Food and Agriculture Organization
of the United Nations

ALL ABOUT POTATOES

An Ecological Guide to Potato Integrated Crop Management

2006

Authors	Warsito Tantowijoyo (CIP) Elske van de Fliert (FAO)
Editors	Handoko Widagdo (WE) Jan Willem Ketelaar (FAO)
Contributors	Gunawan Junaedi Sri Wahyuningsih Basing Sembiring Raja Ulung Sagala Agustoni Tarigan Eko Istiyanto
Translation	Mark Havard
Photography	Elske van de Fliert Warsito Tantowijoyo International Potato Center: *Major Potato Diseases, Insects, and Nematodes*
Graphic design	Mukti Wibowo Warsito Tantowijoyo Elske van de Fliert

All about Potatoes
A Handbook to the Ecology and Integrated Management of Potato

International Potato Center (CIP-ESEAP Region) &

FAO Regional Vegetable IPM Program in South and Southeast Asia

In cooperation with:

Lembaga Pengembangan Teknologi Pedesaan
World Education
Food and Agriculture Organization

With technical and financial support from:
Food and Agriculture Organization of the United Nations

For additional technical information on potato production and protection, please consult the following website: www.cipotato.org. For additional information on vegetable production and protection, including technical and training materials, please consult the following website: www.vegetableipmasia.org.

FOREWORD

This handbook is an integral part of Integrated Pest Management Farmer Field Schools for potato. Although a thorough understanding of potatoes will develop through studies in Integrated Pest Management Farmer Field Schools, we hope this handbook serves as a facilitation resource for facilitators of Integrated Pest Management Farmer Field Schools. It intends, on the one hand, to give a broad overview of the basic technical issues relating to potato cultivation, but, on the other hand, broaden its users' horizons into the areas of ecology, marketing and farmer empowerment.

In this handbook we have tried to use language understandable to farmers, purposely keeping material as simple but as thorough as possible. It opens with an explanation about the principles of integrated pest management, then moves on to technical production topics about potatoes. These cover cultivation techniques, the ecology of pests and natural enemies, major potato pests and diseases, types of natural enemies, and so on. **This handbook is not like a book of fixed recipes**. It accentuates fundamental technical issues for potatoes, all of which still require considerable development more specific to the conditions in each location. This guide will become richer in scope if further trials are conducted under local conditions.

The involvement of individuals with diverse backgrounds and experiences has given this handbook on the ecology and integrated management of potato plants a very different feel in terms of language style and content. The authors would like to thank all those who have been so actively involved.

January 2006

We welcome your comments and suggestions. Please contact:

FAO Inter-Country Programme for IPM in Vegetables in South and Southeast Asia

c/o FAO Regional Office for Asia and the Pacific
A-25, Maliwan Mansion, 39 Phra Atit Road, 10200 Bangkok, Thailand

Email: vegetable-IPM@fao.org

For more information on vegetable IPM, including other training materials and ecological production guides, please consult www.vegetableipmasia.org.

HOW TO USE THIS MANUAL?

Why this manuals?

Farmers, practitioners, non-governmental organizations and researchers have all drawn on their experiences in developing this handbook to the ecology and integrated management of the potato crop, which is enriched with information from literature references.

Our objective in developing this guide was to provide a simple, yet complete picture of an environmentally friendly approach to cultivating potatoes under tropical upland conditions. Our ultimate hope is for potato-farming systems to change and become healthier for farmers, their farming enterprises, the environment and consumers. Healthy potato farming conditions will result in improved farming sustainability.

Who is it for?

This handbook is for use by facilitators of Integrated Pest Management Farmer Field Schools (IPM FFS) who preferably have graduated from a season-long training of trainers.

How can it be used?

This handbook forms the basis for the technical and ecological content of the potato IPM FFS. The FFS is a farmer training methodology that through experiential learning aims at enhancing an understanding of all aspects of the potato enterprise among farmers. This does not mean the handbook cannot stand alone as a reference on potato cultivation, but it will be more useful when considered the basis for thoughts to be explored and enriched through the participatory learning processes in potato IPM FFS. It should be noted that this handbook was developed under tropical upland conditions in Indonesia. Although an effort was made to generalize its content and make it applicable to other countries and environments, the user should be cautious and always cross-check information gained from this handbook with locally existing knowledge.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Integrated pest management: an overview

Integrated Pest Management (IPM) grew from a history of damage to agricultural environments resulting from inappropriate cultivation practices. The green revolution, which aimed at increasing agricultural productivity to meet the growing need for food, in fact gave rise to new problems. The green revolution only stressed higher productivity, while ignoring the capacity of the environment to support continued use and paying no attention to increasing farmers' incomes.

In Indonesia, the green revolution came into being through the so called mass guidance and mass intensification programs, which focused on promoting improved seeds, pesticides and chemical fertilizers to farmers. Pesticides and chemical fertilizers did initially result in substantially larger harvests, but were utilized unwisely without any clear understanding of exactly how to use them. Ultimately, farmers became dependent, unable to farm their fields without using chemical fertilizers and pesticides.

The program had negative effects and led to fresh problems such as new pests, problems controlling pests and diseases, environmental pollution, and farmers' dependence on products from outside. Farming sustainability became threatened, as it was no longer profitable. These problems lead to the realization that the farming system had to change. The central problems were those relating to pests, therefore, pest management had to become an important focus of attention.

In 1986, Integrated Pest Management (IPM) began with rice crops in Indonesia. Initially, the basic concept of IPM was a pest management approach stressing balanced agroecosystems and making the best possible use of nature. The hope was this concept could change farmers' minds away from "pest eradication" and towards "pest management". The "management" approach emphasizes a balance between pests and natural enemies in a managed environment able to support that balance. You do not eradicate pests, but manage them in such a way that their numbers do not damage crops. When you eradicate pests, you also exterminate their natural enemies, as pests and natural enemies are mutually interactive.

The basic principles of IPM are:

- Grow a healthy crop.
- Conduct routine field observations to look at development of pests, diseases, weeds, plants, natural enemies, and the surrounding environment.
- Preserve natural enemies.
- Farmers as IPM experts in their own fields.

The original concept has now changed. IPM no longer focuses on pests alone, but has expanded to encompass the whole cultivation system. IPM combines various approaches and technologies in an effort towards sustainable and healthy farming.

IPM will be more effective when implemented across whole farming blocks with groups of farmers than in individual fields as to ensure a stable ecological balance at the ecosystem level. IPM has to be the concern of farmer groups, traders, consumers, government agencies, non-governmental organizations, and farming businessmen.

Originally, IPM was developed for rice crops and its concepts were socialized through Integrated Pest Management Farmer Field Schools (IPM FFS). Rice IPM FFS were first launched in 1989 in Indonesia through the National IPM Program. Later, when IPM was developed for vegetables and potatoes, complicated problems experienced by farmers in intensified potato cultivation led to an IPM approach different from the one used for rice.

1.2 Potatoes: an overview

The potato (*Solanum tuberosum*) originates from South America, most likely from the central Andes in Peru. The potato was domesticated and has been grown by indigenous farming communities for over 4,000 years. Introduced into Europe in the sixteenth century, the crop subsequently was distributed throughout the world, including Asia (Smith, 1995).

The potato is a major staple fulfilling human nutritional requirements. Worldwide, the potato comes forth in terms of production after wheat, maize, and rice. In many countries potato serves as their staple food because of its excellent nutritional content.

According to Indonesian farmers, the advantages of the potato over other crops are:

- Its potential for high productivity.
- Its potential for being extremely profitable and easily marketed.
- Its price is relatively stable.

Its production challenges include:

- It is vulnerable to pests and diseases hence implying a high risk of failure.
- Growing potatoes requires substantial capital.
- It needs intensive care and attention.

The main constraints to potato farming in Indonesia are farmers’ lack of healthy seed, and attack by late blight, bacterial wilt, viruses, and leafminer fly. Other important constraints for farmers include potato tuber moth, weeds, unfavorable weather, low soil fertility, inadequate post harvest management, and marketing.

2 POTATO PLANT GROWTH AND DEVELOPMENT

2.1 The potato plant

The potato plant consists of the following parts: leaves, stems, roots and tubers. Some potato varieties planted in particular environments can produce flowers and berries. The function of each of these plant parts are as follows:

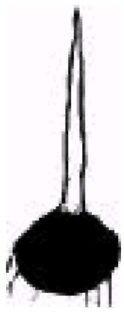
- Leaves are the part of the plant used for supplying nutrients.
- Stems are for supporting plants, and have vessels and growth cells inside.
- Roots absorb nutrients from within the soil.
- Tubers are receptacles for storing nutrients.

2.2 Potato plant growth

There are no *fixed* development stages in potatoes as these are influenced by varieties, shoot size, soil fertility, weather etc. Unlike rice, potato development stages overlap with each other making it difficult to distinguish between stages. For example, sometimes during the early growth stage, developing tubers have already begun to grow from the roots. Nevertheless, a division of potato growth stages can provide a picture of crop's critical development periods. This knowledge is extremely important for developing management strategies.

Potatoes planted from seed have the following growth stages:

Sprout development stage



This stage begins with several eyes sprouting when the tuber is in storage, continues through planting and up until shoots emerge from the surface of the soil. The time involved for the shoots to emerge from the ground varies greatly depending on the length of the shoot, moisture in the soil and other environmental conditions. With a sprout at the ideal length of 1-2 cm, shoots should begin emerging from the ground at around 21-30 days after planting (DAP). During this stage the plant still uses nutrient reserves stored in the tuber.

Vegetative growth stage

This stage shows rapid growth of leaves, stems, new shoots and roots. The plant still relies on food reserves stored in the seed tuber, but has already begun to take small quantities of nutrients from the soil. With the Granola variety this stage generally occurs between 30-50 DAP.

Tuber initiation stage

In the Granola variety, although tuber-forming roots begin to form during the vegetative stage, formation of actual tubers only occurs at 40-55 DAP. This stage takes place over a relatively short period of about 10-15 days. Tubers formed after 65 DAP will not reach optimum size when harvested. Plants require nutrients in large quantities during this stage.

Tuber bulking stage

At this stage the plant itself has already stopped growing, and only the tubers become any larger. In the Granola variety, this stage occurs at 50-80 DAP.

Tuber maturation stage

Yellowing leaves and drooping stems characterize this stage. Tuber skins gradually harden and do not pare away easily. Tubers harden due to their increased starch content. In Granola variety this stage occurs at 80-95 DAP. The best time to harvest a plant is at over 100 days old, because tubers will have reached maximum maturity signified by their hardness and sturdy skins.

2.3 Potato growth stages and vulnerability to pests and disease

At each growth stage plants are vulnerable to certain pests and diseases (see figure 1). The critical time for a potato plant is during the vegetative growth and tuber formation stages. Severe pest and disease infestations during these stages can reduce yield and can even cause crops to fail. Experience from highland areas in Indonesia shows leaf wilt infection at 30-45 DAP, along with high levels of rainfall and humidity, causes plants to die before forming tubers. Appropriate plant management and pest and disease control during the critical growth stages will support successful potato cultivation.

Days after planting	20	30	40	50	60	70	80	90	100
ARTHROPOD PESTS									
Leafminer fly		■	■	■	■	■	■	■	
Potato tuber moth							■	■	■
Aphid		■	■	■	■	▒	▒		
Thrips		■	■	■	■	■			
Cutworm	■	■	■	▒					
White grub							■	■	■
Mole cricket							■	■	■
Armyworm		▒	▒	▒	▒	▒	▒		
Looping caterpillar		▒	▒	▒	▒	▒	▒		
Whitefly		▒	▒	▒	▒	▒	▒		
Mite		▒	▒	▒	▒	▒	▒		
DISEASES									
Late blight	■	■	■	■	■	■	■		
Bacterial wilt	■	■	■	■	■	■	■	■	■
Virus		■	■	■	■	■			
Soft rot		▒	▒	▒	▒	▒	▒		
Common scab						■	■	■	■
Early blight		▒	▒	▒	▒	▒			
Dry rot						▒	▒	▒	
Nematode		▒	▒	▒	▒	▒	▒	▒	▒

Legend:
■ *Commonly found and harmful*
▒ *Rarely found and not so harmful*

Figure 1: Potato growth stage and vulnerability to pests and diseases

3 SOIL

3.1 Soil ecology

What do we imagine when we hear the term soil? Something made up of piles of dead creatures possibly, or leaf litter, sand or dust. However, soil is much more than that. Soil can be called a living entity, because within it there are millions of different living organisms. Some are large and visible; others are so small that we cannot see them with the bare eye. Examples of larger ones are white grubs, mole crickets, crickets and earthworms, while smaller ones are fungi, bacteria and nematodes. The total mass of living organisms, including plant roots in a 20 cm deep area of soil covering one hectare is around 5,000 – 20,000 kg.

The living organisms in the soil interact with each other, in that some are mutually beneficial, while others are detrimental to one another. Mole crickets and white grubs are pests that attack plants, roots and tubers under ground. Some bacteria and fungi cause plants to become sick; while other bacteria and decomposers break down plant remnants turning them into fertile humus.

Soil that contains no living organisms will become degraded as leaves cannot decompose and are left to pile up on the soil surface. They will not decompose and form the nutrients that plants need.

Soil is a vital resource that must be preserved to support farming sustainability. In order to maintain life in the soil:

- Organic matter must be kept and added when necessary, as it can increase the diversity, quantity and roles of beneficial living organisms.
- Contour crops, cover crops and build terraces to prevent soil erosion.
- Soil must not be polluted with pesticides. Pesticides kill off beneficial organisms and can upset the soil's ecological balance.

3.1.1 Soil types

Soils are composed of three essential minerals – sand, clay and loam. There are three classes of soil:

- *Clayey soil.* Made up mainly of clay and silt, it is difficult to work when dry, is tough, and does not absorb water easily.
- *Sandy soil*. Dominated by sand and characterized by its ability to absorb water and be worked easily. This soil type can lose its organic content easily, so a lot of organic matter must be added in order to maintain fertility.
- *Loamy soil*. The most prevalent component is sand, but this is balanced with clay and silt. Loamy soil usually has the good characteristics of clay and sand; it has a friable nature, the ability to hold water well and is fertile. This soil is often found in mountainous regions or on the slopes of volcanoes. Loamy soil is suited to all crops, and particularly to potatoes.

You can determine soil types by doing a "Sediment test":

- Put soil samples into clear bottles,
- Add water at a ratio of 3 parts water to 1 part soil,
- Shake the bottles until the water and soil are thoroughly mixed together,
- Leave to settle,

- Observe the sediment: the top layer of sediment will be loam, under that will be clay, with sand at the bottom.
- Compare these three components, and determine each soil type based on the soil textural triangle (See figure 2).

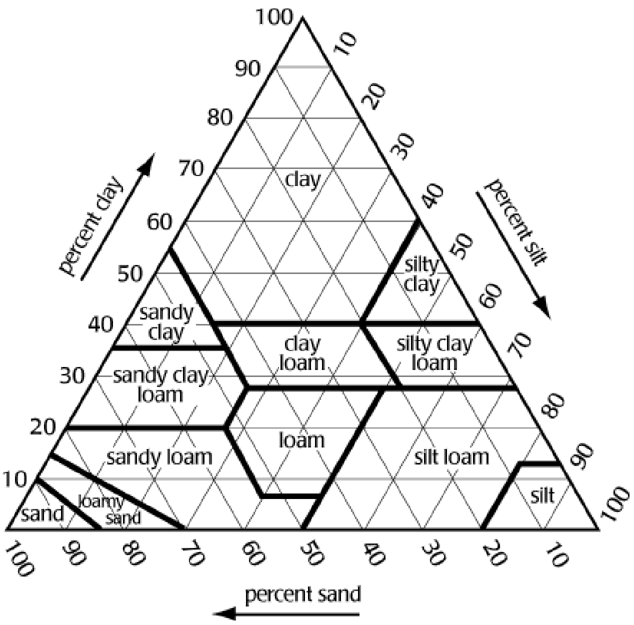


Figure 2: Soil textural triangle

3.1.2 Soil acidity

The pH of soil indicates the level of acidity and is measured by using a pH meter. Unfortunately this is quite expensive, so a cheap and easy method for measuring pH balance is to use litmus paper, which you can buy at any pharmacy. Instructions on how to use it will be found on litmus paper packaging. The lower the pH level, the higher the acidity, while the higher the pH level, the lower the acidity. Potato plants grow well in soil with a pH value of between 5.0 and 6.5. Potatoes planted in soil with pH levels lower than this will produce poor quality tubers and abnormal growth. Potatoes planted in high pH soil will have problems with common scab.

Generally, soils in potato producing areas have high acidity or pH levels below 5.0. The lower pH soil is caused, among other things, by the use of acidic chemical fertilizers, particularly urea and ammonium sulfate. Adding lime and/or reducing use of urea and ammonium sulfate fertilizers can increase the pH level of a soil. One kind of liming material is dolomitic limestone, which is added to soil four weeks before planting. Quantities have to be adjusted in accordance with requirements and soil type. The amount of lime required is measured based on the initial soil pH and the desired pH increase. Estimated amounts of lime required for increasing pH of different soil types are displayed in Table 1 below. It may take several seasons before the soil pH is close to neutral. Liming of soils with a pH higher than 6 is not recommended, since further increase in pH may induce potato common scab.

Table 1: Lime requirements as per soil type and pH value

Initial pH	Lime needed, by soil type (t/ha)		
	Sandy	Loamy	Clayey
6.0	1.0	1.7	2.4
5.5	2.2	3.7	4.9
5.0	3.2	4.5	7.3
4.5	3.9	7.3	9.7
4.0	4.9	8.5	11.2

3.1.3 Soil conservation

Erosion is a crucial problem in mountainous potato producing areas. The likelihood of erosion is very high, due to sloping fields with steep gradients and high rainfall. Erosion causes the surface layer of soil to be carried away. This layer (20 cm or less) is fertile and rich in nutrients and therefore essential for healthy potato production.

Land management principles for controlling erosion are as follows:
- *Ensuring soil is always covered with vegetation*, by planting cover crops at times when production crops are not being cultivated. Exposed soil is easily affected by rain, flowing water and sunlight causing it to become degraded and easily carried away by water.
- *Sustained use of organic matter can improve soil structure*, as it can act as an adhesive. Soil with high organic matter content is not easily dispersed, and therefore not easily carried away by surface water.
- *Contour crops on areas with steep gradients*. These should not interfere with main crops, so you should choose plant species that do not grow too tall and use wide plant spacing. Potato crops are more susceptible to pests and disease in shady conditions.
- *Making bench and live terraces* as these can contain the flow of water and reduce erosion. Live terracing is done by planting terraces with slope reinforcing/contouring crops.
- *Making rows of raised beds running across the gradient*.
- *Making irrigation systems that reduce the speed of flowing water*. Make water channels slightly sloping so they do not cause flooding in the field. Potatoes become very vulnerable when inundated with water, as humidity increases and stimulates fungal and bacterial growth, thus causing disease.

3.2 Soil fertility management

3.2.1 Nutrients in the soil

Soil contains nutrients that support the growth and development of plants. Types and quantities of nutrients needed depend on the growth stage of a plant.

Plants cannot use all the nutrients found in the soil, because most of them are bonded to soil particles and are therefore unavailable. Plants can absorb nutrients when they are dissolved in ground water. Factors influencing the availability of nutrients in the soil are:
- The content of each nutrient in the soil.
- The availability of water in the soil - Good soil conditions are when sufficient water is available. The field is neither too dry nor inundated with water.
- Soil type and structure – If soil is too dense it bonds to nutrients, meaning plants cannot absorb them.

- Rainfall - Rain causes washing off of nutrients and reduces their availability.
- Soil pH - Low pH causes the soil to release certain nutrients making their content too high and poisonous to plants. High pH causes certain nutrients to be tightly bonded by the soil, making them unavailable as plant nutrients.

3.2.2 Types and functions of nutrients

Nutrients are grouped into two types:
- *Macro nutrients* - these are nutrients potato plants require in large quantities. Macro nutrients are nitrogen, phosphorus, potassium, calcium and magnesium.
- *Micro nutrients* - these are nutrients required in relatively small quantities. Some nutrients included in this group are boron, zinc, calcium, iron, etc. Even though they are only needed in small amounts, they are vital for supporting plant growth. Many micro nutrients are found in organic fertilizer.

Common functions of macro nutrients are described below:

A. Nitrogen (N)

Function:
- Stimulates plant growth and enlarges leaves and tubers.
- A component of chlorophyll helping plants to absorb sunlight and produce carbohydrates.
- Increases tuber protein content.

Important points:
- Required in larger quantities than any other elements.
- N-containing compounds are very unstable and hence easily lost from soil through washing off, evaporation and organic/microbial activity.
- Potato crops need N particularly during the vegetative growth, tuber initiation and tuber bulking stages.

B. Phosphorus (P)

Function:
- Plays a part in chemical processes in plant growth.
- Encourages root and tuber development.

Important points:
- P is very stable, but bonds tightly to soil particles making it quite insoluble in soil water and difficult for plants to absorb.
- Very high P content can poison and kill plants.
- Potato plants need P particularly during the vegetative growth and tuber initiation stages.

C. Potassium (K)

Function:
- Stimulates leaf growth.
- Stimulates tuber growth and enlarges tubers.
- Plays a part in producing proteins.
- Counteracts the effects of excessive application of P.
- Increases resistance to disease.
- Improves tuber quality, reduces sugar content and improves storability.

- Increases vitamin A content.

Important points:
- K is relatively easily soluble in water and hence washed off in the soil.
- Excessive quantity of K can poison plants.
- Potato plants need K during the vegetative growth and tuber initiation stages, and especially during the tuber maturation stage.

D. Calcium (Ca)

Function:
- Proper cell division and elongation
- Proper cell wall development
- Nitrate uptake and metabolism
- Enzyme activity
- Starch metabolism

Important point:
- Calcium helps reduce soil pH.
- Calcium does not easily leach from soils, but over time moves to deeper layers. Sub-soils are therefore often richer in Calcium.

E. Magnesium (Mg)

Function:
- Essential for chlorophyll formation; Mg forms the central part of chlorophyll.
- Carrier of phosphorus in the plant .
- As enzyme activator and a constituent of many enzymes.
- Sugar synthesis.
- Starch translocation.
- Plant oil and fat formation.
- Nutrient uptake control.

Important point:
- Potato plants need Magnesium in the early sprout development and vegetative growth stages in order to produce green tissue.
- Deficiency of Magnesium leads to leaf yellowing with brilliant colors.
- Excess causes calcium deficiency.

3.2.3 Testing soil to determine fertilizer needs

Fertilizer requirements depend on quantities of nutrients already available in the environment (soil, water and air) and to what extent plants require these nutrients. If quantities already available are lower than plants' needs, then fertilizer is applied. Excessive application can damage plants and waste money, while applying too little can prevent plants from growing to their optimum size.

It is possible to determine what nutrients are present in the soil by testing soil samples. These tests can be conducted in laboratories. Simple Soil Test Kits, available in several Asian countries for ready use in the field, can also provide farmers and extension workers good indications of available nutrients in soil and corresponding fertilizer management requirements. If so desired, soil testing should be done 2-3 weeks before planting potatoes. Soil nutrient content varies greatly from field to field and at different times of year, however, testing is not necessary every season.

3.2.4 Organic fertilizers

A. The role of organic matter

Organic matter consists of the substances originating from plant remnants and animal remains and contains nutrients beneficial to soil health. The need for organic matter is unlimited, the more added to the soil, the better the soil will become. Organic matter functions to:

- Increase soil friability - Organic matter will balance soil forming components making soil crumble easily. Friable soil is important for supporting tuber growth.
- Increase soil fertility - Organic matter contains and gradually provides many macro and micro nutrients.
- Increase beneficial organisms in the soil, such as decomposers of plant remnants.
- Positively influence soil temperature and moisture levels.

B. Compost

Compost results from the decomposition of various forms of organic matter. It plays an essential role in enriching nutrient content in the surface layer of the soil. Finished compost contains an abundance of nutrients.

The benefits of using compost are:

- Compost contains readily available nutrients for plants. In the composting process raw organic matter decomposes and becomes ready for plants as nutrients to absorb.
- Compost contains a balanced composition of both micro and macro nutrients.
- Compost is made from materials that are readily available in the farm environment, such as plant remnants and/or animal feces.
- Compost facilitates good soil structure. High levels of organic matter in the soil can improve its capacity to hold water and increases soil friability thus simplifying tillage.
- Compost increases the diversity and quantity of beneficial living organisms in the soil and suppresses the development of damaging living organisms.

Disadvantages of using compost:

- Required in large quantities to supply the required amount of nutrients. Optimal use of organic fertilizer for potato crops is 20 tons/ha.
- Labor intensive, both in its production and application.
- Compost takes a long time to make: 1-4 months.
- Unfinished compost may still contain pests and diseases that are dangerous to the potato crop.

There are various ways to make compost and different farmers use different methods. However, the general principles of making compost are as follows:

- Collect raw materials for compost (plant material and/or animal feces). Compost made from a combination of greenery and dung has a better composition than compost made from only one of the two. All greenery, including weeds, can be used as raw material for compost.
- Sort the raw materials. This stage is done to remove pollutants such as plastic, tin cans etc. that will not decompose, and plants infected with diseases (rotten potato tubers, diseased potato plants etc.)

- Removing diseased plant materials is not necessary if composting is done well, i.e. when sufficiently high temperatures (45-65°C) are reached throughout the compost heap, and over a sufficiently long time period (approximately 12 weeks).
- Mix all materials evenly and pile them up, while adding water and lime to a height of 1-2 meters. To allow air to flow through the compost, stick a piece of bamboo with holes bored in its sides into the middle of the pile.
- To accelerate composting, starters can be added such as animal internal organs, plant remnant composting bacteria and/or commercially-available starters.
- The compost should be turned and observed at least once a month. The composting process occurs when the temperature of the pile increases (up to 60°C).
- The pile should be watered if it is rather dry and covered when it rains.
- Take the finished compost. Not all the raw materials in the compost will be decomposed, particularly plant stems, branches etc. Therefore selection of unfinished materials is necessary before the compost can be applied to the fields.

Characteristics of finished compost:
- The temperature of finished compost has gone down to the same level as that of the surrounding environment. This shows that the decomposition process has taken place because all the raw materials have been thoroughly broken down and become softer.
- The smell of the compost has changed to a fresh earth smell.

Important considerations when making compost:
- Composting requires oxygen from the air, so covering compost heaps with plastic for too long is not recommended.
- Composting requires humid air for decomposers to work effectively, however, if it is too wet, the composting process will cease. So, if a compost heap is set up in the open air, make sure to cover it when it rains.

C. Cover crops, green manure and mulch

Cover crops are crops planted to cover a field when it is not being used for growing crops. The aim of planting cover crops is to improve soil fertility, control weeds and prevent erosion. Cover crops are not harvested but dug into the soil when it is tilled. They need to decompose first before the nutrients are available for the next crop. Suitable cover crops are legumes, because they can increase the nitrogen content of the soil.

Green manure is greenery (non-decomposed plant remnants) applied to the soil. As with cover crops, green manure needs time to decompose and become beneficial to plants as a source of nutrients. It is best to apply green manure one month before planting.

Mulch is a soil cover used when potato crops are cultivated. Types of mulch that can be used are plastic mulch (black-silver, black, or transparent) and organic mulch (rice-straw, groundnut foliage, etc.).

The benefits of mulch are:
- A more stable microclimate in the soil by regulating temperature and moisture, which promotes plant growth.
- Increased availability of nutrients in the soil as a result of higher activity of soil microorganisms that decompose organic matter at more favorable soil temperature and moisture.

- Prevention of erosion and washing of organic and inorganic (chemical) fertilizers.
- Prevention of weed growth thus reducing competition between main crops and weeds.
- Reduction of production costs because no weeding is required on fields using mulch, and inorganic fertilizer dose can be reduced.

Its disadvantages are with soil infected by bacterial wilt, as applying mulch increases temperature and moisture levels accelerating growth of wilt causing bacteria. Also if plastic is left lying around after several seasons' use, it becomes a source of pollution.

D. Manure

Manure has the same function as other organic fertilizers, but is richer in nitrogen, because of its urine content. Different types of manure have different water and nutrient composition depending on the type of animal providing the manure and the food it got (see Table 2).

Table 2: Water and nutrient content of several types of manure

Source of manure	Water content (%)	Nutrient content (kg/ton)		
		Nitrogen	Phosphorus	Potassium
Beef cattle	85	26.2	4.5	13.0
Dairy cattle	85	22.0	2.6	13.7
Poultry (chicken, duck etc.)	62	65.3	13.7	12.8
Pig	85	28.4	6.8	19.9
Sheep	66	50.6	6.7	39.7
Horse	66	32.8	4.3	24.2

Manure can be applied before or after it is decomposed. Direct application of non-decomposed manure is not recommended for the following reasons:
- It may contain pests and diseases that can negatively affect plant health.
- It is difficult to apply because it smells bad and is too wet.
- Applying fresh manure at planting time can actually temporarily reduce quantities of available nutrients in the soil, because of decomposers using nutrients for decomposition processes.
- Fresh manure needs the oxygen in the soil in order to decompose, so direct application can starve plants of oxygen.
- It contains toxic gases that can kill plants.
- It reduces soil pH.

3.2.5 Chemical fertilizers

Chemical fertilizers are fertilizers that contain one or a few nutrients (see Table 3) and are mined or produced in factories. The most common nutrients contained in chemical fertilizers are nitrogen (N), phosphorus (P) and potassium (K). Chemical fertilizers are generally applied directly to the soil. They contain nutrients in a form that plants can readily absorb, so they must be applied when plants require them.

Chemical fertilizers are categorized according to their composition into single nutrient and compound fertilizers. Single nutrient fertilizers are chemical fertilizers that contain one type of nutrient. For example, KCl contains potassium, Urea contains nitrogen and SP- 36 contains phosphorus. The benefits of using single nutrient fertilizers are their cheaper prices and they can be applied to suit plants' requirements for a certain nutrient at any given crop growth stage. For example if a plant only needs N then you only need to apply urea. In certain conditions, single nutrient fertilizers can be mixed to replace compound fertilizers. To mix them properly, you need to know the nutrient content of each single nutrient fertilizer.

Table 3: Types of common chemical fertilizer in Indonesia and their nutrient content

Fertilizer type	Nutrient content (%)		
	N	$P_2 0_5$	$K_2 0$
Urea	46	0	0
KCI	0	0	50-60
SP-36 (super phosphate)	0	36	0
Ammonium sulfate	21	0	0
NPK (compound)	15	15	15

Compound fertilizers contain fixed quantities of more than one nutrient. NPK, for instance, contains 15% of N, P and K each. The advantages of these fertilizers are they are easy to apply and easy for plants to absorb. However, compound fertilizers are more expensive, contain relatively small quantities of nutrients and you cannot apply the individual nutrients in the required proportion to suit specific needs.

The advantages and disadvantages of organic versus chemical fertilizers are summarized in Table 4.

Table 4: Advantages and disadvantages of organic versus chemical fertilizers

	Organic fertilizer	Chemical fertilizers
Advantages	• Rich in balanced nutrient content • Increases soil friability and health • Improves soil water-holding capacity. • Releases nutrients in stages, suiting plants' ability to absorb them • Contains decomposers that play an important role in increasing soil fertility. • Stimulates growth and the work of beneficial living organisms in the soil • Farmers can make it themselves from readily available materials	• Contain recognized quantities of certain nutrients • Releases nutrients into the soil quickly making them immediately available to plants • Easy to determine dose • Easy to apply
Disadvantages	• Required in large quantities • Actual nutrient content not known and highly dependent on raw materials • Application is more difficult as it is more labor intensive	• Very water soluble and easily lost through washing off • Carriers may have negative effects on soil. • Relatively expensive

3.2.6 How to apply fertilizer

Successful fertilizer use is determined by application strategy covering fertilizer types, dosages, times and methods. Application strategy is based on a crop's nutrient requirements during different stages of its growth. In IPM there are no fixed recommended doses for fertilizers since the required dose depends on the specific conditions in a specific field. Table 5 below provides some guidelines that, however, should be tested and adapted in each specific field. General principles for the application of the various commonly used fertilizers are given in the paragraphs below.

Table 5: Fertilization strategy for potato

Growth stage	Application time	Type of fertilizer	Dose
Soil preparation	2-4 weeks before planting	Organic	100%
Sprout development stage (planting)	At planting	Phosphorus	75% of total dose
		Nitrogen	25% of total dose
Vegetative growth and tuber initiation stages	30-35 days after planting	Phosphorus	25% of total dose
		Nitrogen	75% of total dose
		Potassium	100% of total dose

A. Organic fertilizer

- Apply at planting time by mixing it straight into the soil or by placing it to the left and right of the seeds.
- Organic fertilizer requirements for potato crops are minimally 20 ton/ha. Using more than this will further improve soil structure and fertility.

B. Nitrogen

- Is particularly needed during the vegetative growth and tuber initiation stages.
- Nitrogen is very soluble and volatile, so is best applied in split application. Avoid applying it when fields are flooded or there is water flowing on the surface of the soil. Nitrogen evaporates easily so should be covered over by soil immediately after application.
- It is best to do two (or three) applications, applying 25% at planting (0 DAP) and 75% at 30-35 DAP, by putting it 10-20 cm deep into the soil.
- To save energy and expense, you can apply nitrogen fertilizer at the same time as weeding and hilling up.

C. Phosphorus

- Required during the vegetative growth and tuber bulking stages.
- P fertilizer takes time to release its P content into a form readily available for plants to absorb. It bonds easily to minerals in the soil.
- It is best to apply it at planting time as basal application.
- Soils in mountainous areas generally contain natural P, so they need little P content fertilizer.

D. Potassium

- Is essential during the tuber bulking stage.
- K fertilizer releases its K content in a form available for plants.
- K fertilizer is applied once at 30-35 DAP.
- K easily dissolves in water and should therefore be covered by soil after application.

3.2.7 Potato plant fertilizer requirements

Balanced fertilizer use will produce healthy plants that can resist pests and diseases and compensate for any damage done. For example: adequate levels of potassium helps hardening the cell walls, making them less penetrable to fungal growth. Healthy potato plants can produce additional cells around a leafminer fly egg and hence push it out of the leaf tissue, after which the egg drops to the ground and dies.

Important things to know when applying fertilizer are:

- Plants' nutrient requirements in relation to estimated yield.
- Quantities of nutrients in the field available for plants.

It is difficult to recommend a fertilizer use balance for potato crops as requirements vary greatly for different times, seasons, plant types, growth stages and environmental and market conditions. Fertilizer balance should be based on experimentation in each location. Farmers' experiences are the basis for experimenting with quantities of fertilizers used.

4 SEED PREPARATION AND PRODUCTION

4.1 Seed tubers and True Potato Seed

Farmers generally use seed tubers to plant a new crop. However, there is an alternative known as True Potato Seed (TPS), which is the botanical seed of the potato plant. TPS is already in use in several potato producing countries, including India, Vietnam and Indonesia. TPS is not widely used in Indonesia due to a number of drawbacks. Table 6 summarizes the pros and cons of tuber seed and TPS. The remaining text of this chapter deals with seed tubers, generally referred to as 'seed'.

Table 6: Advantages and disadvantages of potato tuber seed versus True Potato Seed

	Tuber seed	True Potato Seed
Advantages	• Planting technique is relatively easy and familiar to farmers. • Seed tubers generally originate from local crops and are adapted to prevailing conditions. • Plants and tubers produced are the same as parent plants. • Crop growth duration is relatively short. • Seeds planted are already sprouting so there is a high likelihood they will grow quickly. • Production is stable when seeds are selected properly	• Small quantity of seed required - 120 g/ha, meaning seed cost is relatively low • Can be sown when needed. Seeds can be stored for long periods of time. When farmers need them, they can be immediately germinated. Germination takes 21 days. • Free from viruses and nematodes. High production potential. • Storage and transportation costs are relatively low
Disadvantages	• Difficult for farmers to obtain quality seed. Many of the seeds produced by farmers are infected with viruses, nematodes and potato tuber moth larvae • Seeds need to be stored for a long time (3-4 months) before they are ready for planting • Seed storage and transportation is relatively expensive	• Cultivation is complicated and requires a lot of attention, particularly during germination. Specific training is recommended • Cultivation takes more than 120 days • Some plants and tubers display unusual characteristics

4.2 Seed generations

We often hear farmers using the terms G0, G1, G2, G3, etc., for potato seed. Farmers consider G0 potatoes to be better than G1, G1 better than G2, and so on. But what does G actually mean?

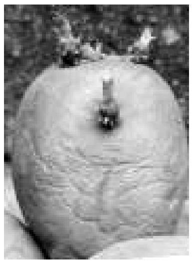
G stands for generation. G0 means generation 0, which is the original parenting stock from botanical seed or tissue culture. Explanations for the meanings of G0, G1, and so on, vary greatly from person to person. Some say that imported potatoes fresh from their crates are G0, so when they are planted their produce is G1. Others say that potatoes produced by tissue culture are G0 potatoes. A more important factor than generation is the necessity for using healthy seed, which to a certain extent is related to generation.

Some people think that seed generation influences production characteristics. However, a seed potato not originating from true potato seed will have the same characteristics as its parent stock, as no hybridization takes place. In the production process, however, plants can get infected by viruses, which are passed on to the next generation in seed tubers, as well.

4.3 Criteria for healthy seed

The seed tubers produced by farmers usually originate either from plants they have farmed themselves, from other farmers, or from seed producers. General criteria for healthy seed are:

- Seed must originate from healthy parent stock; and be free from disease, particularly bacterial wilt and viruses.
- Seed bearing plants should be more than 100 days old at the time of harvest.
- Tubers for seed should not be damaged by pests or improper harvest and post-harvest handling. Damaged tubers are more susceptible to diseases that influence growth.
- Tuber size is not a criterion for healthy seed, however it is best to use seeds of uniform size, weighing between 40-60 grams/tuber. Seeds of this size are large enough to provide the nutrients potato plants need during the early stages of growth, and not too large a volume of seeds will be required per hectare.
- Tuber skins appear fresh and not wrinkled.
- Uniform sprout size of around 1-2 cm. Uniform sprouts will produce uniform growth, and make it easier to manage pests and disease (see the chapter on managing leaf rot). Shorter sprouts will mean plants take longer to emerge from the ground and extend the plants' critical period. Sprouts that are too long will make transporting and planting more difficult as they are prone to snap easily.
- Robust sprouts with bluish colored bases.



Seed from producers follow certificated standards. Seed potato certification is very strict making it difficult for farmers to produce them. Certified seed standards are given in Table 7.

Table 7: Standards for certified potato seed categories

	Certified seed category (%)		
	A	B	C
Plants in the field			
Purity	99.95	99.90	99.50
Bacterial wilt	0.0	0.1	0.5
Dry wilt	0.5	1.0	2.0
Virus	1.0	2.0	3.0
Weak/non-productive	2.0	3.0	4.0
Tubers			
Bacterial rot	0.0	0.5	1.0
Dry rot	0.5	1.0	1.0
Black rot	0.5	1.0	1.0
Late blight	1.0	2.0	2.5
Nematodes	1.0	2.0	3.0
Tuber moth larvae	1.0	2.5	3.0
Mechanical damage	1.0	2.0	3.0

4.4 Seed selection

4.4.1 Positive and negative selection of parent stock

Selecting plants for seed is the key to getting healthy seed. There are two methods of selection: positive and negative selection. Both of these are done by marking plants with stake markers.

Positive selection is selecting and marking potato plants as parent stock. Plants chosen must display good growth and most importantly should show no signs of bacterial wilt and/or viruses. Negative selection is selecting plants that will not be used as parent stock. Plants marked are those infected with bacterial wilt and/or viruses.

Follow selection with a harvesting strategy as follows:
- Removing plant foliage - Plants are pruned at 80 DAP and all foliage is removed. This is to prevent pests and diseases from moving into the tubers.
- If you use positive selection, then you should harvest the selected parent stock before harvesting potatoes for consumption or sale.
- If negative selection is used, pull up the marked plants and four plants to the left and right of them before harvesting the remaining plants. Only tubers from unmarked plants are used for seed.

4.4.2 Sorting seed tubers

Seed tubers need to be sorted at harvest time, during storage and before planting. The objectives of sorting are to:
- Remove sources of pests and disease that can damage that seed potatoes.
- Stop pests and diseases spreading from one seed tuber to the others.
- Get healthy seed.

A. Sorting at harvest time

Sorting at harvest time is usually done in the storage area before seed tubers are stored. Seed tubers are taken from healthy plants chosen either by positive or negative selection. When sorting, choose seed tubers with smaller class tuber measurements (less than 60 g/tuber).

B. Sorting in storage

Sorting is done at least twice at one and two months after storage. Some farmers sort as many as three or four times. This depends on the condition of the seed tubers at sorting and the amount of time available. If you find high levels of pest and disease, then you must sort more frequently.

At one month, sort by removing and destroying tubers infected with pests and disease. Pests appearing during sorting are usually potato tuber moths. At two months, sort by removing and destroying tubers infected by pests and disease, and observe sprouting. Turn over and spread out heaped seed potatoes to stimulate more uniform sprouting.

C. Sorting before planting

Sorting before planting is done twice; once in the storage area and again in the field before the seed potatoes are planted. Sort in the storage area by removing those seeds damaged by pests and disease. You should not plant seed potatoes damaged by pests and disease. Another important characteristic to pay attention to when sorting is the uniform length of the shoots. In the field, seed potatoes that have been damaged in transport should also be separated out.

4.5 Treatment of seed tubers

Before they are put into storage, seed tubers should be cleaned of any soil sticking to the tuber, as the soil can contain disease. Clean tubers by washing them, or airing them, spreading them out in the storage area. Any soil stuck to tubers will fall off by itself. Tubers should be turned over at least once a day to help them dry more quickly.

To prevent potato tuber moths from infesting the tubers, many farmers apply chemical insecticides to seed potatoes in storage. This practice is very hazardous to the farmers' health, even more so when the seed potatoes are stored in their homes. As an alternative in areas with severe infestation, farmers can use the biological insecticide Granulosis Virus (GV) (see chapter 8.3.1). Seed potatoes in storage can also be covered over using Lantana camera leaves (lantana flowers).

4.6 Seed storage

4.6.1 Storage conditions

Storage conditions influence sprout quality of seed potatoes. Proper storage will provide high quality, large, robust and uniform-length sprouts. Storage techniques vary depending on where storage takes place. Sometimes seed potatoes are stored in sacks, in baskets or spread out on top of each other. Using sacks or baskets can save space, but can cause uneven sprouting as tubers on the top sprout more quickly than those underneath. Furthermore, storing sacks or baskets on top of each other can damage seed tubers making them more vulnerable to pests and disease.

If spread out in storage, tubers will sprouts uniformly. This requires a larger storage area, which must always be kept dry as damp or wet floors allow diseases, particularly tuber rot, to affect seed potatoes.

There are three storage lighting categories:

- *Dark storage*: when there is no light in a storage area.
  - o Advantages: reduces pest attack in storage and produces seeds potatoes with more uniform sprout growth.
  - o Disadvantages: sprouting takes a long time - up to 3 or 4 months. Sprouts are white in color showing that sprouting is not so good.
- *Light storage*: when there is full light in a place. This can be sunlight or electric light.
  - o Advantages: sprouts are robust and bluish in color, which is a sign of good sprouting. Storage time is shorter at about 2-3 months.
  - o Disadvantage: Lighting increases the temperature in the storage area and causes seed tubers to sprout prematurely. Uneven lighting causes sprouts to grow irregularly and abnormally, with small and elongated sprouts. Full electric lighting will increase storage costs. Furthermore, pests like potato tuber moths enjoy relatively bright places and more damage occurs in these conditions.
- *Dark-light combination storage*: is a storage technique used to overcome the drawbacks of the two methods above. Seed tubers are stored in the dark for two months, and then exposed to full light for the following month.
  - o Advantages: uniform and robust sprout growth, sprouting time is quicker, and potato tuber moth damage is low.

- o Disadvantages: requires more than one storage place and is more labor intensive.

Good storage conditions imply that:
- Seed potatoes are stored in a purpose-built stand-alone storage area with good air circulation.
- Average temperature in the storage area is kept to 18°C.
- Light conditions are altered using the dark-light method.
- Racks for spreading out seed tubers are used. Allow enough distance between the racks so you can turn over the seed tubers.
- Seed tubers are not piled up to a depth of more than 20 cm.
- Seed tubers are observed, sorted and turned over once a month.

4.6.2 Pest and disease management during storage

Pests and diseases that can affect tubers in storage are potato tuber moths, bacterial rot and mold. These diseases are carried by the tubers themselves or caught from other affected tubers.

Take the following steps to manage pests and diseases in storage:
- Build a good storage area with good air circulation and adjustable lighting. The temperature inside should not be hot and the air should not be too humid.
- Clear away potato remnants, sacks or any other waste, as these can be breeding grounds for potato tuber moths.
- Make routine observations looking for pest and disease infected tubers.
- Manually remove and destroy seed tubers affected by pests and diseases.
- If potato tuber moths are a problem, sprinkle GV onto the affected potato tubers.

4.7 Quality seed production

Tuber seed of high quality is best produced from mini-tubers or plantlets that are derived from either TPS plants or from tissue cultures. This requires special procedures and equipment, and is only done by farmers who devote their farming to seed production. The production of quality seed implies the following process:

A. Determine location

Location is all-important in success in quality seed production, because it requires more intensive handling. Ideal conditions for a location are:
- Close to a water source to facilitate watering,
- Not too far from home or the village to facilitate supervision,
- Shade free so seedling growth is not disturbed. Seedbed nurseries should ideally run from east to west.

B. Building a screenhouse

A screen house has walls made from soft screen or gauze to prevent insects and other potentially harmful organisms from entering. Made big enough to suit farmers' needs, a screen house is simple and inexpensive to build. The frame can be made from readily available bamboo. The roofs are made of clear plastic and the walls are closed using nylon gauze. A screen house should have a door that is easy to open and close. Racks are made inside the screen house for seedling trays.

C. Prepare seed bed media

Seed beds in screen houses use a media made of a mixture of soil, sand and manure in a ratio of 1:1:1. The mixture is sterilized (living organisms are removed) by steaming it for approximately 7-10 hours. This can be done by using an old oil drum. A layer of water is put in the drum and a sieve is placed above the water to stop the soil from getting wet. The soil is placed on top of the sieve and bamboo sticks with holes down its sides are stuck into the middle of the soil mixture to regulate the temperature. After it has been steamed, the media is spread over the seedbed trays and allowed to cool.

D. Planting materials and method

Tools needed in this process are a penknife and buckets. Materials necessary are clean water (mineral drinking water can be used), 95% alcohol, root growth stimulating chemicals (available in farming supplies shops), tray with media and seed materials. All tools must be sterilized before use by wiping them with the 95% alcohol. Seed materials that can be used are mini tubers and plantlets produced from tissue culture.

How to plant:

- *Mini tubers* - Plant mini tubers with a spacing of 20 cm x 20 cm at a depth of 5 - 10 cm into the media.
- *Tissue culture plantlets* - Pull up tissue culture plantlets and clean their roots. You must do this carefully to prevent roots and stems from breaking. Then plant them with a spacing of 10 cm x 10 cm.

E. Plant care

Plants are tended while they are growing by removing those plant parts damaged by pests and disease, as well as loosening media, applying fertilizer and watering. Soil is loosened and hilled up at 14 DAP. Fertilizer is applied by spraying a solution of compound fertilizer made by dissolving 5 grams of compound fertilizer in 1 liter of water.

F. Taking cuttings for propagation

When seed material is growing well, take stem cuttings for propagation at about 8-15 DAP. These stem cuttings, taken from parent stock plants, should be about 3-4 cm long (1-2 shoots), be dipped in a solution of a root growth stimulating chemical and planted in different trays with plant spacing of 20 cm x 20 cm. Cuttings should be taken in the afternoon taking care to use a sterile knife. After planting, shade parent stock plants and stem cuttings with banana leaves. You may take cuttings five times from each plant.

G. Harvesting

Harvesting takes place at 75 DAP, or when the plants start to die. Do this by dismantling the soil around the plants. One plant typically produces 2-4 tubers each weighting 10-20 grams. Select tubers based on their size and then store them. The tubers can be used for seed to plant in the fields or propagated in a screen house to produce the next generation of seed tubers.

5 CULTIVATION PRACTICES

5.1 Choice of location

What are the best conditions for potatoes to grow? Potatoes can grow well in areas with:

- An elevation of more than 800 meters above sea level. Under Indonesian upland conditions, the best elevation is over 1,300 meters above sea level.
- Daily temperatures ranging between 10-22°C, with an average of 15°C.
- Around 12 hours of daylight a day.
- Adequate water supply. This could be high rainfall of around 1,500-5,000 mm, with a balanced pattern of rainfall between the dry and rainy seasons. In areas with relatively low rainfall, irrigation management is a crucial factor. The best potatoes are grown in dry irrigated land.
- Friable sandy soil that contains organic matter so it is highly fertile and drains well.
- Soil free from bacterial wilt, nematodes and viruses, particularly when cultivating seed potatoes.

5.2 Potato varieties

In their place of origin (South America), there are many potato varieties, some of which are indigenous varieties and others of which are hybrids. Thousands of varieties with their manifold strengths and weaknesses are cultivated in South American countries.

Farmers in Indonesia plant very few varieties. The most commonly cultivated varieties in Indonesia are Granola, Atlantic, and Columbus. Atlantic and Columbus have almost the same characteristics, but both of these differ from Granola, which is the preferred and most easily marketed potato variety for Indonesian farmers as it is familiar and easily marketed. Table 8 shows the differences in the characteristics of potato varieties commonly grown in Indonesia.

5.3 Field preparation

5.3.1 Tilling the soil

Preparing fields for potatoes requires heavy tillage turning the soil over. You can use hoes, tractors or ploughs in tilling to a depth of around 20 -50 cm. Hoes are usually used when tilling the soil to a depth of 50 cm. This is done in two stages: the first is to a depth of 20 cm, and then the second is digging and turning the lower layer of soil over for a further 30 cm.

When tilling the field, remove unwanted weeds, especially grasses. Collect the weeds and burn them after they are dry. Another method is to bury them more than 50 cm down so they cannot grow again. Leave tilled soil for one week in order to neutralize soil temperature before planting any potatoes.

The benefits of tilling by turning over soil are:

- It allows other parts of the soil to be planted thus maintaining soil fertility.
- It improves the condition of the soil.
- It controls weeds.
- It exposes pests and diseases present in the soil to sunlight and causes them to die.

Table 8: Differences in potato varieties commonly grown in Indonesia

Criteria	Granola	Atlantic-Columbus
Growth characteristics	• Plant heights average 50-70 cm. • Stems are small and one clump consists of 3-5 stems. • Roots reach a maximum length of 50 cm. • Only one tuber per root.	• Plant heights average 80-110 cm, with large strong stems. • One clump consists of 2-3 stems. • Roots reach a maximum length of 90 cm.
Age	• 90-110 days	• Can reach 150 days
Seed availability	• Easy. Many farmers can produce their own seeds or buy them from seed companies.	• Difficult. Farmers have trouble producing their own seeds because harvested tubers are large in size. • Farmers depend on relatively expensive seeds from seed companies.
Farmers' views on cultivation	• Relatively easy	• Relatively difficult • Long growth duration can affect normal cropping pattern.
Vulnerability to disease	• Relatively susceptible to leaf rot and bacterial wilt, but quite resistant to viruses.	• Relatively susceptible to bacterial wilt, but quite resistant to leaf rot.
Productivity	• Low, averaging 15-18 tons/ha	• High, averaging 20-22 tons/ha
Tuber shape	• Oval – egg shaped	• Oval – long
Sugar content	• Relatively high – will burn quickly when fried and not dry completely.	• Relatively low – suitable for processing
Uses	• Vegetable potato	• Processing potato
Marketing	• Easy to market, accepted in the local fresh market (in Indonesia)	• Not so widely accepted in the local fresh market. Usually sold to potato processing factories.

Nevertheless, tilling the soil can:
- Change the composition and balance of living organisms in the soil and reduce soil fertility.
- Increase erosion. Newly tilled soil is very crumbly and easily carried away by water.
- Accelerate decomposition of organic matter.

To avoid these negative impacts, you need to add organic fertilizer immediately after tillage and till lightly.

5.3.2 Seedbed preparation

Make raised seedbeds to suit the direction and gradient of the field. They should be made to run across the slope. If fields are too steep, you will have to level them and build terraces to prevent erosion.

The width of and distance between raised seedbeds should be made appropriate to plant spacing. Raised seedbeds are generally made when planting in the rainy season so furrows are deeper, thus allowing water to flow more easily. Raised seedbeds should be around 10-20 cm high. You do not need to make raised seedbeds before planting in the dry season, as they will form when you cover seeds with soil, weed and hill up.

5.4 Planting

5.4.1 Planting time

A good time to plant potatoes is at the end of the dry season or the end of the rainy season. It is best to determine when to plant by considering the critical period for plants and how that will relate to environmental conditions. The critical period for potato plants is during the vegetative growth stage. At this stage they should not get too much rain or wind, or be too dry. Soil should be sufficiently moist when planting, as moist soil can accelerate plant growth.

5.4.2 Planting method

When planting without mulch, place seeds at the planting points with their sprouts facing upwards. Apply organic fertilizer to their left and right. Potato farmers generally apply chemical fertilizer on top of the manure. This is not recommended as it is untimely, unless the fertilizer contains phosphorus. Cover the seeds and manure with soil to a thickness of 10-15 cm.

When planting with mulch, make raised seedbeds 40-60 cm high and 60-80 cm wide, with a distance of 30 cm between the seedbeds. Make the seedbeds after tilling the soil, and then cover them using black-silver plastic mulch with the silver side facing upwards. Leave the raised seedbeds for one week, then make planting holes to suit the desired plant spacing.

For monoculture planting, plant two rows of potatoes in one seedbed, but if you are intercropping, plant only one row of potatoes in the middle, and plant the other crops on the edges of the seedbeds. To do this, place seeds and manure into the planting holes.

Plant spacing varies depending on region and variety. Granola potatoes are normally planted with a spacing of 30 cm x 70 cm, or 25 cm x 75 cm.

5.4.3 Intercropping

You can intercrop potatoes with other plants such as kidney beans or spring onions. These can be planted on the edges of the raised seedbeds.

How to plant:
- Plant two rows of kidney beans per seedbed between the rows of potatoes.
- Plant spring onions alternately to the sides of the potato plants.

Advantages of intercropping are:
- It provides another source of income for farmers.
- The other crop can trap or deter insect pests and reduce spread of disease.
- Intercropped plants can attract natural enemies. For instance, parasitoids prefer to attack leafminer fly larvae on kidney beans planted among potato plants.
- Intercropping with pulses can improve soil fertility, as pulses can harness nitrogen from the air.

Disadvantages are:
- Intercropping can increase plant density making the environment damper and stimulating the development of diseases.
- The main and secondary crops compete for space and nutrients.
- The secondary plants can be a source of pests and diseases.

5.5 Hilling up and weeding

When you use mulch, hilling up is not necessary and weeding only involves pulling up those weeds present in planting holes or furrows between seed beds. When you do not use mulch, you should weed and hill up at the same time as applying fertilizer. Do this at least twice in a planting season; at 30 DAP and 50 DAP.

Weed by pulling up weeds directly or by scraping them out of the soil with a hoe, collecting them and burying or composting them. If there are not so many weeds and those present are not grasses, dig them out and pile them up around the plants.

Hilling up is done initially by loosening the soil around the potato plants, and piling it up around the plants. Seedbed height after the first hilling up should be around 30 cm. For the second hilling up, remove soil from the furrows and pile it up around the plants. You should do this more carefully to avoid damaging the plant roots. Seedbed height after the second hilling up should be about 60 cm.

Seedbeds for planting in the rainy season should be higher than those used in the dry season. This is to reduce soil moisture, which can stimulate development of plant diseases.

Advantages of weeding and hilling up:
- Covers fertilizer and prevents fertilizer loss resulting from evaporation or washing off.
- Gets rid of weeds thus preventing competition between potato plants and weeds.
- Loosens the soil helping potato plants to better develop roots.
- Makes water flow more easily down the furrows and prevents flooding in the rainy season.
- Improves environmental condition of the plants and the soil.
- Covers potato tubers forming close to the surface of the soil, hence reducing the risk of damage from potato tuber moths.

Disadvantages of weeding and hilling up:
- Can damage potato plant root system.
- Can cause lesions on the roots and tubers, thus increasing the risk of disease.

5.6 Water management

5.6.1 Irrigation systems

Irrigation systems are systems that allow water to enter and leave the field. They should be planned and constructed before planting begins.

Good irrigation systems:
- Prevent the field from flooding.
- Prevent the entry and spread of water-borne diseases.
- Make it easy for water to enter the field when plants need it, especially in the dry season.

Potato fields should have a minimum of three lengthwise and three transverse water channels. For each direction this implies two channels at the edges and at least one in the middle. These channels should be deeper than the furrows between the raised seedbeds.

5.6.2 *Watering*

Watering potato plants is very important in the dry season. Sloping fields in potato planting regions make water management a crucial factor in the success of potato crops. You can irrigate plants in two ways; by using water channels or by watering using hoses, buckets, etc. Table 9 below shows the advantages and disadvantages of the two irrigation methods.

Table 9: Advantages and disadvantages of irrigation methods in potato production

	Using irrigation channels	Using hoses, buckets, etc.
Advantages	• Makes the fields wetter • More even distribution of water across the field • Less expensive	• Can be done even when the water source is far from the field • Prevents water-borne diseases being carried into the field • Does not require a complicated system of irrigation channels
Disadvantages	• Difficult to do if the water source is far away and/or lower than the field • Water flowing in or between fields can spread water-borne diseases • Requires a complicated system of irrigation channels	• Watered areas not very wet and watering is uneven across the field. • Require more expensive equipment • Is labor intensive

5.6.3 *Water management and water-borne diseases*

Water can lead to an increase in diseases in the following ways:
- Increases in moisture levels around plants, caused by flooding for example, can lead to rises in leaf blight, stem-end rot and bacterial wilt.
- Water can carry diseases from one plant to another. Water-borne diseases include bacterial wilt and tuber dry rot.

Proper water management in potato fields is essential in preventing the above from occurring. Key points are:
- Water should be able to exit the field easily when it rains.
- If bacterial wilt is discovered, it is best to water using hoses or buckets to prevent it from spreading in water flowing on the surface of the soil.

5.7 Crop rotation

Reasons for rotating crops are:
- *Avoiding increased levels of pest and disease damage*. Potatoes cannot be planted two to three times in a row. Increased populations of pests and diseases from one generation to the next make it difficult to achieve satisfactory harvests with the next crop. This is particularly a concern for Golden Cyst Nematode. Bacterial wilt will increase in prevalence in the second and third consecutive crops, leading to a substantial reduction in yield. Even though bacterial wilt survives for about two years in the soil, rotation with other plants, particularly corn, cabbage and sweet potato, can reduce levels of infection in the next potato crop.
- *Exploiting the most appropriate time for planting potatoes*. The success of a potato crop is influenced by the weather. High rainfall and drought can both cause potato crop failure. During certain months of the year, farmers should substitute their potato crops with other safer plants.

- *Maintaining and improving soil fertility*. Continual planting of potatoes can reduce quantities of nutrients in the soil. Potato plants need large quantities of nutrients, so rotation with crops such as pulses and sweet potato can help maintain and increase soil fertility.

6 INSECT ECOLOGY

6.1 Introduction

Ecology is the study of the relationships between living creatures and their environments. Like humans, insects' lives are influenced by environmental factors such as the availability and quality of food, natural enemies and weather conditions. When they have an abundance of high quality food and supportive weather, and there are no natural enemies getting in their way, insect pests will increase in number.

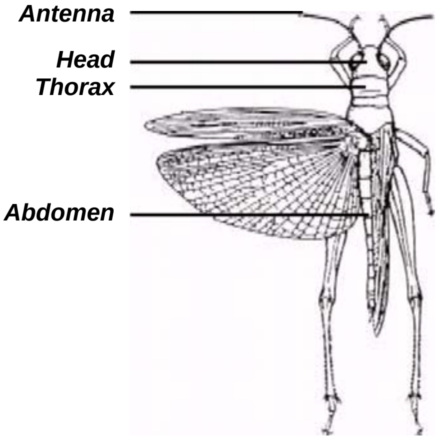
An understanding of the relationships between insects and the factors supporting their existence is important in order to develop techniques for their management. This understanding will develop by conducting observations and agroecosystems analysis. These activities are an essential part of IPM FFS.

In an agroecosystems analysis, farmers look not so much at individual insects, but at their relative numbers and the roles they play. This is because individual insects cannot cause economically important damage. Every living creature has its enemies. Nature maintains a balance between the numbers of prey and predators, insect pests and their natural enemies. Changes in one of these components will upset this balance. Insecticides upset the balance between pests and natural enemies, since natural enemies are generally more susceptible than pest insects and hence may lead to increased pest numbers and more damage to crops. Farmers must develop an understanding of the balance between insect pests and their natural enemies in order to develop strategies for managing insect pests. These strategies should focus on keeping pest populations at numbers that do not cause yield loss, but support the development of their natural enemies.

The environment influences the presence of insect pests. Pests prefer the dry weather of the dry season. Of course we cannot control the weather. We can, however, gain an understanding of the relationship between the weather and insect pest life cycles in order to determine planting times and management practices. Understanding agroecological processes will encourage development of management patterns that are healthier for farmers, the environment and harvest produce.

6.2 Insect anatomy

The main body of an adult insect is made up of three parts: the head, the thorax and the abdomen. Insect mouthparts vary. For instance, a grasshopper has mouth parts that bite and chew, butterfly mouth parts probe and suck, whereas flies lick. On the thorax are three pairs of jointed legs and also one or two pairs of wings. Some insects move around actively while others just stay on one plant. For example, leafminer flies are very active and therefore difficult to observe, while aphids tend to stay on one plant. Adult insects have hard exoskeletons making it difficult for contact insecticide to enter their bodies.



6.3 Insect life cycle

In their lifetimes insects change their skin and form. Generally, insect life cycles are divided into three stages, namely egg, larva and adult. Insects change their skin during each of these stages. During the larval stage, insects change their skin more than once. When they do, they are vulnerable as they are still weak and their skins are soft.

The adult stages of many insects, such as butterflies, beetles and mosquitoes, are very different and feed on completely different things than their larval stages. For example, certain caterpillars eat plant leaves and stems, while the adult butterflies feed on nectar.

Grasshoppers, crickets and locusts are almost the same in their young and adult stages. You can differentiate between these stages by looking for the presence or absence of wings; adult insects are the ones with wings. These insects eat the same food in their young and adult stages, and are plant pests. Insect pests are easier to control before they reach their adult stage because their skins have not hardened yet, and they do not move around so actively. Exceptions are insect pests that remain inside plants during their pre-adult stage (e.g., leafminer fly larvae). These are difficult to control with most insecticides, as those applied do not reach their target.

It is very important to understand the life cycle of insect pests. Generally, farmers are familiar with the stage of insect pests that affects their plants or tubers, but are unaware that other seemingly harmless creatures are actually the same species at a different stage in their life cycle. For example, farmers recognize the caterpillars that bore into their potato tubers, but consider the moths flying about in their storage areas to be a different and harmless species.

An understanding of WHAT turns into WHAT, WHERE, WHEN and HOW, provides information about insects’ strengths and weaknesses at each growth stage, and is the basis for developing insect pest management strategies.

6.4 Insect pests

Insect pests can damage plants in a number of ways:

- *Eating leaves and stems making holes in the plant and breaking off stems*. Insects with biting and chewing mouthparts cause this kind of damage. Examples are armyworms, cutworms, grasshoppers, and crickets.
- *Cutting or boring*. Signs are often found on potato leaves and tubers. Larvae bore into and remain inside leaves hollowing them out and leaving only the dry outer layer. Tubers become full of holes. Examples are larvae of the leafminer fly and potato tuber moth.
- *Puncturing and sucking*. Aphids and thrips are insects with these mouthparts. Usually they affect young and soft plant parts causing leaves to roll, wilt and dry out.
- *Spreading viruses*. Insects can carry viruses from one plant to another. When they stick their mouthparts into an infected plant, the virus sticks to or enters the insect and spreads when the carrier moves on to the next plant.

Insects can cause direct and indirect damage:

- *Direct damage* is caused when a pest attacks a part of a plant that will be harvested such as the potato tuber.

- *Indirect damage* is caused when a pest either attacks parts of a plant that will not be harvested or spreads disease. For example pests that attack potato leaves, roots or stems and pests that spread viruses.

Direct damage generally causes greater financial losses than indirect damage. With indirect attacks, plants have compensation strategies. When leafminer flies infest a crop during the tuber initiation stage and 20-30% of the foliage is infested, yield will not be affected because undamaged leaves can still produce enough to bulk the potatoes.

You can do leaf cutting tests to observe how different levels of pest damage on leaves can affect tuber yield. The steps for testing loss of produce are as follows:
- Plant potatoes in 12 buckets.
- When they are 35-40 days old, cut off leaves as follows; 0% (no leaves removed) in 3 buckets, 25% in 3 buckets, 50% in 3 buckets and 75% in the remaining 3 buckets.
- Tend each plant until ready for harvest.
- Harvest each plant, weigh and classify the tubers.
- Make comparisons to see how removing different percentages of foliage affects plant yield.

When we make observations in the field, we will come across many kinds of living creatures, insects and non-insects. But do all of these creatures damage potato plants? Farmers always worry when they find insects on their potato plants and try to eradicate them with insecticide.

Evidently, not all insects are farmers' enemies. In fact, only a few of the insect species in the field will damage crops, while most of them actually help farmers. The functions of some of the others have yet to be discovered, as they seem to be neither damaging nor beneficial.

Some insect species eat plants in quantities too small to cause any economic loss. Spraying these insects with insecticides will not increase harvest produce, but will increase costs, hence making production more expensive.

Many insects are farmers' friends because they prey on other damaging insects. Generally, these species are extremely sensitive to insecticides. Insecticides actually kill more beneficial than damaging insects.

When you find an insect, ask yourself about its role and function in the agro-ecosystem: is it a pest, a natural enemy or playing no part and just passing through? To answer this question you can set up an 'insect zoo', or enclosure, to observe feeding habits of insects. The steps in this are as follows:
- Isolate several potato plants in the field or in pots. Keep each plant isolated from other plants.
- Make sure these plants do not get any pesticide on them.
- Place several specimens of one insect species onto each isolated plant.
- Observe insect behavior every day.
- If an insect species does not eat any plant parts within 3 days, put other insect species inside.
- Observe what happens and keep records.
- Draw conclusions based on observation outcomes.

6.5 Beneficial insects

Insects that prey on insect pests, or diseases that infect insect pests, are called "farmers' friends" or "natural enemies". They help farmers to control the number of insect pests and prevent damage to crops. Natural enemies can effectively control many insect pests. Predators, parasitoids, pathogens (diseases) and nematodes are all classified as natural enemies. The characteristics of natural enemies depend on their class, as is described below.

Predators:
- Predators stalk and catch moving prey.
- Predators eat many preys of different species in their lifetimes.
- In some insect species, both larval and adult stages of insects can be predators. In other species, though, only the larval or the adult stage is predatory.
- Predators commonly found on potato crops are spiders, ladybirds, earwigs, hunter flies, hoverflies, praying mantises and dragonflies.

Parasitoids:
- Parasitoids found on potato crops are specific types of wasps and flies.
- Parasitoids attack their prey when it is vulnerable, usually in their egg or larval stages, by laying an egg inside or on the top of their victim. The egg will hatch and the newly emerged larva of the parasitoid slowly consumes its victim.
- Parasitoids only parasitize one insect in their lifetime.
- Parasitoids have very specific relationships with their host.
- Parasitoids are usually much smaller than their host.

Pathogens:
- Pathogens are similar to diseases in humans, such as flu, typhus, tuberculosis etc. They are extremely small and invisible to the naked eye.
- Pathogens require humidity and certain temperatures in order to infect insects.
- Pathogens are immobile, and wait until they come into contact with their host before they can cause disease.
- Pathogens can only infect certain species of insects during certain stages of their development. For example, the pathogen GV on potato tuber moth larvae.
- Fungi, bacteria and viruses are included in this category.

Nematodes:
- Nematodes are tiny worms. Certain species of nematodes can be pests, while others can act as natural enemies.

To be effective, a natural enemy must:
- Have capacity to develop many eggs and young in order to remain in balance with the number of insect pests.
- Be highly capable of attacking their prey.
- Be host specific.
- Be adaptable to changing environments.
- Proliferate at the same times and rate as their prey.

Strategies for increasing the effectiveness of natural enemies are:
- *Observing natural enemy species in the field* - This is essential as the basis for determining further measures.
- *Manipulating the environment* - Done when the natural enemies found in the field are not playing an effective role (despite the presence of natural enemies, insect pests are still prevalent and causing damage to the crop).

- *Releasing new natural enemies into the field* - Done when no effective host-regulating natural enemies are found, or when they are present only in very small numbers.
- *Making natural enemy release cages* – You can do this to increase the number of leafminer fly natural enemies. Cages measure 1 x 1 x 1m, and are closed on all sides with gauze. The gauze must have holes large enough for the parasitoids to escape, but small enough to keep leafminer flies trapped inside. Collect potato and green bean leaves or weeds showing signs of leafminer fly damage. Put them inside the cage, the place the cage in the middle of the field making sure to keep it sheltered from the rain. Parasitoids will escape and survive, while leafminer flies will be trapped and perish inside the cage.

Ways of manipulating the environment to increase the role of natural enemies are as follows:

- *Accept a low level of insect pests in the field* - Insect pests are a food source for natural enemies. If there are no pests, there will be no natural enemies.
- *Not using insecticides* - Natural enemies are more sensitive to insecticides. Tests have shown that natural enemies are more numerous in quantity and species diversity in unsprayed fields than they are in fields sprayed with insecticides. The overall result is smaller pest populations in fields that have not been sprayed.
- *Planting nectar-producing plants* - Adult insects that act as natural enemies (particularly parasitoids) feed on nectar. Therefore, planting flowers on the edges of fields will provide food for these parasitoid species and induce longevity.
- *Using compost* - Predatory flies need compost as a habitat for its maggots.
- If you are forced to use insecticide, *do spot applications to affected plants only*, and *select insecticides with low toxicity*.

6.6 Pest management

6.6.1 Biological control

Natural enemies have been discussed in the section above on farmer-friendly insects. Biological control will develop better if supported with another strategy, i.e. using natural pesticides, which originate from plants and are less likely to disturb or kill natural enemies. Plant materials that can be used as insecticides are the following:

Neem:
Neem (*Azadirachta indica*) is a tree that is toxic and repellent to numerous pests, particularly insect larvae, aphids and thrips. All parts of this plant are toxic, but toxicity is highest in the seeds.

How to use it: Pulverize plant parts until they are soft, and dilute them with clean water. Spray the mixture onto plants. To help it stick to the leaves you can add detergent. Because the toxicity does not last long in direct sunlight, it is best to spray in the late afternoon. If the mixture is too concentrated, it will poison plants leaving them looking as if they have been burnt.

Tuba:
The tuba plant (*Derris elliptica*) is commonly found in tropical forests. All parts of the plant are toxic, but the roots have the highest toxicity. This plant can be used to control leaf-eating insects such as caterpillars, grasshoppers, aphids, thrips, etc.

How to use it: Squeeze plant roots in clean water and leave them to soak overnight. The water can then be sprayed directly onto the plants. As with neem, you should spray in the late afternoon, and make sure the mixture is not too concentrated.

The benefits of natural pesticides are:
- They are often cheap and easy for farmers to make.
- They are generally not toxic to humans or livestock.
- They do not pollute the environment, because their residues are easily broken down.
- They rarely lead to insect immunity.

Drawbacks are:
- Materials are not always readily available to farmers.
- They must be applied appropriately and repeatedly.
- Some natural pesticides also poison natural enemies.
- It is difficult to determine the correct doses to apply.
- Bits of plants often block sprayer nozzles.

6.6.2 Mechanical control

Mechanical control strategies include using traps and trap crops, and manually removing insect pests.

Effective trap crops for leafminer flies are all kinds of beans, as the flies prefer these plants to potatoes to lay eggs on. Trap crops contribute to increasing the role of parasitoids, and can be used as follows:
- Plant beans at the same time as potatoes on the edges of potato beds.
- One week after emergence conduct observations of these plants. Collect leaves affected by leafminer flies and put them in the parasitoid release cage. Continue to do observations every other day.

Yellow sticky traps are only appropriate for leafminer flies, as they are attracted to the color yellow. Initially yellow traps were only used for observing the presence and quantity of these insect pests, but recently many farmers have been using them as a means for reducing leafminer fly populations.

Anything yellow such as yellow plastic, yellow painted boards, oil bottles etc. can be used for making traps. Smear them with something sticky such as glue, starch solution or old engine oil, then put them in the field about 10-20 cm above the tops of the plants. You can use bamboo stakes for supporting the yellow boards. Normally about 80 traps will be used for 1 ha. Position flat traps in line with the path of the sun (west-east). Traps that gleam in sunlight will be more effective.

Many farmers have changed their insecticide use patterns as a result of the success of yellow traps. When farmers find lots of leafminer flies on their traps, they feel they are controlling them successfully and no longer spray insecticide. This supports the development of natural enemies, increasing their numbers, diversity and impact. Finally, natural enemies can control leafminer flies by themselves.

Drawbacks of yellow traps are:
- They only trap adult insects, while the actual pest is the larva. Trapped insects may have already laid their eggs on leaves. Hence, the effects of such traps on population regulation are limited.

- Some natural enemies in the parasitoid and predator groups are caught, as they are also attracted to yellow.

To lessen these drawbacks, do not install yellow traps continuously. Install and remove every other week. Traps should be removed when natural enemy populations are increasing.

Insect pests can be removed manually when their populations are not too high. For this to be effective, it must be done in an organized, thorough and timely manner. Any pests collected should be destroyed. The drawbacks of this method are that it is time consuming and labor intensive, and difficult to do with pest species that actively move around.

6.6.3 Chemical control

A. Introduction

PESTICIDES ARE NOT MEDICINES, BUT POISONS THAT CAN KILL ANY KIND OF LIVING ORGANISM. Pesticides are generally killers, and are used extremely inappropriately when applied once a day or every other day. In the rainy season, some farmers even spray their crops twice a day. Farmers often apply a mix of several types of pesticide. Frequencies of an average of 15 times per cropping season have been recorded in certain potato-growing areas in Indonesia.

The main reasons farmers say they use pesticides are that they are easy to use, and that the results are immediately apparent as many insects are visibly killed instantly. The improper use of pesticides, however, makes potato production costs very high. In Indonesia, about 27% of the total costs for production inputs are spent buying pesticides. When farmers see insects or symptoms of pests or disease, they immediately assume they should spray their crop with pesticide. In the end, the pesticides cause more problems than they resolve, as resistance to pesticides develop and natural enemies are killed.

B. Pesticide types

Chemical pesticides can be categorized in various ways as described below.

Based on their intended targets:
- *Insecticides* are pesticides intended to kill insects.
- *Herbicides* are pesticides used to kill off weed growth. Generally, they kill weeds by destroying plant tissue or accelerating growth.
- *Fungicides* are pesticides aimed at fungi. Many contain sulfur or copper.
- *Rodenticides* are used to kill rodents (rats and mice). Several of them are extremely toxic to other mammals.
- *Nematicides* are pesticides used to kill nematodes (tiny worms).
- *Acaricides* are pesticides used for killing mites.

Based on their formulations:
- *Emulsifiable Concentrates (EC)*: Emulsifiable concentrates are thick solutions of active ingredients in oil that contain detergent-like emulsifiers that allows the thick solution of active ingredients to be diluted in water to form a solution for spraying in the field. The important components of EC formulations are the active ingredients, organic solvents and emulsifiers. Mineral oil solvents are used.
- *Water-Soluble Concentrates (WSC) / Soluble Concentrates (SC)*: These pesticides dissolve completely in water. Their active ingredients might dissolve in

water or may already be dissolved in an organic solvent (alcohol for example) making them water-soluble. The consistency and color of these pesticides are similar to EC, but become clear after being diluted with water. The important components in these formulations are active ingredients and organic solvents. Solvents used are types of alcohol.

- *Wettable powder (WP)*: WP contains active ingredients, a wetting agent and other materials such as adhesives. The wetting agent allows an even mixture of powder and water when it is diluted for spraying. Without the wetting agent, the active ingredients would not mix with water, but float on the surface. Carriers are generally in the form of mineral powder such as talc or clay. This talc or clay settles at the bottom of the tank and needs continuous shaking to maintain suspension.
- *Flowable (F)*: In these formulations, active ingredients are mixed with a carrier (a mineral powder) and a small amount of water producing a formulation fine but wet granules. This "wet mixture" is easy to mix evenly with water and can be sprayed using the same type of sprayers as used for WP formulations. This formulation requires continuous stirring.
- *Soluble Powder (SP)*: Active ingredients in SP formulations are either in a powder form that dissolves in water or formed into pellets containing small amounts of wetting agent to increase water solubility. Different from WP and F formulations, SP formulations do not require continuous stirring when spraying as the mixture remains in continual suspension.
- *Granules (G)*: The components of this formulation are an active ingredient, carrier and adhesive. This mix of materials is made into small granules. Active ingredients make up around 2-25%. Carriers are clay and mineral substances.

Based on their mode of action:

- *Contact pesticides*: There are pesticides that kill their intended targets by coming into contact with them. These pesticides remain on plants just after application, but are generally only effective for short periods of time and are easily affected by weather factors, particularly temperature and sunlight. They must be applied directly to the plant parts where pests and diseases are often found.
- *Systemic pesticides*: These are pesticides that can enter and spread through all parts of a plant and affect the pest or disease after it consumes plant parts. Systemic insecticides generally poison stomachs or nerves, and are effective for controlling pests that suck, eat plant tissue or bore. Spraying needs not necessarily be on the affected parts of plants as these pesticides spread to all parts including the roots. Toxicity of these pesticides is generally long-lasting. These should not be used before harvesting as they can pollute crop produce and pose toxicity hazards to consumers.

C. Pesticide toxicity classification

The WHO (World Health Organization) has classified pesticides based on their toxicity. Pesticide classes depend on how hazardous they are to humans:

- EXTREMELY HAZARDOUS (Class Ia): Pesticide formulations with, for example, the active ingredients parathion-methyl, mevinphos, alachlor.
- HIGHLY HAZARDOUS: (Class Ib) Pesticide formulations such as those containing the active ingredients methamidophos, edifenphos, dichlorvos, monocrotophos, or methomyl.
- MODERATELY HAZARDOUS (Class II): Pesticide formulations with the active ingredients ofatox, dimethoate, cypermethrin, fenvalerate, deltamethrin, fenobucarb, cartap, fipronil, endosulfan, fluvalinate and paraquat.

- SLIGHTLY HAZARDOUS (Class III): Pesticides with the active ingredients trichlorfon, dicofol.
- UNLIKELY TO PRESENT ACUTE HAZARD IN NORMAL USE (Class IV): Pesticide formulations unlikely to present acute hazard in normal use such as those with the active ingredients zineb, benomyl and maneb.

D. How to apply pesticides

The effectiveness of a pesticide is highly dependent upon:

- *Appropriate target*: The pesticides used should be appropriate for the organisms they are targeting. For example, to control leafminer attack, an insecticide able to kill larvae inside the leaves should be used. A list of target living organisms can be seen on the labels of the packaging.
- *Appropriate timing*: Timing should be based on the behavior of the targeted pest and the weather at the time of application. If a pest is active in the morning, it is best to apply the pesticide in the morning too. Weather, especially rain and sun shine, can be very influential. Many pesticide types cannot resist washing by rainwater and long hours of sunshine.
- *Appropriate quantities*: Recommended quantities are shown on the pesticide packaging. These should be adhered to, as inappropriate quantities will cause negative effects, such as ineffectiveness and build-up of resistance.
- *Appropriate application methods*: Pesticides should not be mixed when they are applied, as some will counteract each other and reduce toxicity to target organisms.

The amount of pesticide the spraying equipment releases can also influence effectiveness. Generally, a finer spray is better because the smaller droplets will adhere better to the plants and the bodies of targeted pests, provide better coverage and will reduce the amount of water and pesticide required. The problem of a finer spray is that it can be blown away by the wind.

When spraying, consider wind direction to prevent poisoning from becoming covered with pesticide.

E. Resistance and resurgence

Evidence shows that the more farmers use pesticides, the more problems arise with pests and diseases. Examples of this are increasing numbers of brown plant hoppers on rice crops and leafminer flies on potatoes as a result of insecticide use.

The processes causing increased numbers of insects after insecticide application are as follows:

- *Insecticide causes resistance in insect pests*. In a population, each individual insect reacts differently to the insecticide applied. Sensitive ones will die when coming into contact with insecticide. However, somewhat resistant insects will survive. When the survivors reproduce, their offspring will be resistant, too. Through selection the population will be more and more resistant until the insecticide is totally ineffective. The same process applies to fungi and fungicides.
- *Insecticides kill natural enemies*. Natural enemies, particularly parasitoids, are generally more sensitive to insecticide than insect pest. Without natural enemies, pest insect populations can increase rapidly. This process is called resurgence.

F. Pesticide hazards to humans and the environment

The dangers of pesticides to humans and the environment are:

- *Poisoning in humans*: Farmers commonly spray pesticides using no or limited form of protection, without covering their noses and mouths, or wearing long-sleeved clothes and long trousers. Poison that sticks to the skin and is breathed in through the nose, can poison farmers. Blood tests conducted among vegetable farmers showed that all the farmers tested had traces of pesticide in their blood. Pesticide poisoning does not only cause death, but can cause skin diseases, nausea, weakness, headaches, convulsions etc. Some chronic symptoms include cancer, allergies, abnormal blood pressure, etc.
- *Polluted produce*: Poisons, particularly systemic poisons can enter all parts of potato plants, including tubers. These poisons remain there for a long time, and when potatoes are consumed, the poison can enter the body of the person eating them. An accumulation of these poisons can affect health. International markets have banned vegetable produce with too high pesticide residues.
- *Kills living creatures other than those targeted*: Pesticides applied in the field do not only kill targeted pests/diseases, but can also kill beneficial insects such as honeybees, as well as livestock.
- *Water and air pollution*: Water is polluted and poisoned by discarded packaging and bottles being left lying around in the field, by cleaning spraying equipment in rivers, and also by rain water flowing from sprayed fields. This is extremely hazardous to farmers in mountainous regions as they commonly use river water for their daily consumption needs.

7 MAJOR POTATO PESTS

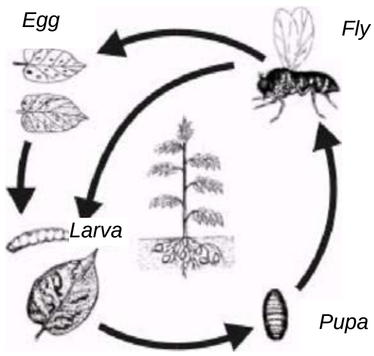
7.1 Leafminer fly

The potato leafminer fly (*Lyriomyza huidobrensis*) originates from North America, and was accidentally introduced into Southeast Asia in the 1990s on ornamental plants. This pest affects numerous crops and weeds, and has more than 40 species of host plants, including potatoes, kidney beans, green beans, okra, Indian mustard, and several weeds.

Farmers control this pest mainly with insecticides, but this has been ineffective and has actually increased their numbers. Leafminer flies that are accidentally introduced are generally already resistant to insecticides.

Life cycle

The leafminer fly reproduces by laying eggs. Its life cycle is divided into egg, larval, pupal and adult fly development stages:



- *Eggs* - Laid inside leaves, they are very small and clear in color. Larvae hatch after about two or three days.
- *Larvae* – These remain inside leaves. They are very small and have no legs so cannot move from one leaf to another. The larval stage lasts around 6-12 days.
- *Pupae* – These are formed in the ground or inside leaves. On potato plants, pupae usually fall to the ground. The pupal stage lasts around 14-16 days.
- *Adult flies* – These are extremely small at 2-4 mm in length, black in color with two yellow spots on their backs. They are most active in the morning from 7:00 to 9:00 and in the afternoon from 16:00 to 18:00. Adult flies produce an average of 166 eggs per female. They are attracted to the color yellow.

Damage symptoms

The leafminer fly damages plants during its larval and adult stages mainly on the lower third of plants. Larvae begin eating the insides of leaves immediately after hatching, and bore mines inside them. In instances of severe infestation, all that is left of leaves is their upper and lower skins. Affected leaves become dry and drop off the plant. Adult flies puncture holes in leaves in order to lay eggs and feed on plant juices.

If this pest infests a crop during the early plant growth stage, potato yield can be reduced by up to 70%.

Management

Methods for managing this pest are:

- Clearing and destroying non-crop host plants and residues.
- Planting trap crops such as green beans and pulses at the right time and in the correct quantities.
- Hilling up at the appropriate time (four to six weeks after planting). This is to bury and kill the pupae that have fallen to the ground.

- Balancing fertilizer use to produce healthy plants that can protect themselves from leafminer flies by ejecting eggs from inside their leaves.
- Rotating with crops that do not host this pest such as maize or sweet potato.
- Protecting natural enemies by not using insecticides as these affect natural enemies more than leafminer flies.
- Collecting leaves infested with leafminer flies and putting them in parasitoid release cages.
- Attracting parasitoids and increase longevity by planting nectar-producing flowers around the field.
- Using organic fertilizer in abundant quantities as predators, for example the predatory fly *Coenosa*, breed in organic matter. This will provide them with more space to breed and develop in larger numbers.
- Putting up stakes as places for predators to wait and view their prey before striking.
- Place yellow sticky traps for monitoring of adult flies and their natural enemies.

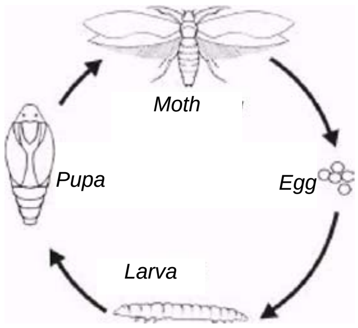
Observation methodology

You can observe leafminer flies directly or by using yellow traps. With direct observation, look out for plant damage and the presence of adult flies. It is best to do this in the early morning or late afternoon when the flies are most active. Indirect observation can be done by using sticky yellow traps, which when put up in high density can contribute to fly control.

7.2 Potato tuber moth

Potato tuber moths (mainly *Phthoremaea operculella*) are found both in storage areas and in fields. Farmers do not usually consider them to be an important pest in seed tuber production because affected tubers will still grow when planted.

Life cycle



Potato tuber moths lay eggs. Their life cycle is divided into egg, larval, pupal and adult moth stages, and lasts for around 20-30 days:

- Eggs are very small and usually laid on tubers, on the underside of leaves, on storage sacks, on the ground or on waste close to tubers. Eggs hatch after five days.
- The resulting larvae make holes in tubers and leaves. They bore into the eyes of tubers and grow for about 14 days.
- Pupae are covered in fine hairs and are found on dry leaves, on the ground, on potato eyes, on the walls of storage areas and on sacks. The pupal stage lasts for eight days.
- Adult moths have blackish brown colored front wings. They are active at night and are attracted to light. During the day they hide under sacks or under piles of tubers stored in the storage area. Adults live for around 10-15 days.

Damage symptoms

Potato tuber moths affect both tubers and foliage. Larvae eat their way inside tubers either in the field or the storage area. However, severe infestation generally occurs in storage. Larvae feces can be seen near boreholes.

On foliage, larvae attack the stems and leaves of potato plants. They enter leaves, eat the inside and leave only a dried up outer skin. Severe infestation occurs in same areas, but yield loss is generally limited.

Management

Ways to manage potato tuber moth:

- *Using healthy seed tubers* – Affected tubers with eggs, larvae or pupae still inside them can become the source of infestation in the following crop. You should sort tubers before storing them or planting them in the field. You should destroy affected tubers by burning or burying them in the ground.
- *Mechanical control* – Either in the storage area or in the field by removing and destroying affected tubers and leaves.
- *Cultivation practices* – You can prevent adult moths from laying eggs on tubers in the field by hilling up, irrigating and covering over those tubers appearing on the surface of the soil. Cutting back plants at 80 DAP can prevent larvae on the foliage from moving into the tubers.
- *Crop rotation* – Crop rotation is a good way of breaking the cycle of reproduction when populations are large and causing a lot of damage. The population will be a lot lower the next time a crop is planted.
- *Using sex pheromones* – Sex pheromones are useful for observing populations, but can also be used for management when combined with other management practices.
- *Preserving natural enemies* – Create favorable conditions for predators and parasitic wasps. Further research is necessary to look at the potential of these natural enemies to reduce populations.
- *Using Granulosis virus (GV)* – Some research institutes produce a formulation of GV, which can be an effective means for controlling potato tuber moth larvae, particularly in storage areas. Tubers for storage are cleaned first and then coated with GV powder and prepared for storage. Farmers can produce GV themselves cheaply and easily, but prior training is needed.
- *Using Lantana camara* – You can also cover stored tubers over with *Lantana camara* leaves.

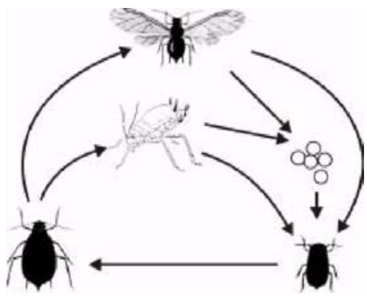
Observation methodology

You can make observations of larvae and adult moths. Observe larvae in the storage area by removing holed tubers and cutting them in half. Observe larvae in the field by looking for leaves showing signs of damage and opening them up. Observe presence of adult moths by using sex pheromones, which attract male insects.

7.3 Aphid

Aphids are always found on potato crops, from when shoots emerge up until the end of the vegetative growth stage. They are small, soft and green-yellow in color. Some of the adults have wings and some have not. These pests always group together, especially on those parts of plants shaded from direct sunlight.

Life cycle



Aphids reproduce in two ways: by laying eggs and having live young. Which birth process is used depends on environmental conditions and the availability of food. When food is plentiful, aphids give birth to live young. Populations develop quickly as this pest has many young, a short lifespan and pre-adult insects can also give birth.

Eggs hatch after three or four days. Young aphids, called nymphs, need five to eight days to become adults.

Damage symptoms

- *Direct damage*: Aphids damage plants by 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, 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.

Management

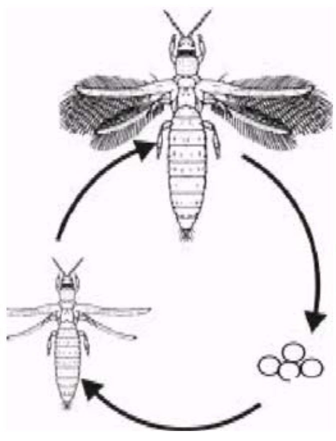
Aphids have many natural enemies: parasitoids, predators and pathogens. Potential predators include ladybird beetles, both adult and grub and,syrphid larvae all of which are commonly found in potato fields not sprayed with insecticides. A common parasitoid is *Dieretella* spp, easily recognized by the presence of mummified aphids in the colony. Aphids can also be killed by fungal infections and dead aphids blanketed in a white powder (the spores of the fungus that has killed them) are often found in fields that are not sprayed with insecticides.

Observation methodology

It is best to observe aphids in the morning by opening new leaf shoots or observing the undersides of young leaves. Another way to detect their presence is by looking for ants on the potato plants as they feed on the sugars secreted by aphids.

7.4 Thrips

Thrips (*Thrips* spp) are very small, have elongated abdomens and are yellowish or blackish in color. Although the adults have wings, these insect pests do not usually fly. They are often found on potato plants throughout all growth stages, from sprout development to tuber maturation.



Life cycle

Thrips reproduce by laying eggs. Nymphs emerge from the eggs. It takes between 7 and 12 days to develop from eggs into adult thrips.

Damage symptoms

As with aphids, thrips also cause direct and indirect damage:

- *Direct damage*: Thrips damage the undersides of leaves by sucking their juices. 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*: Thrips can carry and spread viral diseases.

Management

Thrips can be controlled by:

- *Natural enemies* – Particularly generalist predators can regulate thrips populations
- *Sufficient watering* – Thrips thrive in dry conditions and watering will increase moisture and inhibit their development.
- *Using black silver mulch* – Light reflected from the silvery surface illuminating the undersides of leaves can repel thrips.

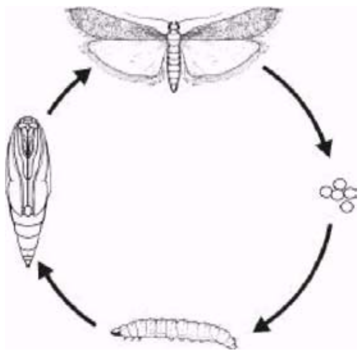
Observation methodology

It is best to observe thrips in the morning by looking directly at the undersides of young leaves.

7.5 Cutworm

Cutworms (*Agrotis* spp.) can be found in potato fields from when they are tilled up until crops are ready for harvesting. Cutworms not only damage potato plants, but also affect almost all types of plants including weeds.

Life cycle



Cutworms reproduce by laying eggs. Their life cycle includes eggs, larvae, pupae and moths. It takes up to 36 days for them to develop from eggs to adult insects. The various stages display the following characteristics:

- *Eggs* are laid on the surface of the soil, but are very difficult to see. On average, each female adult insect produces about 970 eggs, with a maximum of 2,370.
- *Larvae* live in the soil and are either yellow or blackish- green in color. They have striped markings running down the sides of their bodies. It is during this stage of their life cycle that cutworms affect potato plants.
- *Pupae* are brown, about 1.5 to 2.0 cm in length and are usually found in or on piles of leaf mould.
- *Adult insects* are black and white colored moths. They are not pests, as they feed on nectar.

Damage symptoms

These pests 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. Plants with severed stems have difficulty growing again. This pest can cause serious damage; particularly when crops are at 25 – 35 DAP.
Signs of damage on tubers are boreholes larger than those made by potato tuber moths.

Management

Management practices for this pest include:

- *Manual control* – Collecting larvae when tilling soil, planting, weeding and hilling up. Any larvae collected should be destroyed by burning or fed to chickens. You can collect larvae by dismantling the soil around affected plants.
- *Attracting cutworm larvae using rice bran* – Heaps of rice bran should be placed in several places in the late afternoon. Cutworm larvae are attracted to rice bran (and vegetable residues, such as chopped cabbage leaves) and will usually come

to eat them. They can be removed from the rice bran the following day and destroyed.

- *Biofumigation*- The use of biofumigation derived from brassica residues could be considered on soils heavily infested with cutworms.
- *Flooding field prior to planting*- Where/whenever possible farmers can consider temporarily flooding fields, particularly on severely infested fields.

Observation methodology

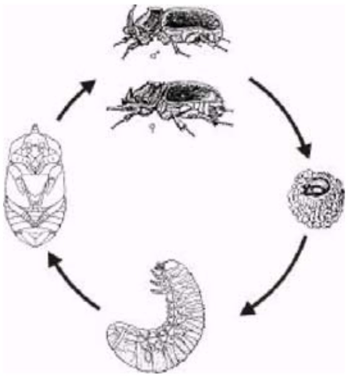
You can make observations in the morning, by looking for signs of cutworm damage and dismantling soil around affected plants. However, it is sometimes difficult to find the remains of affected plants as they are pulled into the ground. It is relatively easy to identify the larvae of the cutworm; when picked up, the caterpillar will curve itself in a characteristic C-shape.

7.6 White grub

Many plant species host this pest. White grubs live in loose soil, leaf mould or manure. This pest attacks potato tubers. Affected tubers can still be sold or consumed by farmers themselves.

Life cycle

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. This insect develops by laying eggs. White grubs develop for up to seven months, and then have a rest period of 40 days after which they pupate and remain in that form for two months.



Damage symptoms

Tubers damaged by white grubs have 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

This pest can be managed by:

- Collecting larvae when tilling soil, planting, weeding and hilling up. Any larvae collected should be destroyed by fire or fed to chicken.
- Avoiding to use *uncomposted* organic fertilizer, as it is a suitable breeding ground for this pest.
- Avoiding to plant potatoes in fields that were previously covered with grasses. If there is no choice, then you should plant several weeks after tilling the soil.
- *Biofumigation*- The use of biofumigation derived from brassica residues could be considered on soils heavily infested with cutworms.
- *Flooding field prior to planting*- Where/whenever possible farmers can consider temporarily flooding fields, particularly on severely infested fields.

Observation methodology

It is difficult to observe this pest, as it lives in the soil. Some plants can be pulled up at 70-75 DAP to look for signs of damage.

7.7 Mole cricket

Mole crickets attack numerous types of plants. They are active at night and adult insects are attracted to light.

Life cycle

They reproduce by laying eggs. Their life cycle is divided into the egg, pre-adult and adult stages. Pre-adult insects are similar to adults, but have no wings. Adults are similar to crickets, but have large, strong front legs, which they use for digging into the ground. All of their development stages take place in the ground.

Damage symptoms

Economic losses arise from damage to potato tubers. Affected tubers are full of holes eaten out by these insects. They cause more damage in the dry than in the rainy season.

Management

You can control mole crickets by clearing plant remnants from the field and using well composted organic fertilizer.

Observation methodology

This pest is active under the ground and therefore hard to observe.

7.8 Whitefly

Whiteflies not only affect potato plants but also other vegetable and grain crops. This pest has never caused a potato crop to fail.

Life cycle

Their life cycle is divided into egg, pre-adult and adult stages. Generally, it is easy to find adult whiteflies in potato fields. They are small in size (1-2 mm long), have wide wings, are white in color and are usually found on the underside of leaves.

Damage symptoms

Whiteflies damage plants by sucking their juices. Affected leaves become weak and eventually dry out. Whiteflies secrete sugars that stimulate growth of black mold, which affects the way leaves absorb sunlight.

Management

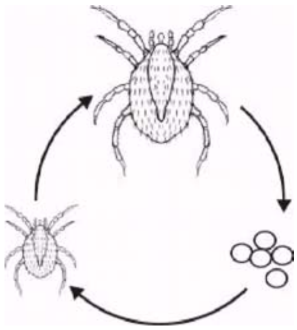
Conserve natural enemies and avoid the use of insecticides. Insecticide use actually triggers the resurgence of this pest.

Observation methodology

You can observe white flies by looking at the undersides of leaves.

7.9 Spider mite

Spider mites are not actually insects but still belong to the arthropod family. They are small (about 0.5 mm in length), have four pairs of legs and are yellow or reddish in color.



Lifecycle

The stages of the spider mite's lifecycle are egg, pre-adult and adult. Eggs hatch after three or four days. In both their pre-adult and adult stages spider mites are similar to spiders. They are pests during both pre-adult and adult stages. The pre-adult stage lasts for about 6-10 days. Adults can lay 10-15 eggs a day.

Damage symptoms

This pest damages young parts of plants by puncturing them and sucking the juices. Affected leaves look spotty, while affected shoots curl up and do not grow. In severe infestations, leaves and shoots dry out and die.

Management

Management techniques for controlling spider mites:

- Conserve natural enemies. Spider mites have many natural enemies, including predators (e.g. predatory mites), parasitoids and pathogens.
- Avoid warm dry environmental conditions. Make sure you water plants, especially when you plant them in the dry season.

Observation methodology

It is best to make observations in the morning, by looking directly at the undersides of leaves or at new shoots.

7.10 Picture of major potato pests

Lyriomyza huidobrensis – adult leafminer fly

Leafminer fly damage

Potato tuber moths (2 species)

PTM larva in stem

PTM damage on leaves

PTM damage in tuber

Thrips on underside of the leave

Aphids on underside of leaves

Whitefly adults

Cutworms in tubers

Cutworms on leaves

Mite adults

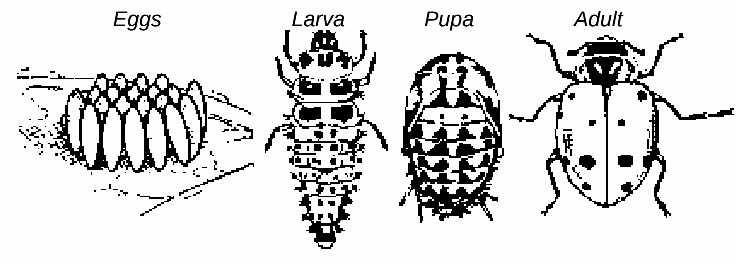
Mite damage

8 MAJOR NATURAL ENEMIES OF POTATO PESTS

8.1 Predators

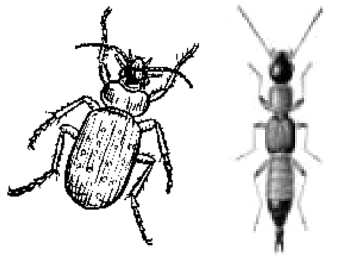
8.1.1 Ladybird

There are two kinds of ladybirds; dull-colored ladybirds that eat plant and shiny ones that are predators of other insects. Numerous species of predatory ladybird can be found on potato crops. You can differentiate between ladybirds by the color of their hard wings. There are red ladybirds, yellow ladybirds and speckled ladybirds. Both pre-adult and adult insects are equally effective preying and at controlling pests. They particularly prey on aphids, thrips and mites. Pre-adult insects are more voracious, and can eat more than 30 preys in a day. They kill and eat all parts of their prey.



8.1.2 Ground and rove beetles

Beetles are hard-bodied flying insects. There are many species in this insect group. Grubs and adults of the ground beetle can prey on around three to five insects a day. They prey on insect larvae, aphids, thrips and mites. Rove beetles, which are black and red in color and have short outer wings, are very active and can be seen running around on the crop foliage hunting for eggs, larvae and small insects.



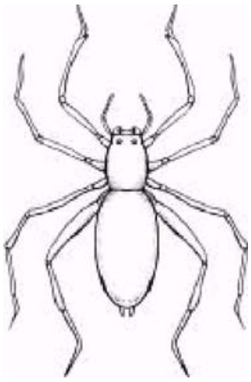
8.1.3 Hoverfly or Syrphids

These flies are found on all crops and include a variety of species. Adult insects tend to hover or fly in one spot, hence the name hoverfly. Pre-adult insects are predatory, commonly referred to as syrphids, while adults feed on nectar.

The larvae of these insects have extremely small heads, with hooked mouthparts; they have no legs, and soft translucent bodies. You can find them preying on groups of aphids by puncturing them with their hooks and sucking out their fluids. These predators can prey on around 8-22 insects a day.

Adult insects are brightly colored with different species having different colorations. They have one pair of wings and move around very actively.

8.1.4 Spider

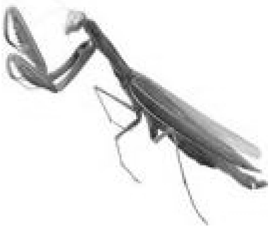


Spiders have great potential as predators on potato crops. Apart from their many species, spiders also proliferate over large areas. Commonly found spiders on potato crops are hunting spiders, wolf spiders, jumping spiders, orb web spiders and long-jawed spiders. Some spin webs to trap their prey, while others pursue their victims. Some spiders live on potato plants, and others live on the surface soil.

Both pre-adult and adult spiders are predatory. Spiders prey on either flying or crawling insect species that move around actively. Their predatory capacity depends on the spider species and type these could be butterflies, moths, grasshoppers, crickets, flies, etc.

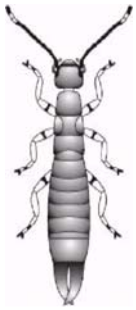
8.1.5 Praying mantis

Praying mantises are rarely found on potato crops. These predators not only prey on pests, but also on other predatory insects or parasitoids. They prey on flies, bees, butterflies and small spiders.



Pre-adult and adult praying mantises are predatory. They use their strong front legs to capture their prey. These predators do not actively pursue their prey, but wait and catch those insects that come too close. Because of their wide range of prey, these predators are not so important in regulating numbers of insect pests on potato crops.

8.1.6 Earwig



Earwigs move around actively on the surface of the soil. They have a pair of pincers at the back of their abdomens. These predators vary greatly in color and size. They are regularly found in dry regions, hunt at night and hide in the soil during the day. Adult insects can live for three to five months. These predators prey on aphids, thrips and several kinds of insect larvae.

8.1.7 Predatory fly

Predatory flies (or killer flies) look similar to houseflies but are smaller in size at around 0.4 - 0.6 cm in length. They are black with abdomens that narrow towards the end and prey on aphids, thrips, leafminer flies, etc.

Predatory flies (e.g., *Coenosa spp.)* are often found preying on other insects in potato fields. Adult flies actively hunt their prey, which may be in the air or settled on plants. They grasp their prey with their two front legs, and then suck out their juices until their victims die. Before striking, these flies usually wait on stakes or the higher parts of plants to spot their prey. They can prey on between 5-10 insects a day. Their larvae develop well in soils rich in organic matter.

8.1.8 Other predators

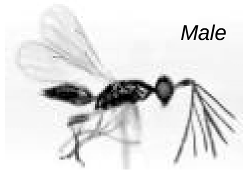
Other predators found in potato fields are dragonflies, crickets and red ants. These insects are highly abundant on potato crops that have not been sprayed with insecticides, and are suitably effective at controlling insect pest numbers. Predatory ability depends on the species and development stage of the predator and its prey.

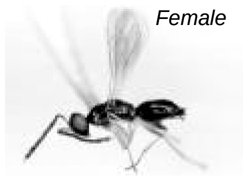
8.2 Parasitoids

8.2.1 Parasitoids of leafminer fly

A. Hemiptarsenus varicornis

Adult insects are a kind of parasitic wasp. They have blue-green metallic bodies measuring 1.3-1.2 mm in length and have two pairs of wings. These parasitoids are commonly found on potato crops. This parasitoid specifically parasitizes leafminer flies when they are still in their larval form. The wasp lays eggs on the leafminer larva. After hatching, the parasitoid larva lives on the leafminer fly larva by sucking its body fluids. Host larvae growth is stunted and they often die. On potato crops, rates of parasitism can reach 70%, albeit mostly too late in the season after a lot of damage has already been done. This parasitoid is not that effective at controlling quantities of leafminer flies by itself, but is complementary in a diverse natural enemy complex in the potato field.





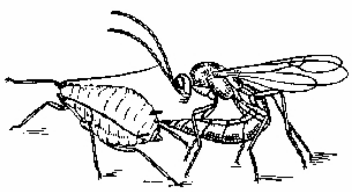
B. Opius sp.

Adult *Opius* wasps have black bodies, two pairs of wings and jointed antennae. Although it is not so common, this parasitoid is generally more effective than *Hemiptarsenus*. It also parasitizes flies in their larval and pupal stages. The larva and cocoons of this parasitoid live inside leafminer fly larvae and pupae. Parasitized larvae and pupae will die. Intensive use of insecticides on potato crops will cause very low levels of parasitism.

C. Gronotoma sp.

Adult insects have black bodies and jointed antennae that look like beads. This insect solely parasitizes leafminer fly larvae. Parasitoid larvae live inside the bodies of leafminer fly larvae. Parasitized leafminer larvae can pupate, but will not develop into adult flies.

8.2.2 Parasitoids of other potato pests



Other parasitoids are found not only on leafminer flies, but also on other insect pests, such as aphids, cluster caterpillars, potato tuber moth larvae or cabbage looper larvae. The appearance of mummified aphids is a clear indication of the presence of the common parasitoid, *Dieretella* spp. Another way to determine whether parasitoids are present is to remove insect pest larvae from the field and keep them in an enclosure for several days. Observe what insects emerge, the insect pest or a parasitic wasp or fly.

8.3 Pathogens

8.3.1 Granulosis Virus (GV)

GV is a virus that can infect potato tuber moth larvae and is effective for managing this pest on potatoes in storage. Tuber moth larvae infected with GV are apparent from their slow movement, smaller bodies, their milk-white color, and ultimate death. Dead larvae will break open and exude slime.

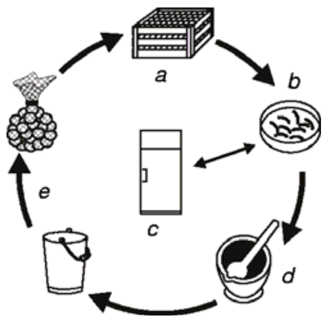
Farmers can produce GV themselves and use it in storage areas. The steps in producing GV are (1) rearing potato tuber moths as hosts, (2) propagating GV, and (3) formulating GV for use.

A. Propagating potato tuber moths as media for producing GV

- Rear potato tuber moth larvae collected from the field in propagation boxes, providing them with potatoes to feed on. To make it easier for the larvae to enter the potatoes, cut them into 1-1.5 cm thick slices and make holes in these slices with a nail.
- Check and clean the box every day to make sure the larvae do not die from fungal or bacterial infection.
- When larvae are ready to pupate, move them to another box lined with a 2-3 cm layer of sterile soil to allow pupation.
- Harvest the pupae when you are sure all the larvae have pupated.
- Move the pupae into plastic boxes covered with gauze.
- When the pupae become moths, smear a 10% concentration of honey on the walls of the box.
- Place a thick layer of tissue paper on the box top for the moths to lay their eggs on.
- Collect eggs every day and label them showing the date they were collected.
- Place eggs in a refrigerator or a cool place for several days to stop them from hatching too soon.
- The next stage is hatching the eggs to propagate larvae or produce GV.

B. GV propagation

- The virus can be sourced from the field or supplied by a laboratory.
- Crush up 20 larvae infected with the virus and add a liter of water and some emulsifier compound.
- Immerse potatoes or potato tuber moth eggs into the mixture for one minute, and then allow them to air dry. The virus will stick to the surface of the tubers or potato tuber moth eggshells.
- Place the tubers and the eggs into the propagation box.
- To treat tubers, eggs or newly hatched potato tuber moth larvae, place them into a storage box that already contains a tuber covered with GV. To treat eggs, dip them into a GV solution and then put them with a potato that has not been treated with GV.
- After 2-10 days, harvest infected larvae for use as a



a. Collect potato tuber moth larvae infected with GV
b. Isolate larvae infected with GV
c. Store them in a cold place
d. Grind them up
e. Mix GV with water and dip

biological insecticide or for the next propagation. It is best to remove larvae when they have just died and their bodies are still intact.

tubers in solution

- Keep larvae infected with GV in a refrigerator at 4-7°C.

GV formulation

- Crush up 20 infected larvae and add 1 liter of water and some emulsifier.
- Add 1 kg talc (magnesium silicate), stir thoroughly and allow the mixture to air dry for several days in shallow trays.
- The formulation is ready for application when storing tubers in the storage areas.

C. Applying GV at storage

- Apply the GV formulation before storing tubers. You will need 5 kg of GV formulation for every ton of tubers.
- Place GV formulation into a sack(amount according to recommended dose and volume of sack). Put the tubers for storage into the sack and shake it until you think all the tubers are evenly coated with GV formulation.
- The coated tubers can then be put into storage.

8.3.2 Bacillus thuringiensis (Bt)

Bt is found naturally in soil and plants. There are numerous strains of Bt capable of infecting various insect types including larvae and beetles that can affect potatoes. Bt is now available in commercial formulations in farming supplies shops. Example of commercial formulations of Bt are Thuricide, Dipel, and Delfin.

Bt poisons and kills insects when they eat it. It is best to apply Bt directly to the parts of plants being eaten by pests. Apply Bt in the late afternoon as Bt-toxins are easily inactivated by direct sunlight. After application, the insect will die only after 2-3 days, but will stop eating very soon.

8.3.3 Nematodes

Nematodes (tiny worms) can be a component in biological control as they can attack and kill pests. One insect susceptible to nematodes is the leafminer fly in its pre-adult and adult forms. Various species of nematodes, both those in the ground and on plants, can infect leafminer flies. They infect them by entering their bodies, growing inside them and eating their bodies from the inside. Affected flies will eventually die.

8.3.4 Fungal pathogens

There are many types of fungal pathogens that can infect insects. Some examples are *Beauveria bassiana* and *Metarhizium anisopliae*. Collecting diseased insects and observing their symptoms will provide a lot of information about these pathogens that can be developed as agents of control. Some commercial formulations are currently available on the market.

8.
MAJOR NATURAL ENEMIES OF POTATO PESTS

9 DISEASE ECOLOGY

9.1 Plant diseases and their causes

Disease is a process in which certain parts of a plant are infected by a microorganism and cannot function properly. Common causes of diseases are fungi, bacteria and viruses, which are incredibly small organisms mostly invisible to the naked eye. Nematodes are also classified under the disease causal agents, although strictly spoken they are not microorganisms.

The various disease causal agents are characterized as follows:
- *Fungi* – These are important agents of disease because there are so many kinds. Fungi have many cells that are formed like threads, and can reproduce from cut threads or spores. These disease agents can enter plants actively through lesions, natural holes in plants, be carried by insects, or enter directly through the surface of a plant. Fungal diseases can spread through water, soil, wind and seeds and on farming tools. One example of a fungal disease on potato is late blight.
- *Bacteria* – Bacteria, smaller in size than fungi, are single-celled organisms capable of reproducing by spores and splitting themselves. They develop incredibly rapidly in supportive environmental conditions. Bacteria enter plants passively through lesions and natural cavities or are carried by insects. Diseases caused by bacteria are bacterial wilt and tuber rot.
- *Viruses* – Viruses are even smaller than fungi and bacteria. They cannot live independently and have to be supported by living in the cells of other organisms. Viruses require plants cells to split and reproduce. Viruses spread from one plant to another through plant matter (seeds), or carried by insects such as thrips and white flies.
- *Nematodes* – Nematodes are classified as animals, are multi-celled and shaped like tiny worms. They affect plants by puncturing and sucking. Nematodes can spread actively or passively when carried by soil, water and wind, or on farming tools and seeds.

Diseases are more difficult to detect than insect pests, because their causes are extremely small and invisible to the eye. The presence of a disease is only apparent when symptoms begin to appear.

9.2 Disease management

9.2.1 Principles of disease management

Diseases can break out when there is the following favorable relationship between the disease causal agent (also called the pathogen), host plants and the environment:
- The pathogen has the capacity to infect.
- Plants are in a vulnerable condition, due to one or more of the following possible reasons:
  - The plant type and/or variety has no genetic resistance to the disease.
  - Plants are at a vulnerable growth stage during which the disease can develop more easily.
  - Plants suffer from poor health as a result of inadequate or unbalanced nutrients management, which makes them more susceptible.

- The environment supports the development of the pathogen, for instance:
  - Suitable temperature and relative humidity for disease development (often high temperatures and high humidity).
  - The presence of pathogen carriers, such as wind, water, farming tools, insects, etc.

These three factors are related to each other as depicted in the so-called disease triangle (see Figure 3).

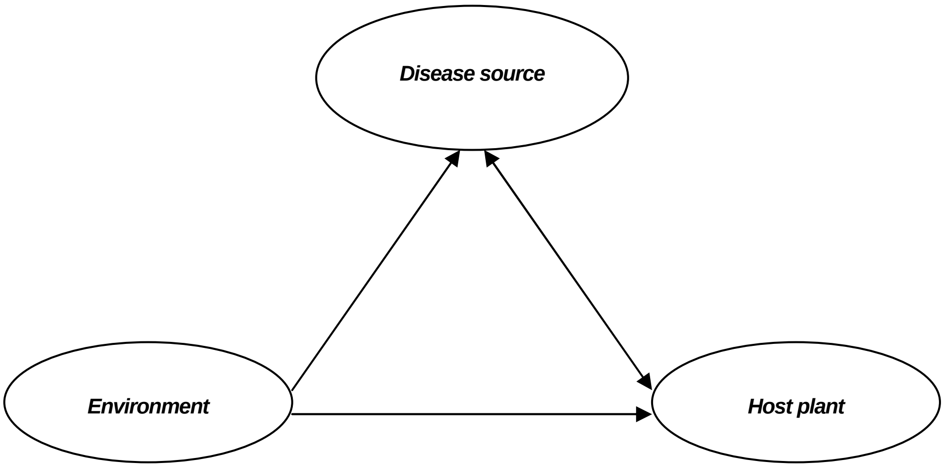


Figure 3: The disease triangle

A disease management strategy can be designed by influencing or changing any one of these factors of the disease triangle, and hence obstructing disease development, for instance in the following ways:

Influencing the DISEASE SOURCE by:

- Reducing the presence of diseases in the field by carrying out sanitation, destroying infected plants, selecting disease-free fields, using clean water for irrigation and using disease-free seed.
- Breaking the disease chain by rotating crops.
- Using composted organic fertilizer, which increases the quantity and role of living organisms that can combat diseases, and does not introduce disease causal agents.

Influencing HOST PLANT health by:

- Using healthy seed to produce a homogeneous, healthy crop.
- Providing balanced fertilization and using composted organic fertilizer to promote plant health.
- Using resistant varieties where possible.

Influencing and changing ENVIRONMENTAL conditions by:

- Planting potatoes at the end of the rainy season or at the end of the dry season, so the weather is drier and less suitable for disease agents to develop (note: this refers to wet tropical highland conditions).
- Making seedbeds higher in the rainy season so the soil is not too wet or moist.
- Adjusting planting density as to reduce humidity around the foliage during the wet season.

9.2.2 Biological control

As with insect pests, disease agents also have enemies. These are in the form of fungi or bacteria, many of which can be found in healthy soil and composted organic fertilizer. These natural enemies either parasitize on or compete with the plant pathogen. It is advisable to use large quantities of organic fertilizer when trying to cultivate healthy potatoes, which provides beneficial microorganisms to the soil to compete with soil-borne pathogens. Some of these microorganisms are available in commercial formulations, for instance the antagonist fungus Trichoderma which is a fungus that eliminates other soil-borne fungi.

9.2.3 Chemical control

It is still hard to remove pesticides for disease management from potato production systems, particularly fungicides used for controlling late blight. Farmers have been using pesticides very inappropriately, causing resistance in disease causal agents and residues on produce, so better management techniques are essential. Furthermore, pesticides are an environmental pollutant. More information on fungicide management is provided in the section on late blight (10.2.1) below.

10 MAJOR POTATO DISEASES

10.1 Bacterial diseases

10.1.1 Bacterial wilt

Bacterial wilt is a disease caused by the bacterium *Ralstonia solanacearum*. It does not only infect potatoes, but can also damages plants such as chili, tomato, tobacco and eggplant, as well as several species of weeds. This disease is extremely dangerous, especially in regions where potatoes are cultivated intensively. In some areas, it is the biggest cause of reduced production. Fungicides are sometimes used by farmers to control this disease, but these are ineffective, because the causal agent is not a fungus.

Symptoms

The symptoms of bacterial wilt infection can be seen on all parts of infected plants. They begin to wilt, starting from the tips of the leaves or where the stems branch out, and then spreading to all parts of the plant. Leaves become yellow at their bases, then the whole plant wilts and dies. When stems are cut a brown colored ring will be visible.

Mildly infected tubers will not show any outward signs of disease as symptoms will be hidden from view. When a tuber is cut in half, black or brown rings will, however, be visible. If left for a while or squeezed, these rings will exude a thick white fluid. A further symptom is fluid coming out of tuber eyes. This can be signified by soil sticking to tuber eyes when crops are harvested. Serious infection causes tubers to rot.

Source and spread

On potato crops, bacterial wilt originates from:

- Soil - bacterial wilt can survive in soil without a host for several seasons.
- Water.
- Seed tubers.
- Rogue potato plants or other crop or weed plants that can host bacterial wilt.
- Potato plant remnants.

The disease can spread from field to field or from plant to plant in one field via:

- Infected seed.
- Air.
- Water.
- Soil.
- Farming tools.
- Livestock and people.

You must not store tubers infected with bacterial wilt or use them for seed. The disease will spread rapidly in the warmer temperatures in storage areas, and will cause tubers to rot. Infected seed can also be a source of the disease in the field.

Management

Bacterial wilt cannot be controlled with fungicides, and bactericides are seldom available to farmers and generally very expensive. Management principles for bacterial wilt are as follows:

- Remove sources of disease from the field by:
  - Planting potatoes in soils free from bacterial wilt.
  - Using healthy seed not infected with bacterial wilt.
  - Rotating potato crops with other non-solanaceous crops. Good practice is to rotate potatoes with corn or sweetpotato. In fields with serious infections, it is best to plant non-host plants for more than 2 years, as agents of bacterial wilt can survive in the ground without host for that amount of time.
  - Removing infected plant debris before planting and clearing weeds away before planting, while plants are growing and at harvesting time.
  - Using composted organic fertilizer not infected with bacterial wilt.
  - On heavily infested soils, apply brassica residue based biofumigants.
- Inhibit the development and spread of bacterial wilt in the field by:
  - Putting dolomitic lime on the soil around infected plants as this increases soil pH, creating a less favorable environment for the pathogen..
  - Carefully managing irrigation in the field by digging channels that allow water to flow freely from the field. Bacterial wilt will spread rapidly in flooded fields. Also when watering the field, try to make sure water does not flow over the surface of the field.
  - Using water not contaminated with bacterial wilt to irrigate the crop.
  - Cleaning the field by destroying (burning or burying) plants and tubers infected with bacterial wilt throughout the whole season.
  - Cleaning farming tools after use.

Observation methodology

You can begin making field observations for bacterial wilt at 35 DAP by looking at symptoms on affected plants. Identifying an infection as bacterial wilt can be done by using the following methods:

- *Testing plants with vascular flow test* – This will determine whether plants with symptoms of wilting are infected by bacterial (and not fungal) wilt. Cut 2-3 cm lengths off stems at the base of plants showing signs of infection. Suspend these pieces vertically in water and leave for a while. If the plant is infected with bacterial wilt, milky threads of bacterial ooze will flow from the stem pieces into the water.
- *Testing tubers* – Cut a sample tuber near its base, leave it for a few minutes, or squeeze it. If it is infected with bacterial wilt, it will exude a thick white fluid.
- *Testing soil with bioassay test* – Three-week old tomato seedlings grown on BW-free substrate and several soil samples suspected of infection are used for testing. Put the soil samples in pots and water them with clean water. Plant five tomato seedlings in each pot, and tend them for one or two months. Make observations by looking at symptoms that appear on each of the plants in the pots. When wilting appears, test the plants with vascular flow tests. Wilting plants that exude a milky flow in the vascular flow test are proof that their pots contain infected soil. You can also do this test to determine if manure contains bacterial wilt.

10.1.2 Blackleg or soft rot

Blackleg or soft rot is a widespread disease caused by the bacterium *Erwinia* spp., which affects stems and tubers particularly in warm and humid regions.

Symptoms

Blackleg or soft rot can affect potatoes at various stages in their growth. Stem bases become black, rot and exude slime. Mild attacks in young plants can stunt growth and cause leaves to yellow and curl upward. Severe infection can cause plants to wilt and die. Tubers may become infected either in storage or in the field. They rot, but do not exude the white slime you will find with bacterial wilt. Damage caused by pests, small worms or harvesting can facilitate infection as the soft rot pathogen can not infect healthy tissue on its own..

Source and spread

Blackleg or soft rot is spread in nearly the same way as bacterial wilt, i.e. through seeds, other infected plants, soil and water. It can spread from plant to plant via water, wind, soil, and seed, and on farming tools or people.

Management

Management of Blackleg or soft rot implies the following practices:

- Avoiding planting in wet or flooded fields.
- Improving irrigation systems to allow water to flow in and out of the field more easily.
- Using healthy seed not contaminated with the disease,
- Destroying sources of the disease, particularly infected plants.
- Avoiding damage to tubers when weeding, hilling up, harvesting and transporting harvest produce.
- Harvesting in dry weather conditions.
- Sanitation of the field for the whole season.

10.1.3 Common scab

Common scab, caused by the fungus *Streptomyces scabies*, is common in fields with low soil pH. This disease does not cause reduced production, however, it does affect the appearance, and hence quality, of tubers. These can still fetch almost the same price as unaffected tubers in local markets, but problems arise when they are sold to potato processing companies or for export.

Symptoms

Common scab affects potato tubers. Damaged tubers have rough, cracked skins, with scab-like spots. Severe infections leave potato skins covered with rough black welts.

Source and spread

Common scab can come from soil, uncomposted manure or seed, and spreads through contaminated soil, seed and water.

Management

You can control common scab by:

- Avoiding planting in fields with low soil pH, or increasing soil pH by adding lime.
- Using healthy, disease-free seed.
- Rotating potatoes with other non-host crops, such as cabbage or corn, to prevent the disease from spreading to the following season’s potato crop.
- Avoiding damage to tubers when weeding, hilling up, harvesting and transporting produce.

- Destroying infected plants and tubers.
- Managing tuber damaging pests, as damaged tubers are more susceptible to common scab.

Observation methodology

You should make observations for common scab just prior to and during harvest time, by taking random tuber samples and inspecting them for symptoms of the disease.

10.2 Fungal diseases (mold)

10.2.1 Late blight

This is the most important disease, caused by the fungus *Phytophthora infestans*, affecting potato crops in the tropical highlands. It regularly causes crop failure, infecting plants from the tuber initiation stage up until harvest. Severe infections occur at times of high rainfall, high humidity and low temperatures. Farmers rely solely on intensive use of fungicides for controlling the disease, but this is mostly ineffective.

Symptoms

This disease damages leaves, stems and tubers. Affected leaves appear blistered as if scalded by hot water and eventually rot and dry out. When drying out, leaves turn brown or black in color. When infections are still active, spots appear on the undersides of leaves blanketed in what looks like flour. Affected stems begin to blacken from their tips, and eventually dry out. Severe infections cause all foliage to rot, dry out and fall to the ground, stems to dry out and plants to die. Affected tubers display dry brown-colored spots on their skins and flesh. This disease acts very quickly. If it is not controlled, infected plants will die within two or three days.

Source and spread

Sources of late blight are the air, soil, water, seed and remnants of infected plants. It spreads very rapidly via air, soil, water and seed. The white powder on the surface of affected leaves can be carried by the wind and spread the disease to other plants.

Management

This discussion is for farmers who can identify the symptoms of late blight. Late blight management practices must be based on the relationship between the disease and factors that influence its development. These factors are as follows:

- The amount of initial inoculum to start the disease off with.
- The rate at which the disease progresses.
- The time since the initiation of the disease

Key practices in late blight management are (1) the use of resistant varieties (if available), (2) routine observations, and (3) developing management techniques based on these observations. Varieties with good resistance to this disease are not yet commonly available to Asian farmers. Therefore, management techniques still emphasize the more judicious and appropriate use of fungicides. The main aims of fungicide management when dealing with late blight are:

A. Limiting initial inoculum of the disease in the early plant growth stages.
B. Reducing the spread of the disease.
C. Reducing the duration of infection.

D. Avoiding serious contamination of the environment.
E. Reducing potato production costs.

The first three points of this list are discussed in more detail below.

A. Limiting initial inoculum of the disease in the early plant growth stages

A.1. Clearing fields of sources of infection

- Using healthy seed not infected with late blight.
- Removing sources of infection by destroying remnants of plants from the previous crop.
- Destroying infected leaves, plants and tubers.
- Crop rotation.

These techniques are extremely important and provide a high likelihood of success if farmers plant potatoes in fields that have never been infected with late blight. However, they can be less effective if surrounding potato crops are infected with late blight and are not managed using the same techniques. Pathogens are more likely to spread from other fields on the wind than they are through seed or plant remnants.

A.2. Using resistant plants

Many resistant varieties can reduce instances of early late blight infection. However, late blight resistant varieties are as yet scarcely available in Asia.

A.3. Fungicide use management

Proper management of fungicide use can protect plants from early infection. But where, when and how is fungicide use effective?

Fungicide application techniques:

- *Treating tubers.* Research has shown that the most effective way to use fungicides is to treat seed. The drawback to treating seed with fungicides is it can increase the possibility of resistance in the disease itself.
- *Treating foliage.* The most common form of application is spraying foliage with fungicide just after plants emerge from the ground. If many plants around the field are infected with late blight, then newly emerged plants must be sprayed with fungicide. Any further application should be done based on observation results. When active spots are found, the plants should be sprayed again.

Initial application:

- The first application is done immediately after you suspect late blight spores are present in the air. They will be if the surrounding fields are infected. This requires more thorough observations of farmers' own, and surrounding fields.
- If you are unsure, assume that spores are present in the air, and you will need to spray plants soon after they emerge from the ground.

Fungicide types used for initial application:

- Do not mix fungicides in a single application.
- Use systemic fungicide for the initial application. Almost all systemic fungicides contain adhesive chemicals, so no other adhesive compounds are necessary.
- Four reasons for using systemic fungicide:
  - o When we think there are pathogens present in the air, we assume that latent infection has occurred so we must spray plants using systemic fungicide.

- In their early growth phase, plants grow rapidly and systemic fungicide can spread into new tissue, thus protecting all parts of plants from early infection of late blight.
- Spraying during the early growth stage only requires a small amount of fungicide and minimal cost.
- Systemic fungicides can also control late blight carried by seed potatoes.

How to increase effectiveness of initial fungicide application:

- Try to ensure plants reach their early growth stage simultaneously. Uniform growth will improve fungicide use effectiveness. You can achieve this by:
  - Making good seed beds.
  - Planting at a uniform depth.
  - Using good quality seeds. Good quality seeds are characterized by uniform shoot length.
  - Using proper equipment - Choose a small spray nozzle, so the liquid sprayed sticks easily to all parts of the plants.
  - Using clean water - It is best not to use dirty water when making fungicide solutions.
  - Fungicides should evenly coat the tops and bottoms of leaves.

Appropriate doses
Recommended dose for most fungicides is 2.5 g fungicide/liter of water. This is a general recommendation; however, to use appropriate amounts, you should look at the recommended dose mentioned on the packaging. For example, fungicides with the active ingredient fluazinam are used in lower doses.

B. Reducing the spread of the disease

There are four factors to disease development capacity:

- The efficiency of agents causing the disease.
- The development stages of the disease from initial infection to producing spores.
- The development level of lesions.
- The capacity to form spores (per unit area).

Farmers should understand the factors influencing the development of this disease, at least at a conceptual level, because this knowledge is the foundation for developing management techniques. Modifying one factor will change disease development. Techniques that can be implemented are described in the following sections.

B.1. <u>Use of fungicides</u>

Contact fungicides can reduce infection and influence the formation of spores and the spread of rot on the leaves. With the first application, farmers must decide when, what with, and how much?

Fungicide application times
This is very difficult to get right, especially in terms of optimizing fungicide use, because of how it relates to other factors.

- Make regular observations (at least 3 times a week) by looking for symptoms of the disease. Base observation intervals on your experiences with the way this disease develops. Appearance of symptoms can be your sign for applying systemic fungicide.

- A decision-making system can be used as the basis for applying fungicide. You can, for example, base your decision to start spraying on how many signs of the disease appear in the field.
- An application system based on rainfall can be developed based on local conditions. In Latin America, for instance, the following system was tested:
  - If you plant varieties that are not resistant to the disease, you should spray the crop when rainfall reaches 100 mm after falling for at least 5 days.
  - If you plant resistant varieties, you should spray when rainfall reaches 300 mm after falling for at least 10 days.

Types of fungicide to use

- The theory is that appropriate application methods should be used to ensure foliage gets a more even coverage of contact fungicides.
- In very wet conditions, you can use an adhesive compound. It is recommended that you rotate contact and systemic fungicides. In Latin America, it is recommended to use systemic fungicide 7-10 days after applying contact fungicide, and contact fungicide 10-14 days after applying systemic fungicide. Under different condition appropriate intervals should be tested.
- If you find many symptoms of the disease, systemic fungicide is recommended. Systemic fungicides with a low risk of causing increased resistance in late blight should be used. These fungicide types can be rotated in 10-15 day intervals.
- The spraying pattern is: systemic – contact – contact – systemic.

Application methods

To improve effectiveness, leaf surfaces should be completely coated when spraying. Things to pay attention to are:

- *Using suitable sprayers* – These should still have decent spraying pressure and appropriate nozzles (yellow code).
- *Using clean water with a good pH level*. Make sure the water source is disease free.
- *Using appropriate quantities*. Check the quantities recommended on the packaging.

Frequency of application

Systemic fungicides with added adhesives will not wash off for set periods of time, so farmers can arrange their spraying intervals around the minimum amount of time the fungicide can last in the field. Spraying intervals will be longer for systemic than for contact fungicides.

B.2. Management through cultivation techniques

Effective irrigation systems

Fields should not be flooded with water, or be too humid. If possible planting should be in line with wind direction.

Disposing of infected leaves

Farmers usually use this technique, which is effective for reducing levels of infection, especially mild infections during the early growth stage of plants.

Plant density (spacing)

This is an important aspect of late blight management. If plants are too close together, then humidity increases and supports the development of late blight. When planting in the rainy season, plants should be spaced about 30 cm x 80 cm apart.

B.3. Using resistant varieties

Using resistant varieties can reduce infection from disease, disease development levels and spore-forming capacity. However, resistant varieties are currently unavailable at a commercial level in Asia.

B.4. Improving plant health

Evidence shows that healthy plants can increase their resistance to late blight.

C. Reducing the duration of infection

The shorter the time plants are infected by late blight the better. The following strategies are for reducing exposure period.

C.1. Using short-duration varieties

Use short-duration varieties so the crop's critical growth period is not overly long.

C.2. Using seeds that are ready for planting

Seeds should be in optimum condition for planting so they grow quickly, uniformly and healthily. Storage techniques that optimize light will promote uniform sprouting so plants grow quickly and are less susceptible to infection from disease.

C.3. Planting healthy seed

Diseases carried by seed can reduce sprouting levels and cause uneven plant growth.

C.4. Cutting back foliage when tubers reach their optimum size

This technique can help prevent disease moving from foliage to tubers or to surrounding potato plants. You should destroy the parts you cut from the plants either by burning or burying them. Plants can be cut back at 80 DAP.

Observation methodology

Observation of the disease must be intensive, beginning when plants emerge from the ground. It is best to make observations in the morning once every two days, looking especially at active spots.

10.2.2 Early blight

Early blight caused by the fungus *Alternaria solani* is found in all potato producing regions. It is not as important as late blight, because it rarely causes severe damage or crop failure.

Symptoms

Early blight affects old leaves; its symptoms are dry brown spots, usually bound by the leaves' ribs. This disease first becomes apparent during the tuber bulking stage and develops leading up to harvest.

Source and spread

Sources of infection are contaminated seed and plant remnants. The disease is spread via wind, water, soil and seeds.

Management

Management should be carried out when this disease is discovered in the vegetative growth or tuber initiation stages. Infection in the tuber bulking stage does not affect harvest quality or yield; therefore, it is not economical to manage the disease during this stage.

Management techniques for this disease include:
- Removing sources of infection, using healthy seed, destroying contaminated plants and crop rotation.
- Using good irrigation systems to prevent the disease spreading through water.
- Balanced use of fertilizer to produce healthy plants more resistant to infection from this disease.
- Cutting back stems at 80 DAP, to prevent the disease spreading to tubers.

10.2.3 Fusarium wilt

As with early blight, this disease, causes by the fungus *Fusarium* spp, is not a major problem in potato cultivation in the tropical highlands. Attention should be paid when planting in warm temperatures or in the dry season.

Symptoms

Fusarium wilt affects potatoes in the field and in storage. Affected plants display spots and yellowing of leaves. It is more of a problem when it infects tubers in storage. They become dry and hollow, and concentric circles appear on their skins.

Source and spread

The sources of this disease are contaminated soil and other infected tubers. It spreads via soil, wind or water.

Management

This disease is generally managed in the storage area, where infection is more damaging than it is in the field. You can control this disease effectively by sorting and destroying infected tubers in the storage area.

10.3 Viral diseases

A common problem when cultivating potatoes is reduced yield from one generation to the next. Farmers often consider the cause to be old and degenerated seed potatoes.

In fact, this yield reduction is caused by viral infections residing in the seed tubers. These diseases are very varied and display a multitude of symptoms. It is difficult for farmers to gain an understanding of viral diseases because:
- Their causal agents are tiny and invisible to the eye.
- Viral infections rarely cause plants to become damaged or die. The symptoms visible, if any at all, are changes in the shape of plants. Consequently, most farmers consider viral diseases harmless.
- It is difficult to differentiate between symptoms of one virus and another, as they are all very similar. Thorough testing calls for equipment and expense well beyond farmers’ reach.

Viral diseases have developed from one generation to the next primarily due to farmers' habit of basing their seed potato selection on the size of the potatoes alone. Generally, viral diseases lead to smaller potato tubers being produced. Consequently, when tubers are sorted and selected for seed, the majority of seed potatoes chosen are those already infected with viral diseases.

A key factor when obtaining seed from your own field is selecting healthy plants for parent stock.

Despite variations, management principles are nearly the same for all viral diseases. Viruses can be controlled by:

- *Using virus free seed*: It is very risky to select seed potatoes based on size alone, as plants infected with viral diseases generally produce smaller tubers. Strict sorting and selection is highly recommended when a part of the harvest will be used for seed.
- *Destroying plants infected with viral diseases*: Plants displaying symptoms of viral diseases must be pulled up, collected and destroyed. Viruses can spread from one plant to another through vectors, so removing infected plants will also remove the source of disease for other plants.
- *Controlling insects that can spread viral diseases*: Generally, sucking insects such as aphids, thrips, mites and whiteflies can spread viruses. Therefore, management of these insects can reduce the spread of viral diseases.
- *Using plant resistant varieties*: This can only be done if available in sufficient quantities.
- *Not using pesticides*: Viruses cannot be controlled by any form of pesticide.

10.3.1 Leafroll virus

Potato leafroll virus (PLRV) is an important disease in potato plants, and can cause reduced yields of up to 90%.

Symptoms

Leaves curl upward and turn pale yellow. If you press them they feel brittle and fragile. In advanced infections, plant growth becomes stunted, leaf stems stand upright, leaves curl, tighten and turn pale green. Severe infections cause potato plants to produce tiny tubers, or prevent them from producing any tubers at all.

Source and Vector

PLRV can be introduced into a potato field by infected seed tubers or by aphids who act as vector spreading the disease from one field to another.

Observation methodology

Symptoms appear during the early stages of potato growth, so observations should begin at that time. Make observations by walking along the raised seedbeds and looking for plants showing symptoms of the disease.

10.3.2 Potato Y virus

Potato Y virus (PVY) is the second most important virus. It can be passed on through infected tubers or by insects and can reduce yield by up to 80%.

Symptoms

Leaf surfaces become uneven and brittle, leaves shrink and their ribs turn yellow. In mild infections, plants often show no signs of disease at all.

Source and Vector

Although the virus can spread with infected seed tubers and mechanical transmission through tools and plant/tuber handling, PVY is mostly transmitted by aphids who act as vector spreading the disease from one field to another. Aphids can acquire the virus within seconds after starting to feed on infected leaves, can transmit the virus immediately, in a non-persistent manner and usually retain the virus for only several hours without continued feeding on infected leave material.

Observation methodology

These are the same as for leafroll virus.

10.3.3 Mosaic virus

Symptoms

Yellowy-green stripes appear on leaves infected by the Potato Mosaic Virus (PVM). Yield can diminish by up to 40%. In mild infections, affected plants display no symptoms.

Source and Vector

Like other viruses, PVM is caused by using contaminated seed, can be mechanically transmitted through tools and plant/tuber handling or is carried from other plants by aphids.

Observation methodology

These are the same as for leafroll virus.

10.4 Diseases caused by nematodes

10.4.1 Root-knot nematode

Root-knot nematodes damage the parts of plants found under the ground, i.e. roots and tubers. Although this disease is found in many potato producing regions, farmers do not consider it too economically damaging and consequently pay it little attention. Nevertheless, these nematodes can reduce tuber quality and can make them more vulnerable to other diseases. Lesions caused by nematodes facilitate secondary infections by other diseases in the soil such as tuber rot and scab to get in.

Symptoms

Diseases caused by nematodes vary, but common symptoms of these are:

- *Swelling of roots* – Nematodes damage and live in the roots of potato plants, causing them to swell. Swollen roots cannot function normally and affect growth of the plant above them. In hot conditions, plants damaged by nematodes will wilt.
- *Irregular tuber shape* – Tubers change shape and lumps appear on their surfaces.

Source and spread

Sources of these diseases are soil and contaminated seed. Nematodes can move around in the soil with the help of water.

Management

Root-knot nematodes can be managed by:

- Using healthy seed free from nematodes.
- Balancing fertilizer use to obtain healthy plants less susceptible to nematodes.
- Rotating potato crops with corn or other non-solanaceous crops.
- Biofumigation in case of severely-infested soils

Observation methodology

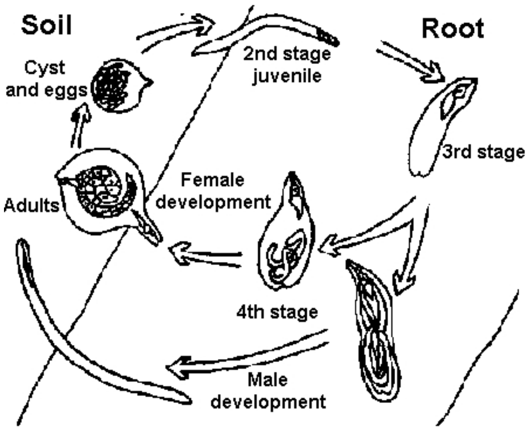
Pull up wilting plants and observe their roots and tubers. If you find any symptoms like those explained above, you could conclude that plants have been infected by nematodes.

10.4.2 Golden cyst nematode

Potato cyst nematodes, probably originating with the potato in South America, are widely distributed throughout potato producing areas all over the world. Although its main host is the potato, it can also reproduce on other solanaceous crops such as tomato and eggplant. There are two main species, the golden (*Globodera rostochiensis*) and the pallid (*G. pallida*) cyst nematode. The golden cyst nematode was first identified in Indonesia in 2003 and is rapidly spreading.

Life cycle

One life cycle of the golden cyst nematode is completed with each crop. Between crops, eggs survive within cysts in the soil. When a potato plant is growing, substances exuded by the roots stimulate the eggs to hatch. Each egg contains a second-stage juvenile which hatches, moves from the cyst into the soil and penetrates a host root just behind the root-tip. The juvenile establishes a permanent feeding site in the root and develops to become an adult.



After reaching the adult stage, males leave the root and move through the soil to find females. Females remain in the root, expanding and eventually rupturing it, remaining attached by the head and neck only. After fertilisation, the female produces 300 to 500 eggs which she retains within her body. The female dies with the root, but her skin hardens and turns brown while forming a protective cyst for the eggs.

Symptoms

Potato cyst nematodes do not cause immediate above-ground symptoms. First symptom is poor growth of plants in one or more spots in the field. These spots enlarge each year that potatoes are planted in the same field, since cysts remain in the soil for a long time. Low populations of the nematode may not be noticed but as the number of nematodes increases, plants become stunted, leaves are smaller and yellowish and plants dry off early. Plants may show symptoms of water and/or mineral deficiency stress with yellow leaves and wilting. Yields may be reduced by as much as 90%, which is the result of smaller tubers. Tuber quality and number of tubers, however, are not affected.

Source and spread

The cysts of the nematodes stay in the soil for long periods of time. They can spread to other fields or other areas through soil on tools, boots and seed tubers.

Management

Of all the crop pests worldwide, the potato cyst nematodes are among the most difficult pests to control. Once they are established in an area, eradication of the potato cyst nematodes seems unlikely. The extremely long survival period of cysts in the soil, which can be over 30 years, limits management options.

The best approach to limiting spread once the potato cyst nematodes are introduced into an area is to integrate control measures. In particular, crop rotation, resistant varieties, and biofumigation look promising. Crop rotation, however, requires a cycle of five to nine years to achieve relatively low populations in the soil that would allow successful potato production again. Resistant varieties are available in Europe, but these are not necessarily suitable for tropical highland conditions and need to be evaluated first. Chemical control is generally not recommendable since it involves pesticides (nematicides) of high toxicity that kill all living organisms in the soil, including nematodes, fungi, bacteria, plants and insects. Biofumigation using brassica residues is a method that should be further explored.

Observation methodology

As with root-knot nematodes, pull up wilting plants and observe their roots and tubers. Roots of infected plants exhibit very small, white bodies, which are the immature females that have erupted through the root epidermis. At very high nematode densities, tubers may become infected, resulting in the appearance of cysts on their surface.

10.5 Problems caused by environmental factors

10.5.1 Low temperatures

Many of these diseases occur in areas with relatively cool temperatures, such as basins. Temperatures falling to below 4°C at night cause plants to appear burnt with leaves eventually drying out. This is caused by a strange property of water, which expands at temperatures of 4°C and below. When the temperature falls to this level, water inside the plants will expand and plant tissue will no longer be able to contain it. Plant tissue will burst and become damaged leaving plants looking burnt.

Management

You can overcome problems with low temperatures by:

- Avoiding planting at times when temperatures are very low,
- If the temperature falls to just above 4ºC, water the plants, as this will prevent the temperature around them from becoming too cold.

10.5.2 Nutrient deficiencies

Signs of a lack of nutrients are:

- Nitrogen:
  - Yellowing of leaves.
  - Stunted plant growth.
- Phosphorus:
  - Dwarf plants,
  - Foliage turning dark green and curling up.

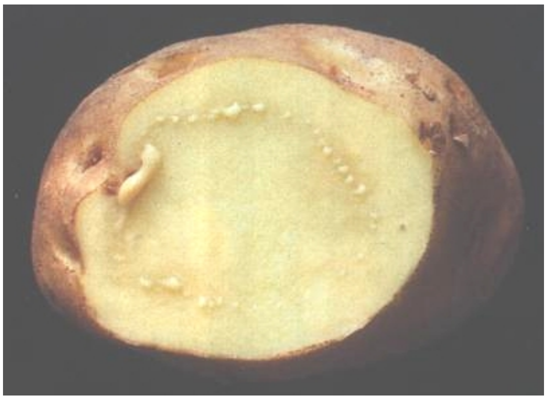
- Potassium:
  - Plant growth might be stunted, foliage appearing blackish in color.
  - Sometimes black spots are clearly apparent on leaves.
- Calcium:
  - Shoots drying out and dieing.
  - Youngest leaves curling upward.
- Magnesium:
  - Yellowing of leaf ribs.

Management

You can manage these disorders by adding the deficient nutrients as and when required. When you encounter symptoms such as the ones described above, but only on a few plants, then you should add more fertilizer only to the affected plants.

10.6 Picture of major potato diseases

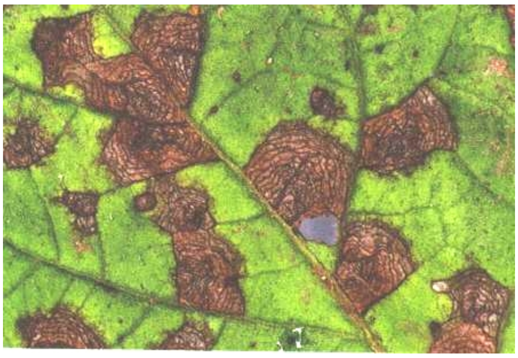

Bacterial wilt – wilting of plants


Bacterial wilt – oozing of tuber


Erwinia spp. – blackleg


Erwinia spp. – soft rot


Common scab


Early blight (*Alternaria solani*) on leaves


Late blight (*Phytophthora infestans*) on stem


Late blight on leaves


Late blight on outside of tuber


Late blight inside of tuber


Fusarium dry rot


Fusarium wilt


Potato leafroll virus – rolling of upper leaves


Potato leafroll virus – stunted plants

Potato virus Y – stunting and yellowing of veins

Potato virus Y – mosaic

Symptoms of mosaic virus

Potato cyst nematode – females attached to roots

Root-knot nematode on roots

Root-knot nematode on tubers

11 WEED ECOLOGY

11.1 Weeds: damaging or beneficial?

Weeds are all the unwanted plants growing on farming land. They compete with the main crop and considered to produce nothing of any benefit.

Weeds are damaging when:
- They compete with potato plants for nutrients, sunlight, water and living space.
- They require expenditure in their control.
- They become a food source for pests enabling them to thrive, even when there are no potato plants in the field.
- They host diseases that affect potato plants. Crop rotation will not work if disease and pest supporting weeds are still present in the field.

Weeds can be beneficial when:
- They serve as green manure providing trace elements and improving soil structure. Weeds form a fundamental ingredient in making organic fertilizer.
- They form a covering layer protecting soil from sunlight or erosion damage.
- They become a food source for natural enemies. Weeds produce flowers and nectar that can be an alternative food source for parasitoids.
- They become a food source for livestock.

Whether a weed is damaging or beneficial depends on its species, its density and its uses. For example, a weed will be extremely useful if it can be used for animal feed.

11.2 Weed types

- *Grasses* – These have small pointed leaves with jointed stem. Every joint has roots. These weeds are extremely hardy, and can grow from cut grass or from seed. They are difficult to control because they can survive even after being removed from the soil.
- *Sedges* – Like grasses but without jointed stems. They grow from rhizomes, roots and seeds. They can even grow from very small pieces of cut root.
- *Broad-leaved weeds* – These weeds have broad leaves, and sturdy stems with many branches. They generally grow from seed and are easier to control than grasses and sedges as they will die when pulled out of the ground.

11.3 Weed management

Weeds have two sides to them; damaging and beneficial. With proper management we can manipulate their damaging traits and make them beneficial.

Herbicides are used to eradicate all living vegetation in the field, not only to eradicate weeds. Using herbicides can actually lead to greater losses because:
- Poisoned weeds cannot be used to make organic fertilizer or utilized as animal feed.
- The poisons herbicides contain last for a long time in the field and can kill or affect the main crops' growth.
- Herbicides kill beneficial living organisms in the soil, and reduce soil fertility.

You can manage weeds in two ways:

- *Prevention* – Do this before planting the main crop by clearing weeds from the field when tilling, making raised seedbeds and planting. Collect the weeds, and make them into organic fertilizer.
- *Management when potato crop is growing* – You can do this by pulling up weeds or burying them in the soil. You should do this twice in a season, at 30 and 50 DAP. Be careful when weeding at 50 DAP as tubers are starting to form, and any damage to potato plant root systems will affect yield and increase susceptibility to disease.

12 HARVEST AND POST-HARVEST MANAGEMENT

12.1 Pruning plants before harvesting

It is recommended to prune plants before harvesting when some of the produce will be used for seed. Under tropical highland conditions, pruning can be done at 80 DAP (depending on the variety), by cutting them at the base of their stems. The foliage can be collected and composted.

Benefits of pruning are:

- To make tubers harden more quickly so they can be harvested sooner. Normally, you can harvest plants two weeks after pruning.
- To prevent diseases spreading from plant stems to tubers. Viral diseases in particular will spread to tubers if stems begin to wilt and dry out. The same occurs to other diseases such as late blight, stem rot and bacterial wilt.

12.2 Harvest time

Each variety has a different preferred harvest age; Atlantic and Columbus, for instance, need more time before harvesting than Granola, which is ready for harvest at 100-110 DAP. It is best to harvest in clear, sunny weather, because sunshine will help tubers to harden and dry more quickly, making it easier to remove excess soil from their skins.

Harvest time is influenced by potato prices and weather. When prices and weather are favorable, you can harvest a bit earlier and spread the produce out for a few days to allow tuber skins to harden. However, when prices and weather are not favorable, you can delay harvesting. Harvesting in the rain might cause tubers to rot. You should not delay the harvest for more than 10 days, as delays of any longer will cause more tubers to become damaged by pests such as mole crickets, or bacterial diseases and scab. Damaged tubers will fetch a lower selling price.

12.3 Harvesting methods and estimating yield

Harvesting methods affect tuber quality. Potatoes can be harvested in two ways, directly by hand or by using a hoe. Harvesting by hand takes longer and is more labor intensive, but will produce good quality, undamaged tubers. Using a hoe is less time-consuming and labor-intensive, but some tubers will be damaged in the process.

On loose soil with no grass growth, you can harvest by dismantling potato beds by hand. Harvested tubers should be put to the side of the dismantled seedbeds so they are easier to collect. When soil is too hard and is covered with grass, you should dig up potato beds using a hoe. This can happen when you harvest too late at more than 120 DAP. Dig from the edge of the seedbeds to loosen the soil, then continue dismantling them by hand. Be careful when loosening the soil so as not to damage potato tubers.

If the whole produce is going to be sold, then you can harvest all the potatoes in one go. However, if some of the tubers are for seed, you should harvest them at a different time from the ware potatoes. You can harvest seed tubers either before or after harvesting tubers for consumption by using either positive or negative selection (see section 4.4.1).

After harvesting, you should sanitize the field, by gathering and destroying harvest remnants such as plant parts, rotten tubers etc. Post-harvest sanitation is an important part of controlling various pests and diseases, by removing sources of contamination for the next crop from the field.

You can estimate potato harvest yield by:
- Weighing several sample tubers taken from randomly selected plants.
- Calculating the average weight of tubers per plant.
- Multiplying that figure by the total number of seeds tubers used (or plants grown) on the whole field.

For example:
- The tuber weights of five sample plants are 0.9, 0.8, 1.2, 1.0 and 0.5 kg. The average weight of tubers per plant is:
  $$\frac{0.9 + 0.8 + 1.2 + 1.0 + 0.5}{5} = 0.88 \text{ kg/plant}$$
- The average tuber weight per plant is multiplied by the number of plants in the whole field to assess the total harvest. For instance, a 1,000 m^2 field contains 2,000 plants. The estimated harvest from the example above is then:
  2,000 x 0.88 = 1,760 kg (or 17.6 tons/ha).
- If the number of plants is not known, it can be assessed from the seed rate. For instance, a farmer planted 100 kg of seed tubers with an average weight of 50 g per tuber. Number of plants is then:
  $$\frac{100}{0.05} = 2{,}000 \text{ plants}$$
  The estimated total harvest is = 2,000 x 0.88 = 1,760 kg

12.4 Treatment of produce

Harvested tubers are treated as follows:
- *Spreading out and drying tubers* – Spread out harvested tubers in the field or the storage area to dry. Harvesting in the dry season enables you to leave the produce in the field for a long time. In the rainy season, it is best to spread out the produce in the storage area under lights.
- *Sorting* – Do this by separating damaged and undamaged tubers and classifying them according to weight. Gather and destroy any rotten tubers. Tubers damaged by pests can be sold. Tuber classification varies greatly between countries and regions. An example of tuber weight classification as used in most parts of Indonesia is as follows:
  - > 80 g/tuber
  - 60-80 g/tuber
  - 30-60 g/tuber
  - < 30 gr.

  Tubers weighing 60 g and over are sold, whereas those below 60 g are normally used for seed.
- *Packing* – You can do this by using sacks or baskets. Packing must be done carefully to avoid bruising tubers.
- *Transportation to the storage area* – Produce can be sold while it is still in the field, particularly when prices are high and not too many potatoes are available. When the main harvest takes place, farmers must store harvested tubers in a

storage area until prices improve. Be careful to avoid any damage when transporting produce from the field to the storage area.

- *Storage* – Tubers for consumption are only stored for a few days. If you are storing them for more than two days, it is best to spread them out on the dry floor of the storage area to prevent them from rotting.
- *Tuber selection for seed* – Selection is done on tubers affected by pests and disease, and tuber size. It is advisable to separate tubers from different weight classes to make it easier to estimate seed requirements. A one-hectare field generally requires 1.5 tons of seed tubers weighing 30-60 g/tuber, but only about 1 ton of tubers lighter than 30 g/tuber.
- *Storing tubers for seed*. See section 4.6 of this manual.

12.5 Marketing and prices

In some areas farmers generally sell potatoes in their fields or in their own villages, while in other areas traders will come right to villagers' homes or fields where potatoes have recently been harvested. An example of a potato marketing channel is depicted in Figure 4. Prices are usually not too different from one farmer to the next at the same moment in time, and are mainly influenced by tuber size, quality, smooth skins, color and whether or not they are damaged. Potato prices can fluctuate greatly from season to season, though. Farmers should quickly circulate information on potato prices among themselves to avoid cases of traders taking advantage of them.

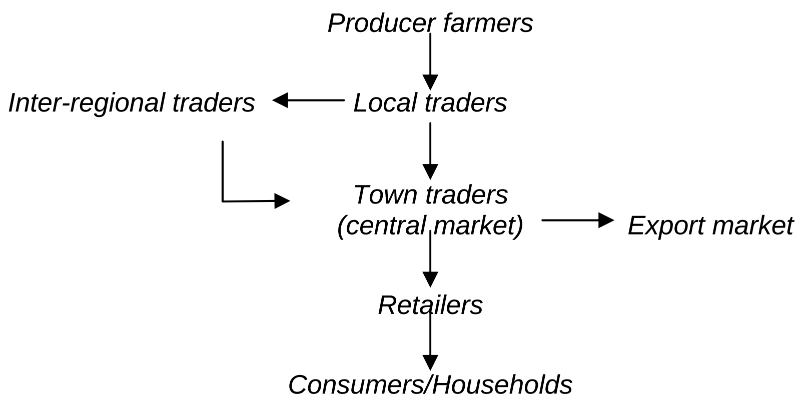


Figure 4: Potato marketing channels

12.6 Potato processing

Potatoes can also be processed into various food industry products. The food processing industry requires increasing numbers of potatoes every year. Unfortunately, Granola potatoes are not suitable for many of these processed products, because of their high sugar content. Processed products that can be made from Granola potatoes are croquettes, potato layer cakes, boiled potatoes, potato crisps and fried potatoes. Varieties more suitable for processing are Atlantic and Columbus.

12.7 Analyses of the potato enterprise

An economic analysis provides information on the status of farmers' businesses and whether they are making a loss or a profit. This information can provide the basis in developing cultivation patterns for the following season's harvest.

Net income or profit from farming is the amount remaining when you subtract expenditure from gross income. Both income and expenditure vary from one farmer to the next.

Income from potato farming:
- Selling potatoes for consumption.
- Selling seed.
- Selling the produce from intercropping.

Types of expenditure vary greatly from one farmer to the next, but generally consist of the following cost items:
- Purchasing seed.
- Purchasing organic and inorganic fertilizer.
- Purchasing sacks to package harvest produce.
- Purchasing fungicides, insecticides, adhesives etc.
- Labor costs, from tilling to harvesting.
- Transportation costs, when buying inputs.
- Spraying equipment rental costs or depreciation value.
- Other potato enterprise related cost.

Important factors in determining gross income are the amount of tubers that can be sold for consumption and for seeds, and the prices of those consumption and seed potatoes. Important factors in calculating expenditure are the number of goods and services used as well as the size of other expenses. Usually, farmers only count income and expenditure in cash form. This means ‘wages’ for farming family members and the value of goods belonging to farmers are not counted. For example, farmers need not include spraying equipment hire when they already have their own, but the depreciation value of the sprayer for that particular season should be included as an expense.

Potato farmers should always record their income and expenditure every planting season. In the IPM FFS process, farmers learn together how to calculate their businesses based on the notes they take. IPM FFS participants are given ‘potato cultivation record’ forms, on which they note down the following things at each meeting:
- *Activities* - what work they have done in the study plot.
- *Labor* – Wages paid for workers and estimated pay for work done by the farming family.
- *Purchase of inputs needed for cultivation* – What inputs have been bought, and how much they cost.
- *Comments* – All interesting things, such as results of observations, are noted down.

At the end of the season, the two columns containing amounts of money (labor and production costs) are added up and recorded on an analysis sheet of the form. When the produce has been harvested and sold, the gross income is also noted down and calculated in the analysis sheet, and the farm economic analysis can be done by calculating the profit.
- *Gross income* – Total harvest (kg) multiplied by product price (money value per kg).
- *Total expenditure* – By adding together the labor costs and production costs.
- *Profit* – Total expenditure subtracted from total gross income.

REFERENCES

BALITSA. 1989. *Kentang*. Lembang, Indonesia: Balai Penelitian Tanaman Sayuran.

Bennet, W.F. 1996. *Nutrient Deficiencies and Toxicities in Crop Plants*. Minnesota, USA: American Phytopathology Society.

Braun, A. R. and M. Shepard. 1997. Lalat Penggorok Daun, *Liriomyza huidobrensis* (Leafminer Fly, in Indonesian*). Technical Information Bulletin*. Bogor, Indonesia: International Potato Center.

Cisneros F. and N. Mujica. 1999. The leafminer fly in potato: plant reaction and natural enemies as natural mortality factors. In: *Impact on a Changing World*, 1997-1998 Program Report. Lima, Peru: International Potato Center.

Department of Primary Industries and Fisheries Queensland. *Potato cyst nematode*. DPI&F Note. http://www.dpi.qld.gov.au/horticulture/4848.html

FAO. 2000. *Tomato Integrated Pest Management: An Ecological Guide*. Bangkok, Thailand: FAO Inter-Country Program for the Development and Application of Integrated Pest Management in Vegetable Growing in South and South-East Asia..

Henfling, J.W. 1987. Late Blight of Potato. *Technical Information Bulletin 4*. Lima, Peru: International Potato Center.

International Potato Center. 1992. Biological Control of Potato Tuber Moths Using Phthorimaea Baculovirus. *CIP Training Bulletin 2*. Lima, Peru: International Potato Center

International Potato Center. 1996. *Major Potato Diseases, Insects and Nematodes*. Lima, Peru: International Potato Center.

Kalshoven, L.G.E. 1981. *Pest of Crops in Indonesia*. Jakarta, Indonesia: PT Ichtiar Baru-Van Hoeve.

Oudejans, J.H.M. 1999. *Studies on IPM Policies in SE Asia; Two Centuries of Plant Protection in Indonesia, Malaysia and Thailand*. Bachuys Publishers, Leiden.

Rauf, A. and B.M. Shepard. 1999. Leafminers in vegetables in Indonesia: survey of host crops, species composition, parasitoids and control practices. In: *Proceedings Workshop on Leafminers of Vegetables in Southeast Asia*, 2-5 February 1999. Selangor, Malaysia: CABI Bioscience.

Rich, A.E. 1983. *Potato Diseases*. Academic Press, New York.

Rowe C. 1993. *Potato Health Management*. Minnesota, USA: American Phytopathology Society.

Sahudi A. 1997. *Kumpulan Petlap Pengorganisasian dalam Program PHT*. Surakarta, Indonesia: Gita Pertiwi, LPTP, Gema Desa, World Education.

Shepard B.M., A.T. Barrion and J.A. Litsinger. 1987. *Helpful insects, spiders and pathogens*. Los Banos, Philippines: IRRI.

Soepardi, G. 1983. *Sifat dan Ciri Tanah*. Bogor, Indonesia: Institut Pertanian Bogor.

Tanada, Y, and H.K. Kaya. 1993. *Insect Pathology*. Harcourt: Academic Press.

Van de Fliert, E. (1993). *Integrated Pest Management: Farmer Field Schools Generate Sustainable Practices. A Case Study in Central Java Evaluating IPM Training.* Wageningen Agricultural University Papers 93-3. Wageningen: PUDOC, 304 pp.

Van de Fliert, E. and A.R. Braun (1999). *Farmer Field School for Integrated Crop Management of Sweetpotato: Field Guides and Technical Manual*. Bogor: International Potato Center. 197 pp. Published in English, Indonesian, Spanish and Vietnamese.

Van de Fliert, E., Warsito, and A. Lagnaoui (1999). Participatory Needs and Opportunity Assessment for Potato IPM Development Planning: the Case of Indonesia. *Impact on a changing world*. 1997-98 Program Report. Lima, Peru: International Potato Center, p. 171-178.

GLOSSARY

Aphid	*Myzus persicae*
Bacterial wilt	*Ralstonia solanacearum*
Bt	*Bacillus thuringiensis*
CIP	International Potato Center
Cluster caterpillar	*Spodoptera litura*
Common scab	*Streptomyces scabies*
Cutworm	*Agrotis spp.*
Early blight	*Alternaria solani*
FFS	Farmer Field School
Fusarium dry rot	*Fusarium sp.*
Golden cyst nematode	*Globodera rostochiensis*
Ground beetle	*Carabidae*
GV	Granulosis virus
Hoverfly	*Syrphidae*
IPM	Integrated Pest Management
Ladybird	*Coccinellidae*
Late blight	*Phytophthora infestans*
Leafminer fly	*Liriomyza huidobrensis*
LPTP	Institute for Rural Technology Development (“Lembaga Pengembangan Teknologi Pedesaan”)
Mole cricket	*Gryllotalpa africana*
Mosaic viruses	PVX, PVS, PVM and PVA
Parasitic nematodes	*Steinernema sp., Heterorhabditis sp.*
Parasitoids of leafminers	*Herriptarsenus varicornis, Opius sp., Gronotomo sp., Diglypus sp.*
Pathogenic fungi	*Metarhizium anosiplae, Beauveria bassiana*
Potato leafroll virus	Potato leafroll virus (PLRV)
Potato tuber moth	*Phthorimaea operculella*
PVY	Potato virus Y
Root-knot nematode	*Meloidogyne* spp.
Root-lesion nematode	*Pratylenchus* spp.
Rove beetle	*Staphilinidae*
Soft rot	*Erwinia spp.*
Spider mite	*Tetranychus spp.*
Thrips	*Frankliniella spp.*
WE	World Education
White grub	*Phyllopaga spp.*
Whitefly	*Bemisia spp*