber

5.3. Curing

Up to 80 % of potato tuber content is water and this needs to be maintained to avoid loss of weight and quality. A warm temperature in the shed or holding area before storage is desirable as it promotes wound healing and further skin set. The shed area should be well ventilated to allow good exchange of air and to achieve good temperature control. High humidity of 85 to 90% is essential for optimum wound healing and curing of the tubers.

5.4. Storage

The potato tuber is a living entity and it continues to respire in storage, this means that the starch is broken down to simple sugars and in turn they are broken down to carbon dioxide and water. An effective storage management protocol will slow this process down but it cannot be stopped completely.

Good storage conditions should be cool, dry, dark and well ventilated so as to: keep tubers alive, reduce deterioration through natural process of starch breakdown, reduce storage pest infestation and damage, and reduce storage loses through rotting, greening and increase tuber dormancy period.

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