POTATO
PRODUCTION IN KENYA

A GUIDE TO GOOD AGRONOMIC AND PLANT NUTRITION PRACTICES

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This guide aims at providing answers to the How? What? Where? and When? questions of potato production in Kenya. This guide is free to use and distribution of its information is welcome. Funding for development of this manual was derived from an AGRA funded fertilizer development project and the OCP-funded Cross Regional Research and Development Initiative.

Preface

Potato contributes greatly to food security, poverty reduction, and economic development in Kenya. The crop is the second most important staple crop grown after maize, and before rice. Potato tubers are best known for their carbohydrate content, but they are also an important source of vitamins and minerals, as well as an assortment of phytochemicals, such as carotenoids polyphenols, and antioxidants that are known to play a role in human health, and disease prevention.

Despite the importance of the potato, yields continue to stagnate through Kenya. Average tuber yield remains at 7 t/ha in Kenya with many fields below 3 t/ha. Kenya has a large potato yield (and income) gap as these low yields fall well short of realistically attainable yields aided by the adoption of good agronomic practices.

Since 90% of the potatoes grown in Kenya come from farms with 0.2 ha or less, a major challenge exists for those involved in agricultural extension within this fragmented production system. There is also limited access to suitable learning resources searching for information on the production of higher-yielding potato crops.

There is especially an insufficient availability of knowledge products focusing on fertilizer recommendations for potatoes in Kenya. Current approaches have generally led to the undersupply of nitrogen and oversupply phosphorus. A high-yielding potato crop in Kenya requires a balanced supply of all major crop nutrients as well as most micronutrients. Potassium plays an especially important role in improving tuber yield and quality, but today less than 20% of potato fields in Kenya regularly receive K-containing fertilizers.

This booklet is intended to provide a set of practical guidelines to aid the establishment of good agronomic practices suited for high-yield potato production in Kenya. The scientific principles provided within this publication can also be considered appropriate for similar potato production systems in other countries in Sub-Saharan Africa.

This hands-on information is designed to assist farmers, and the wide range of agricultural practitioners including extension workers, development workers, researchers, and policy-makers, who work to improve farmer practice and enhance the livelihoods of rural communities.

Dr. Kaushik Majumdar
APNI Director General

Table of Contents

Introduction

Potato cropping remains critical to Kenya's staple food crop production goals. It is estimated that Kenyan farmers grow potatoes on approximately 120,000 to 150,000 ha annually. The total annual output is about 1.5 to 2 million metric tonnes per year. The market value of this annual production is about KES 50 billion (US$500 million). Over 90% of the potatoes are grown by smallholder farmers on less than 0.2 ha of land. Most potatoes in Kenya are grown under rainfed conditions in the higher altitude areas where they compete favourably with maize production. By 2018 it was estimated that approximately 800,000 Kenyan's benefitted directly from potato production.

The yield potential of potato in Kenya has not been achieved. Smallholder farmers produce an average of 7 t/ha, with some farmers producing as low as 3 t/ha. However, the yield potential for potato in most of the suitable regions is in excess of 40 t/ha. The yield gap between what is currently produced and what is achievable is often greater than 20 t/ha. In economic terms, this yield gap represents an income gap of more than KES 1 million (USD 10,000) per ha based on the average farm gate price of KES 20 to 25 per kg.

This large yield (and income) gap can be closed through application of good agronomic practices including better plant nutrient recommendations. For example, the current fertilizer recommendation for potato in Kenya is 500 kg/ha DAP (diammonium phosphate). However, this recommendation presents limitations, notably, it undersupplies N, while oversupplying P. In addition, the 500 kg DAP/ha recommendation omits other important nutrients like K, which is extremely important for potato quality. This unbalanced nutrient supply limits potato production and wastes farmer money.

Other common limitations to optimal potato production are the use of poor-quality seeds, pests and diseases, and low adoption of good agronomic practices. The major crop diseases affecting potato production are potato late blight, bacteria wilt, and viral diseases. Other potato diseases include black leg and powdery mildew. Insects that commonly transmit potato diseases or damage the plant include the potato beetle, potato tuber moth, green peach aphid, potato aphid, beet leafhoppers, thrips, and mites.

Knowledge on the best methods to increase potato yields is housed in agricultural research institutions. However, this knowledge has not been packaged in a format that is easy to use by farmers, extension workers, and policy makers. As a result, the practices of potato production have largely not been guided by the good agricultural practices. This booklet digests scientific knowledge into easy to use guidelines in order to boost potato production. The target audience for the booklet includes extension workers, policy makers, and farmers.

CHAPTER ONE

Quick Summary of Potato Production Steps

1

1.1 Requirements for achieving high yields

Altitude

Potato growers must consider the most suitable altitude for growing potatoes. Potato grows well at altitudes between 1,500 and 3,000 m above the sea level. Knowledge of altitude enables the grower to understand the challenges that exist in their region. At altitudes lower than 2,000 m, farmers face higher disease pressures from potato virus diseases due to higher aphid populations and incidences of bacteria wilt. The recommended altitude range for seed potato production in Kenya is above 2,100 m.

Choice of crop variety

Careful selection of crop variety that is suited for a specific region is crucial for obtaining high yields. Selected varieties should be high yielding, disease resistant/tolerant, and have good storage and processing qualities.

Physiological age of the seed

A grower should use seed potato tubers that are healthy, strong, have good colour, and have broken dormancy with 4 to 6 sprouts per tuber.

Field preparation and planting

First ploughing should be done at least 15 to 30 days before potato planting. This initial ploughing should loosen the soil. Break any big soil clods with the help of spade before those clods harden. During the second ploughing just prior to planting, dig the field manually by spade to about a 30-cm depth and make ridges 25 to 30 cm tall and 30 to 35 cm in wide.

Field sanitation before planting potatoes

Fields should be cleared of the residues from the previous crop. If residues of earlier crops remain in the field, the larva of pests and disease may still be prevalent in the soil and harm the newly planted crop.

Early planting

For rainfed tuber production, the grower should prepare the field at least one month prior to onset of the rains to give any crop residue time to decompose. This will also give the grower adequate time to plant just before the rains start, which promotes quick emergence and crop establishment, and may allow the crop to escape major incidences of late or early blight. A crop that receives all the season's rainfall is more likely to have good growth and produce high yields.

Seed health

Seed potato is generally the main source of insect pest and disease infection, because most seed-borne diseases are systemic, thus favouring disease transmission to the next generation of tubers.

Seed treatment with chemicals can never replace the use of high-quality seed or proper handling. Therefore: (i) use only disease-free seed, (ii) produce seed tubers in a disease-free environment and on land not infested with soil-borne diseases or insect pests, (iii) ensure proper sanitation by using clean tools when cutting seed to avoid transmitting diseases mechanically, (iv) adopt strict rotation procedures between fields, (v) remove diseased plants including tubers, stolons and roots (bury them in a pit outside the field), while carefully avoiding spilling any infected soil on healthy plants, (vi) remove and destroy seed tubers infected by diseases or insect pests during storage, and (vii) make routine observations to identify insect pest- and disease-infected tubers in storage.

FEATURES OF QUALITY SEED TUBERS

- Free from seed-borne disease and pests.
- Seed tubers must not be mixed with other varieties.
- High sprouting vigour.
- Seed tuber weight should be 30 to 50 g to reduce the need for cutting that may introduce infection.
- Visually, the seed tuber should be healthy, free of wrinkles, and disease symptoms.

Seed tuber size

Use seed tubers of uniform size, ranging from 28 to 60 mm or weighing between 30 to 50 g. Seed tubers should have little variation in size. Using seed with a wide variation in size will not produce a uniform crop and makes it more difficult to predict the plant density and to properly manage the crop. Use large seed tubers when soil and weather conditions at planting are unfavourable, if the growing season is short, or where there is the risk the crop may be damaged by night frost, hailstones or drought during the first part of the growing season.

Large tubers may be cut into smaller pieces for planting to reduce seed costs and promote a more uniform crop. This should be done at least two weeks before planting in temperature conditions between 10 to 22°C to allow cutting wounds to heal prior to planting. However, sanitation precautions are needed to avoid transmission of viruses via the cutting blades.

FACTORS TO CONSIDER WHEN SELECTING A POTATO VARIETY

- Select varieties adapted to local climatic conditions to ensure wide adaptability and stable production.
- Abandon varieties with poor storage characteristics and low levels of resistance to major diseases.
- Promote varieties that are already grown in the country and are accepted by farmers and commercial markets.
- Direct sunlight on potato seed should be avoided.

1.2 Preparation of seed tubers for planting

Dormancy period

The newly harvested seed tubers will not sprout until the variety's dormancy period is over (**Table 1**). The dormancy period will range from 20 to 90 days, depending on the variety.

The potato tuber undergoes several physiological stages as soon as they are formed on the parent plant. Innate dormancy can be broken naturally by storing tubers in diffused light until sprouts are observed. Dormancy breaking products and phytochemicals that can be purchased from agro-input stores to initiate sprouting.

Dormancy ends when new growth is visible and when the sprouts have reached 3 mm. Young tubers that only have a single sprout or two at the rose end (the end with the majority of small dents in the skin) will exhibit apical dominance. If such a tuber is planted it will give rise to only one stem and low yields. Therefore, the single top

Table 1: Dormancy period of different potato varieties available in Kenya.

Variety	Time to full maturity (days after planting)	Dormancy period (days)
Asante	90-120	30
Tigoni	>120	30
Dutch Robjin	>120	90
Kenya Mpya	90-120	30
Kenya Mavuno	>120	90
Kenya Baraka	90-120	30
Kenya Karibu	>120	90
Purple Gold	90-120	90
Sherekea	>120	90
Shangi	90-120	20
Jelly	>120	90
Markies	90-120	90
Connect	90-120	30-60
Kerr's pink	90-120	90

NPCK, 2015

sprout should be removed to encourage development of multiple (4 to 8) sprouts. Such seed tubers, when planted in good soil conditions, will produce abundant tubers of normal size at harvest.

To control fungal diseases on seed tubers, they should be dipped in a solution containing 2 to 3 g fungicide/L of water prior to any sunlight treatment. If cut tubers are used, they should follow the given treatment methods:

- When cutting, the knife or sickle should be sterilized between every cut by dipping in hard alcohol or a fungicide solution. Otherwise, the cut seed tuber can easily spread diseases to other tubers.
- After cutting, seed tubers should either be rubbed with ashes or Bordeaux mixture to avoid infection of the freshly cut part, and placed in the shade for 2 to 3 days.

Photo 1.1 *(Photo by Angela Ndanu)*
Careful handling seed tubers before planting.

Sunlight treatment for seed tubers

A sunlight treatment involves exposing seed tubers to sunlight for 20 to 30 days at 10 to 20° C before planting to stimulate healthy and uniform sprouts (4 to 8) on each of the tubers (**Photo 1.1**). Seed tubers with 4 to 8 young sprouts emerged from every eye, which are 0.5 to 1 cm long, strong, healthy, and green are best for planting.

1.3 Planting

Prior to planting, make a planting bed with approximately 20 to 25 cm of loose soil mixed with fertilizer and/or manure to allow proper rooting and hilling.

Most importantly at planting, apply P and K-rich fertilizers. Approximately 30% of the total N requirement should also be applied at this stage. If available, manure should also be applied in the ridges. Manure is not only an important source of nutrients, but also improves the soil organic matter and water holding capacity. Because of the low P-use efficiency of potatoes, P fertilizer applications need to be considerably higher than the 30 to 50 kg/ha of P_2O_5 taken up by the crop. Therefore, fertilizer P_2O_5 recommendations range from 60 to 100 kg/ha for most tropical areas like Kenya. The source of K influences tuber quality, particularly where tubers are meant for further processing into crisps and other snacks. In addition to P application at planting, apply about 230 kg of K_2O.

Some of the common fertilizer used at potato planting include NPK 17:17:17, DAP, Baraka®, Yara Power® and MEA-NPK® 16:8:26. Where DAP is chosen as the planting fertilizer, K should be supplied from another source, because DAP does not contain K. Application of K through sulphate of potash (SOP) is preferred to potassium chloride (muriate of potash or MOP) as potatoes are sensitive to chloride (Cl^-).

Planting density

Planting density varies with tuber size. Depending upon tuber size and the variety, the tuber to tuber spacing can vary between 21 and 30 cm. Line to line planting distance between the beds varies between 70 and 84 cm.

1.4 Management during the crop growth period

Weed control

After emergence of the first potato shoots, it is important that the first weeding to be done early to limit competition for nutrients, water and light. Weeds also harbour pests and diseases. Weeds should be removed early enough to give the plant time to recover from any stress.

Soil moisture

Adequate soil moisture is essential during the crop emergence, tuber initiation and tuber expansion stages. In most of Kenya's potato-growing regions the crop relies on rainfall. If available, supplemental irrigation can be used if rainfall is irregular or insufficient.

Top dressing

During a first fertilizer top-dressing, apply one quarter teaspoon (0.5 g) of urea to each plant on the shoulder of the ridge and immediately cover with soil. The first top dressing should be done one month after planting. This translates to 10 to 20 days after the sprouts emerge from soil. A second top-dressing applies an additional 0.5 g urea to each plant, placed on the shoulder of the ridge. It should be covered by soil immediately after application. The second top dressing should be done at the flower bud-formation stage.

Hilling

Hilling or earthing up should be done twice (**Figure 1.1**), first at 75% crop emergence (approximately 10 to 20 days after sprouts emerge from the soil) and a second time 2 to 3 weeks later (around the time of the second top dressing at the bud formation stage). Adequate ridge volume is essential to give ample room for tuber expansion, to prevent potato tuber moths from tunnelling into the tubers, and to prevent the tubers from being exposed to sunlight that turns them green.

Hilling should be done by loosening the soil around the potato plants. Pile the soil around the plants to almost cover the plant. The height of the ridges after the first hilling up should be around 15 cm (just covering the plant). For the second hilling, remove soil from between the ridges and pile it up around the plants. The height of the ridges after the second hilling should be about 30 cm. The width of the ridge should be 30 to 35 cm after hilling.

1.5 Harvesting

For most commercial varieties, the yellowing of the potato plant leaves and easy separation of tubers from the stolons are indicators

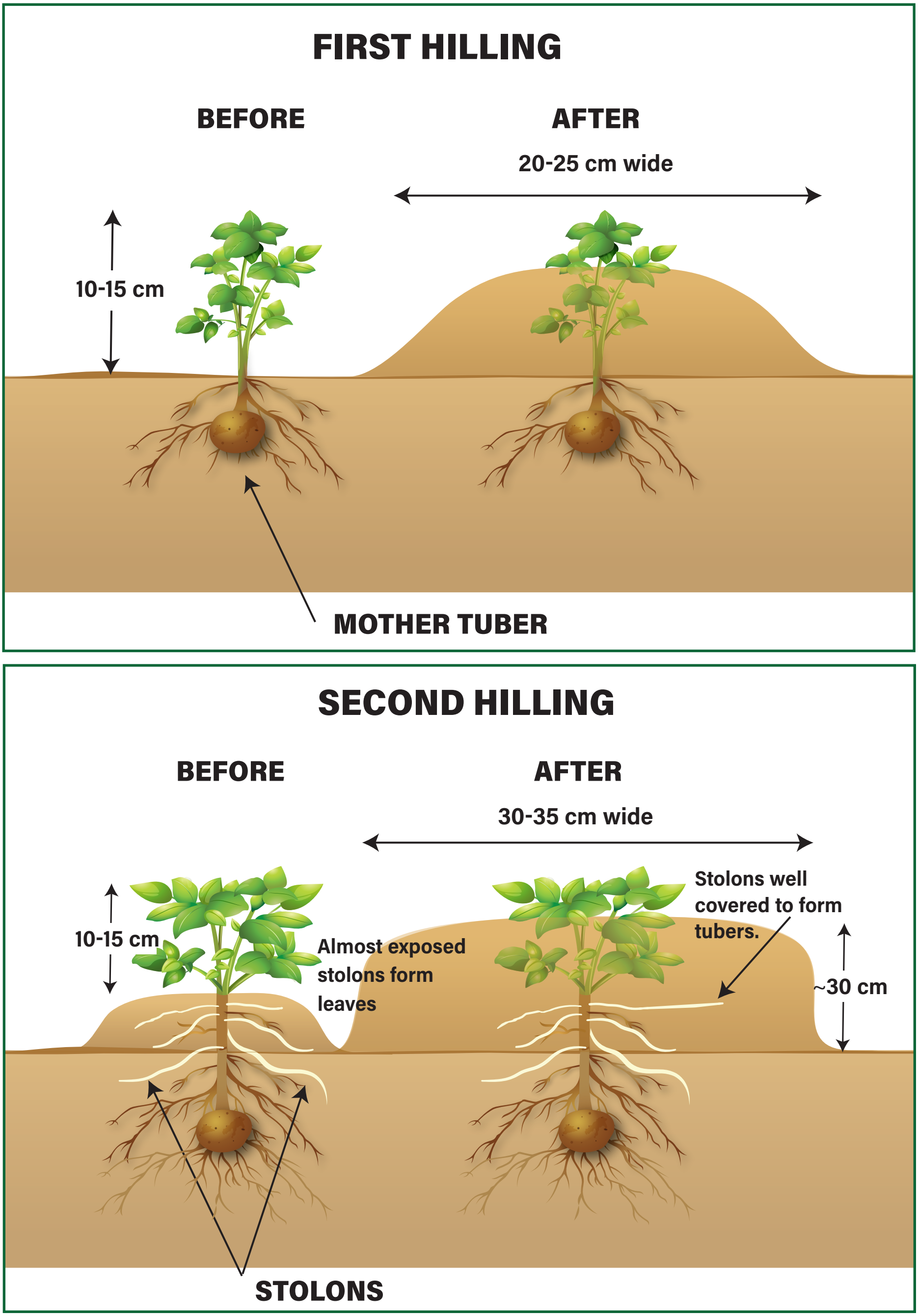


Figure 1.1 Illustration of timing and details of first and second hilling.
(Adapted from Parker, 2018)

BENEFITS OF HILLING UP POTATOES INCLUDE THE FOLLOWING:

- Facilitating nutrient assimilation while reducing risks of flooding conditions.
- Maintaining soft ground for smooth root, stolon, and tuber development.
- Reducing tuber exposure to sunlight which turns the tubers green, and increases the concentration of the neurotoxin, solanine.
- Reducing exposure of tubers to pests and diseases such as potato tuber moth that can cause huge losses in field and storage.

that the potato crop has reached maturity and ready for harvest. If the tubers are to be stored rather than consumed immediately, they should be left in the soil to allow their skin to harden. However, leaving tubers for too long in the ground increases their exposure to the fungal disease black scurf (*Rhizoctonia solani*) and increases the risk of losing quality and marketable yield.

To facilitate harvesting and stop tuber growth, potato vines should be removed two weeks before the potatoes are dug up. Depending on the scale of the production, potatoes are harvested using a spading fork, a plough, or commercial potato harvesters that unearth the plant and shake or blow the soil from the tubers. During harvesting, especially if it is done mechanically, it is important to avoid bruising or other injuries that provide entry points for storage diseases and reduce the commercial processing quality and storability of the tubers.

CHAPTER TWO

Potato Crop Establishment

2

2.1 Suitability of Kenya counties for potato production

Suitability evaluation requires matching of the ecological and management requirements of potatoes with land qualities, while considering the local economic and social conditions. The most favourable climatic conditions for potato production are found in areas with an annual rainfall between 850 and 1,200 mm and at altitudes between 1,400 and 3,000 m above sea level. These areas are situated mainly in the Central, Rift Valley, Upper Eastern regions, Western, Coast, and Nyanza (**Figure 2.1**).

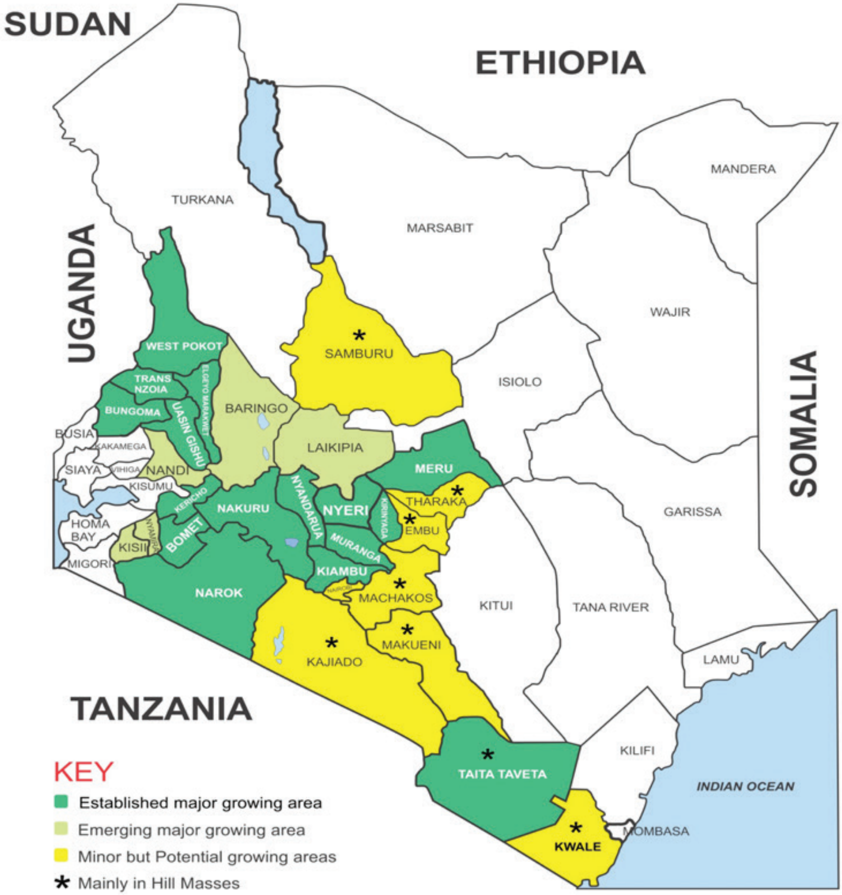


Figure 2.1 Major potato-producing counties in Kenya. (MOALF, 2016)

2.1.1 Important specifications for site selection

A simple scale shown in **Table 2.1** provides criteria for identifying the soils, climate and regions suitable for potato production. The scale, provides four suitability classes ranging from highly suitable to not suitable.

Table 2.1 Potato land suitability levels

Parameters	Suitability class by range of parameters			
	Highly suitable	Mod-erately suitable	Mar-ginally suitable	Not Suitable
Soil pH	5.0-6.0	6.0-7.0	7.0-8.0	>8.0
Soil texture	Loamy	Sandy	Clay	> 30% clay
Soil depth (m)	≥0.75	0.75-0.50	0.50-0.25	<0.25
Soil drainage (class)	Well drained / Moderate drained	Imperfectly drained	Poorly drained	Very poorly drained
Rainfall (mm)	≥1,000	1,000-800	800-600	<600
Mean temperature (°C)	≥18	18-20	20-22	>22
Slope (%)	≤6	6-13	13-25	>25

When selecting a potato-growing site, considerations such as soil properties, plant nutrient status, availability of water, and the pests and diseases status are important. Regular laboratory and field tests to determine the nutrients status, pest and disease pressure are important steps that a farmer should take to ensure success.

IMPORTANT QUESTIONS A FARMER SHOULD ANSWER WHEN CHOOSING A POTATO-GROWING SITE:

- Has the site been used for production of potato or crops in the solanaceous family (potatoes, tomatoes, eggplant, capsicum and chillies) in the previous three seasons and were there diseases or pest incidences?
- Is the site prone to run-off from fields where potato or crops from the solanaceous family have been cultivated before?
- Are the soils adequately drained?
- Is sufficient water available to support potato growth to maturity?
- What is the soil fertility status to support the nutrient requirement of high-yielding potato?

Soils

Potato can be grown in a wide range of soil, but a soil that is well-drained, with a loamy to sandy loam texture is the best. The soil pH can range between 5 and 7, but the ideal pH is 5.5. The soil should be deep, light, loose, and well drained but able to retain sufficient moisture.

Soil moisture

The main effect of soil moisture stress on potato is reduced yields and decreased tuber size. Potatoes require between 600 and 1,000 mm of rainfall for a 120 to 150 day growing period. In marginal rainfall areas, soil moisture can be enhanced through *in-situ* water harvesting technologies and *ex-situ* water harvesting and storage for irrigation during the dry spells within the growing season. Some of the *in-situ* soil moisture enhancement practices include:

- Addition of organic manure to the seed bed improves infiltration and moisture retention.
- Cutting furrows along the contours to harvest and conserve surface runoff.
- Deep ploughing to loosen an adequate amount of soils for water storage.
- Hilling and earthing up to increase surface water harvesting in the furrows.
- Mulching to reduce evaporation losses.

Soil-borne diseases

Where possible, potatoes should not be grown on land where potatoes and other *solanaceous* crops (such as tomatoes) have been growing the previous season. This is necessary to avoid volunteer crops (crops propagating naturally from the tubers that are left during the previous harvest that could harbour pests and diseases), and to minimize soil-borne pests such as nematodes and diseases such as bacterial wilt.

Topography and drainage

The position of the site within the landscape is important because it affects the drainage of the soil. Surface water runoff may carry away soil particles, valuable plant nutrients, and transport soil-borne diseases to other locations within the farm, or to neighbouring farms. Water logging can be a major stress that occurs mainly in flat landscapes receiving heavy rainfall amounts.

Temperature

The cooler the soil temperature, the more rapid the initiation of tubers and a greater the number of tubers will be formed. Optimum soil temperature for tuber formation is between 15 and 20°C. Higher temperatures reduce tuber formation. One way of avoiding high soil temperatures is timely ridging and adequate ridge volumes.

Irrigation

Water shortages continue to be a key constraint to potato production, especially in areas with erratic and variable rainfall. The most critical stages of potato growth when adequate moisture is required is during shoot emergence, tuber setting, and tuber bulking. To unlock the potential of rainfed potato farming, additional investments in better rainwater harvesting and irrigation need to be emphasized.

Common irrigation methods available are drip, sprinkler, and furrow. Drip irrigation is very effective; however, it is more expensive to install and operate than sprinkler irrigation. Furrow irrigation can be used but if the drainage along the furrows is not well maintained, waterlogging may occur and soil-borne disease may be transported within and beyond the farm.

2.2 Land preparation

Being a tuber crop, potato requires loose soil for the development of uniform, large, and smooth tubers. To achieve this soil requirement, raised seedbeds, made after a thorough and deep cultivation of the soil, are the most practical technique (**Photo 2.1**). All stubbles and organic matter that is likely not to decompose quickly must first be removed. Ploughing the land to a depth of 20 cm and breaking large clods to obtain a fine, firm, and weed-free surface is very important. It is recommended to work the land before onset of the rain when possible. Proper soil preparation also allows for aeration, drainage, and management of weeds. Mixing the soil and crop residues during deep cultivation enhances organic matter decomposition.

Photo 2.1 *(Photo by Joses Muthamia, APNI)*
Example of deeply ploughed land for planting potatoes.

2.3 Planting and spacing

After land preparation is complete, the land should be made into either beds or furrows. The furrows are generally spaced 75 cm apart. Tuber to tuber spacing depends on the tuber size and variety. This is because larger tubers produce more sprouts and stems. Therefore, larger seed tubers should be planted at wider spacing compared with smaller tubers. It is therefore generally recommended that seed tuber of size 28 to 45 mm should be spaced at 21 to 25 cm, and those 45 to 60 mm in size should be spaced at 28 to 30 cm. As an example, seed tubers placed 75 cm between rows and 30 cm within rows gives a plant population of 44,000 tubers/ha (**Photo 2.2**).

Planting should coincide with start of the rains in order to maximize water utilization. The seeds should be placed in the furrows with the sprouts facing up for faster and uniform germination. The planting and furrow depth should be 8 to 12 cm (**Photo 2.2 and 2.3**).

Photo 2.2 *(Photo by Joses Muthamia, APNI)*

This recommended spacing allows for cultural practices such as scouting for pests and diseases, spraying, rogueing, and harvesting to be carried out easily.

Photo 2.3 *(Photo by Angela Ndanu, APNI)*

Plant seed potato tubers with the sprouts facing up.

2.4 Stages of potato crop growth and development

Potato growth is generally characterized by the following five stages.

Growth Stage 1: Sprout development - Sprout develop from the eyes using energy from the seed tuber (pinch off the first sprout to remove apical dominance).

Growth Stage 2: Vegetative growth - Development of leaves, branches, and stolons (right time for earthing up). Growth stage 1 and 2 takes roughly **4 to 10 weeks** depending on environmental conditions, physiological age of the tubers, and variety.

Growth Stage 3: Tuber set (initiation) - Tubers begin to form at the stolon tips but with little enlargement. Biochemical signals trigger the plant to initiate the development of belowground tubers. This is the stage where nutrient accumulation is rapid and shortages of nutrient uptake will cause declines in the final yield. Flowering starts at the end of this stage.

Growth Stage 4: Tuber bulking - Tuber enlargement caused by accumulation of water, nutrients, and carbohydrates. At this stage the plant shifts photosynthates and nutrients to the rapidly expanding tubers. This is the peak period of demand for plant nutrients. Nutrient shortage at this stage can cause significant yield reduction. Many agronomists carefully monitor tissue nutrient concentrations during this period to avoid any preventable stress on the plants. This stage is the longest and can last for **more than 1.5 months.**

Growth Stage 5: Maturation - Dry matter content is at a maximum. Vines turn yellow and tuber growth slows down as photosynthesis declines. Tuber growth continues during the phase, but the rate slows as the plants prepare for maturation and harvest at the peak of dry matter accumulation. De-haulming is performed to harden the skin at this stage (very important to ensure good quality produce).

Stages in Potato Development

1. Planted seed tuber
2. Vegetative growth
3. Tuber initiation
4. Tuber bulking
5. Maturation

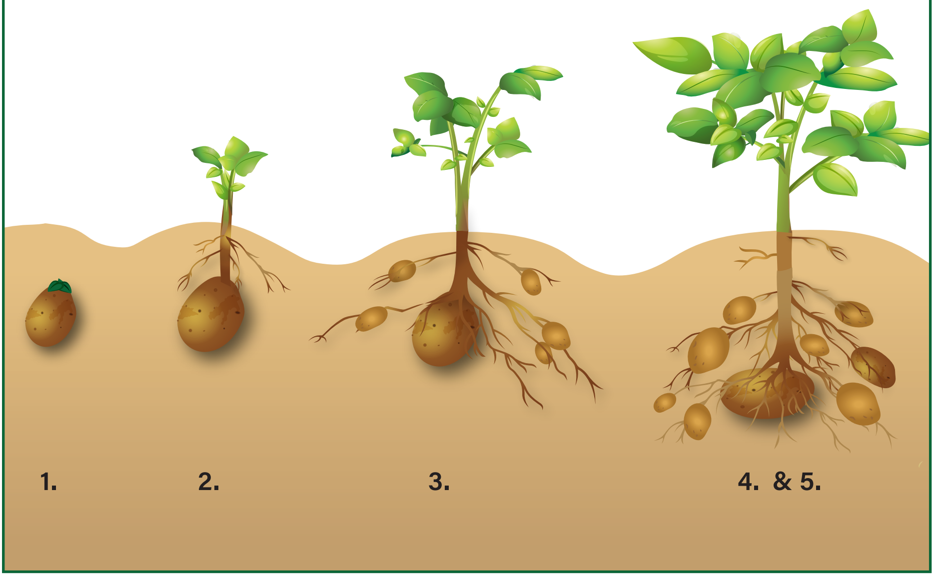


Figure 2.3 Illustration of the five stages of potato growth.
(Adapted from http://www.fao.org/potato-2008/en/potato/cultivation.html)

CHAPTER THREE

Potato Crop Nutrition

3

3.1 Nutrient requirements

Plant nutrients are commonly grouped into three categories. The **major nutrients** that are required in relatively large amounts include carbon (C), hydrogen (H), oxygen (O), nitrogen (N) phosphorus (P), and potassium (K). **Secondary nutrients**, required in smaller amounts, include calcium (Ca), magnesium (Mg), and sulphur (S). **Micronutrients** include boron (Bo), copper (Cu), chlorine (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn), which occur in very small amounts in both soils and plants, but their role is equally as important as the major or secondary nutrients.

A deficiency of one or more of the essential nutrients may lead to stunted growth of the crop, lower yields, and poor-quality potatoes.

Whereas some nutrients are expressed in elemental form, a few nutrients are commonly expressed in oxide forms (i.e., P as P_2O_5, K as K_2O, Ca as CaO, and Mg as MgO).

To convert between elemental and oxides forms:

P x 2.29 = P_2O_5 or P_2O_5 x 0.44 = P

K x 1.21 = K_2O or P_2O_5 x 0.83 = K

Ca x 1.39 = CaO or P_2O_5 x 0.71 = Ca

Mg x 1.66 = MgO or P_2O_5 x 0.60 = Mg

According to the IFDC/AGRA (2018) report, one hectare of potatoes removes approximately 233 kg of N, 30 to 50 kg of P_2O_5, 284 kg of K_2O, 48 kg CaO, 35 kg MgO, 40 kg S, 0.23 kg Zn, 0.19 kg B, 0.10 kg Cu, 0.21 kg Mn, and 3.10 kg Fe.

A tonne of potato tuber removes approximately 3 kg N, 1 kg P_2O_5, 5.2 kg K_2O, 0.2 kg MgO, and 0.3 CaO. For the micronutrients, 30 t removes approximately 0.10 Zn, 0.04 kg B, 0.06 kg Cu, 0.67 kg Mn, and 1.3 kg Fe.

Nitrogen

Nitrogen has the greatest impact on potato yield among all essential nutrients. Potato yield can be divided into the three components: 1) the number of stems per square meter, 2) the number of tubers per stem, and 3) the average tuber weight. Of these three components, N fertilization has the greatest impact on increasing tuber weight. The need for N is comparatively low during the first month of growth, but then rapidly increases. Approximately two-thirds of the total N is accumulated in the first few months following planting. Too high of an N supply can stimulate excessive vegetative growth, and suppress or delay tuber formation.

Phosphorus

Similar to N, the need for P is rather low in the first weeks of growth. However contrary to N, P is consistently taken up after tuber bulking and continues through the maturity phase of tubers. Potatoes need a good supply of available P in the soil because their root system is not extensive. They have relatively shallow roots and do not readily utilize less available P forms. Plant roots extract water-soluble P from the soil, however many tropical potato-growing soils are acidic and rapidly immobilize soluble P inputs. Because of the low P-use efficiency of potatoes, P fertilizer applications need to be considerably higher than the 30 to 50 kg P_2O_5/ha removed by the crop. Therefore, P fertilizer recommendations range from 60 to 100 kg P_2O_5/ha for most areas in Kenya (equivalent to 130 to 220 kg diammonium phosphate [DAP]/ha).

Potassium

Out of all nutrients, K has the highest concentration in potato tubers. It accounts for about 400 mg K/100 g fresh weight, or about 1.7% of dry matter. It is also the most abundant inorganic cation in the stems and leaves. The source of K influences tuber quality, particularly where tubers are meant for further processing into crisps and other snacks. Application of K as potassium sulphate (K_2SO_4) is sometimes preferred to potassium chloride (KCl) as potatoes are sensitive to high doses of chloride (Cl^-). At typical rates of application, there is little difference between the two K sources.

Calcium

Calcium (Ca) is a key nutrient for improving potato tuber quality. It plays an essential role in building strong cell walls and membranes that are more resistant to attack by damaging organisms. An adequate Ca supply reduces the severity of many plant and tuber diseases in the field and during storage.

If the soil has received proper applications of limestone to adjust the pH to the suggested range, there is likely adequate Ca for potato production. Many unlimed acidic soils contain insufficient Ca for high potato yields.

Sulphur

Sulphur is an essential component of amino acid which are essential building blocks for proteins. It's deficiency can result in significant yield penalty. Fertilizing potatoes with K_2SO_4 can also provide plants with the required S. A range of multi-nutrient fertilizers that are available in the East Africa market provide S in combination with other nutrients. The bag label indicates when the fertilizer product has S. Examples of labels containing S are: 18-38-0 (NP)+6S+0.01B; 13-24-12 (NPK)+4S+0.01Zn; and 18-0-21 (NPK)+S+CaO. Most S-enriched fertilizers are applied at planting. On average, each t of potato removes between 0.3 and 0.5 kg of S.

Micronutrients

Potato cultivars can differ markedly with regard to their sensitivity to micronutrient deficiencies. After harvest, the storage life of potato tubers can be reduced as a result of soil B deficiency. Soil application or foliar sprays are the most widely used methods for supplying micronutrients. Deficiencies of Cu and Mn are controllable by soil or foliar application. The high seed rate of potato also makes it possible to supply the micronutrient needs of the crop through soaking the seed tubers in nutrient solutions. Before planting, non-dormant seed tubers are soaked in 0.05% micronutrient salt solution for 3 hours. Dipping seed tubers in a 2% zinc oxide suspension is effective for meeting the Zn needs of the crop.

Table 3.1 describes different nutrient deficiencies, visual diagnosis, and factors that may worsen specific nutrient deficiencies. **Figure 3.1** describes the generalized locations of nutrient deficiency symptoms in plants.

Table 3.1. Potato nutrient deficiencies, visual diagnosis, and causes.

Nitrogen (N)

Functions	How to recognize the deficiency
▪ Component of all proteins, enzymes, and metabolic processes required for synthesis and transfer of energy in the plant. ▪ Component of chlorophyll, the green pigment responsible for photosynthesis. ▪ Promotes rapid growth and increases tuber production.	 Plants have a generally uniform pale green/yellow (chlorotic) appearance. Lower leaves first appear lighter green than normal, but this gradually spreads up the plant. Leaf yellowing progressively worsens and leaves become more erect than normal. Eventually, plant growth stops and the leaves fall off.

Phosphorus (P)

Functions	How to recognize the deficiency
▪ Boosts bulking, promotes production of tubers of uniform size, and increases tuber yield. ▪ Increases tuber dry matter content and starch levels. ▪ Improves storage potential of tubers and reduced disease during storage.	 Plants may first develop leaves that are smaller and lighter green than normal. Over time, the lower leaves darken, have less shine, start to curl, and develop small grey patches along the edges. Plants are stunted with shortened internodes and poor root systems, which can be observed at the early growth stages.

Potassium (K)

Functions	How to recognize the deficiency
▪ Enhances water uptake and root permeability. ▪ Influences the transport of nutrients and plant metabolites from the leaf to the tuber, which improves tuber yield, size, and quality. ▪ Increases resistance to stresses (drought, frost, pest, disease, poor drainage, etc). ▪ Prolongs tuber shelf life.	 Leaves appear dull and are often blue-green in colour with interveinal chlorosis. Leaves also develop small, dark brown spots on the undersides and a bronzed appearance on the upper surfaces. Yellow leaf margins eventually develop.

Magnesium (Mg)

Functions	How to recognize the deficiency
▪ Component of chlorophyll. ▪ Boosts tuber bulking and final yield. ▪ Improved disease resistance and tuber skin quality. ▪ Increased tuber dry matter content and starch levels. ▪ Improves the quality of potatoes (tuber firmness or resistant against mechanical stresses occurring during harvest, transport and storage) particularly for industrial use.	 Mature leaves are first to show mild chlorosis near the veins, which spreads out to the leaf edges. Symptoms prog-ress towards the younger growth. Interveinal chlorosis of older and fully mature leaves.

Calcium (Ca)

Functions	How to recognize the deficiency
▪ Promotes healthy green foliage. ▪ Improves yield and quality. ▪ Enhances storage potential of tubers.	 Deficiencies first become visible when new cell growth is disrupted at the bud tips. Young leaves are smaller, distorted, cupped, and darker green than normal. Margins of the leaves grow more slowly causing the leaf to cup downwards, which is related to poor translocation of Ca compared to the rest of the leaf.

Sulphur (S)

Functions	How to recognize the deficiency
▪ Promotes nutrient uptake and chlorophyll production. ▪ Enhances stress and pest resistance. ▪ Improves carbohydrate formation and vitamin synthesis.	 The young and maturing leaves on the upper plant become yellow while the lower leaves remain a healthy green. Leaves show a general overall chlorosis and upward curving of the leaves. Reddish colour is often found on the underside of leaves. Veins and petioles show a very distinct reddish colour. With advanced S deficiency the leaves tend to become more erect, twisted and brittle.

Boron (B)

Functions

- Role in cell wall formation, germination and elongation of pollen tube.
- Participates in the metabolism and transport of sugars.
- Improved tuber quality.
- Reduced incidence of rust spot.

How to recognize the deficiency

Young leaves thicken, cup upward and may show light brown tissue between veins.

Plants are small and deformed with shorter internodes.

Growing points and the shoot tips die off.

The petiole base may bear a dark striping discolouration.

Iron (Fe)

Functions

- Essential for photosynthesis and plant metabolism.
- Important for early leaf development, strong growth, and crop productivity.

How to recognize the deficiency

Young shoots and leaves are pale yellow or even whitish as chlorophyll formation is impaired; however, veins will remain green and marked.

Severe deficiency causes plant stunting and chlorotic top leaves. Iron deficiency is rare, except in some calcareous, high pH, or clay soils where soil iron may be fixed and less plant available.

Manganese (Mn)

Functions	How to recognize the deficiency
▪ Boosts tuber bulking and yield. ▪ Improves disease resistance and skin finish. ▪ Increases tuber dry matter and starch content.	 Leaf veins first remain green, but black spots develop along their lengths. Slight cupping of entire leaflets. Leaves near shoot tip are small and chlorotic or necrotic.

Molybdenum (Mo)

Functions	How to recognize the deficiency
▪ Improves N metabolism, pigment and chlorophyll synthesis. ▪ Beneficial for growth and yield.	 The early symptom is overall chlorosis, similar to the appearance of N deficiency, but generally without the reddish coloration on the undersides of the leaves. Leaves may also show some mottled spotting along with some interveinal chlorosis.

Zinc (Zn)

Functions	How to recognize the deficiency
■ Essential for the transformation of carbohydrates. ■ Regulates consumption of sugars. ■ Part of the enzyme systems that regulate plant growth.	 Recently matured leaves develop grey tips that eventually die. Young leaves show interveinal chlorosis and necrosis that occurs in irregular patches. Whitish spots appear within the brown necrotic tissue. Symptoms are most severe in leaves furthest from the stem.

Locations of Nutrient Deficiency Symptoms on Plants

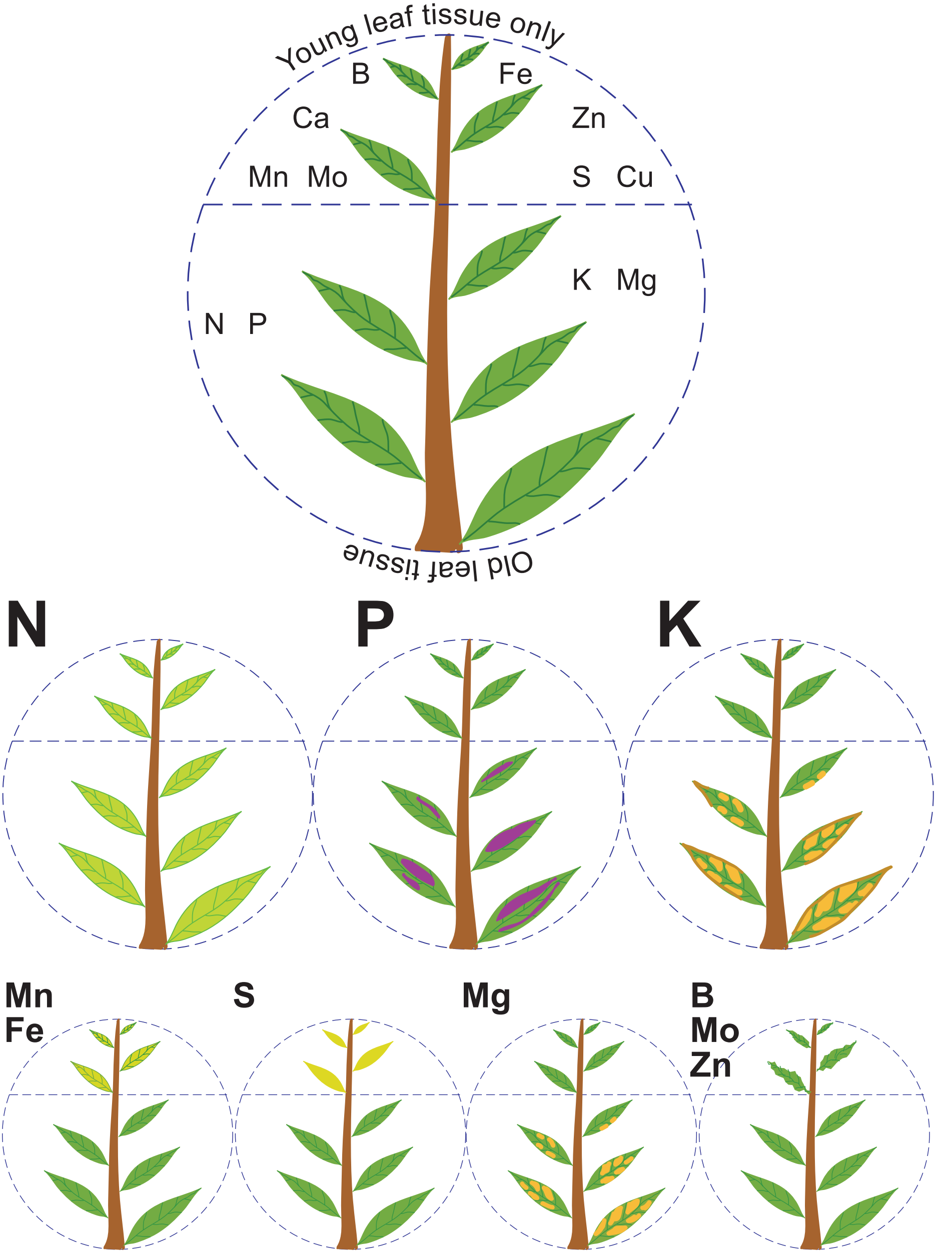


Figure 3.1 General description of where nutrient deficiency symptoms first appear on plant vegetation. (Dierolf, T. et al. 2001)

3.2 Nutrient deficiency causes and management

There are many factors that can cause nutrient deficiencies in plants. Nutrients are sometimes present in the soil but not available to the crop. Such is the case with P-fixing soils, where tests may indicate presence of P, but it is not in a chemical form that is readily-available for plant uptake. Other factors, such as drought, compacted soil layers, or excessively acidic soils can prevent roots from taking up nutrients that may be present in the soil. A negative interaction between nutrients can also cause deficiency. For example, a high supply of K, Zn and Mn could lead to N deficiency. Knowledge of the key interactions is crucial for diagnosis and management of deficiencies. **Table 3.2** below indicates some main causes of nutrient deficiencies.

Table 3.2. Causes of nutrient deficiencies in Kenyan potato production and potential management practices to correct them.

Nitrogen (N)
Causes
▪ Loss of soil N through runoff and leaching. ▪ Impeded N uptake due to compromised root system caused by pests or diseased. ▪ Shallow rooting systems with poor N scavenging ability fails to provide the high N requirement of the crop. ▪ Low organic matter soils with little N mineralization.
Management
▪ Application of N fertilizers based on soil test recommendation. The amount of N applied to a potato crop varies from 100 to 300 kg/ha depending on the purpose of the crop and soil characteristics. ▪ Nitrogen fertilizer should be applied to match the periods of crop demand. Applying some N at planting may be advantageous. Majority of the N is best applied after tuber initiation to maximize tuber development, quality, and fertilizer recovery. ▪ Split applications of N fertilizer during the potato-growing season are generally preferred for superior yields and quality. The second N application should, in general, be given no later than 3 to 5 weeks after crop emergence. ▪ Avoid high or excessive N top dressing as it stimulates haulm (vegetative) growth, delays tuber formation, and affects tuber quality (low dry matter content, high reducing sugar content and high protein and nitrate content).

Phosphorus (P)

Causes

- Low reserve P concentrations in the soil.
- Low organic matter soils contribute little to the pool of plant-available P.
- Availability of P is optimized at the pH range between 5.5 and 7.0.
- The main processes for P losses from soils are erosion, surface runoff, and subsurface transfer.
- Poorly developed root system inhibit access to P.

Management

- Application of recommended P fertilizers at the time of planting. Often more than 100 kg P_2O_5/ha is applied. Much higher doses should be used on P-fixing soils.
- Since a healthy potato root system is critical for P uptake, any time root growth is diminished, the uptake of P is also reduced. Therefore, P fertilizer should generally be applied in close proximity to where the roots will grow.
- Apply the total amount of P fertilizer before or during planting.
- Apply P in the planting furrow in P-fixing soils.

Potassium (K)

Causes

- Soils with low K reserves.
- In sandy soils or over-irrigated soils, some of the added fertilizer K may leach below the root zone and not be accessible by roots for uptake.
- Periods of limited water or environmental stress may limit the uptake of K.
- Large applications of Ca, Mg, or ammonium (NH_4) can compete with K for uptake by roots and may limit K nutrition.
- Acidic soils (low $pH < 5.0$) can increase the downward mobility and loss of K from the soil profile.

Management

- The demand for K by potatoes is greater than for most other crops, especially during the period of tuber formation, bulking, and maturation. During peak demand periods of growth, potatoes may be accumulating as much as 16 kg K/ha/day.
- Split the total amount of K between a basal application during planting and at hilling/earthing up.

Magnesium (Mg)

Causes

- Insufficient Mg is more likely to occur in sandy soils and acidic soils where Mg concentrations in soil tend to be low.
- Imbalance and high concentrations of other cations in the soil, such as NH_4, K, or Ca can suppress Mg uptake.
- Low temperature and water stress can limit Mg uptake by roots.
- Acidic soils.

Management

- Application of recommended amounts of $MgSO_4$.
- Foliar application of 0.2% $MgSO_4$; and organic manure or compost.
- Close attention should be paid to Mg requirements, particularly when potatoes are grown on sandy, acid soils.
- High rates of K, and N application in the form of NH_4, reduce the uptake of Mg.

Calcium (Ca)

Causes

- Soils with acidic pH ($pH < 5$) generally have low concentrations of exchangeable and soluble Ca. High soluble aluminium concentrations in low pH soils can damage roots and hinder Ca uptake.
- Poor root system development, especially at the root tips may limit Ca uptake by the plant.
- Soil and water salinity may interfere with Ca uptake.
- Sandy soils and light soils are susceptible to leaching losses.
- Drought conditions can limit Ca availability.

Management

- Application of recommended amounts of calcium ammonium nitrate (CAN), lime, gypsum.

Sulphur (S)

Causes

- Soil organic matter is the primary reserve of S and it becomes available for plant uptake after mineralization. Low organic matter soils may not supply adequate S for plants.
- A history of harvesting high-yielding crops may deplete the soil of S and make supplementation necessary.
- Sandy-textured soils tend to be depleted of plant-available S as the sulphate leaches below the root zone.
- Acidic or poorly aerated (waterlogged) soils.

Management

- Application of recommended amounts of gypsum, ammonium sulphate, magnesium sulphate, single super phosphate (SSP), potassium sulphate; or organic sources like manure and compost.

Boron (B)

Causes

- Organic matter is the primary soil reserve for B that becomes available for plants over time. Soils with low organic matter content are more likely to be deficient in B.
- Boron deficiencies are more prevalent in alkaline soils.
- Boric acid (the form in which B is available for plants in the soil) is susceptible to leaching from the root zone with excessive rainfall or irrigation, especially in coarse-textured soils.
- Environmental factors that reduce transpiration (high humidity, cool cloudy conditions, dry soils, etc.) will reduce the uptake of B entering the roots. Boron diffusion and mass flow in the soil will be reduced. More B enters the plant when it is rapidly transpiring.

Management

- Foliar spray with 0.2% borax solution.

Iron (Fe)

Causes

- Excessive soil liming or calcareous soils with pH > 7.
- Irrigation water with high pH or excess alkalinity.
- Soils with low organic matter, or high Cu, Mn, or Zn.
- Unfavourable weather conditions (excessive rainfall causing waterlogging, high humidity and low temperature).

Management

- Application of iron sulphate (10 kg $FeSO_4$/ha) or spray ferrous sulphate solution (0.5%) 2 to 3 times at weekly intervals.

Copper (Cu)

Causes

- Copper is generally less soluble and plant available in alkaline and calcareous soils.
- Soils with high amounts of organic matter tend to bind Cu on organic surfaces and keep soluble Cu concentrations low.
- Sandy soils tend to be highly leached and contain little organic matter.
- Excessive P, Fe, or Zn will suppress Cu uptake. High N may reduce Cu mobility within the plant. Copper deficiency occurs most commonly on sandy soils and soils with high organic matter content.

Management

- Copper deficiency can be corrected by soil or foliar application.
- Copper sulphate is the most common form of copper fertilizer, but copper chelate and copper oxide are also used.
- Spray with 0.5 l COPTREL 500/ha applied 7 to 14 days after 100% emergence and following petiole analysis during tuber bulking. Water rate: 200 l/ha.

Manganese (Mn)

Causes

- Potatoes growing in calcareous soils or soils with pH > 7 may be Mn deficient due to reduced Mn solubility.
- Soil with high organic matter may have low Mn availability due to complexation between Mn and organic matter.
- High concentrations of other micronutrient metals (such as Fe, Cu, or Zn) may inhibit Mn uptake by plants from the soil.
- Low temperature can reduce Mn uptake, primarily because of limited root activity.
- Coarse-textured soils with low organic matter content may contain insufficient concentrations of plant available Mn.

Management

- Spray with manganese sulphate (0.2%) 2 to 3 times at weekly intervals.

Molybdenum (Mo)

Causes

- Acid soils (low pH).
- Low levels of soil organic matter.

Management

- Application of foliar spray of $NaMO_4$ (0.05%) twice at weekly intervals; and organic manure or compost.

Zinc (Zn)

Causes

- Zn solubility decreases as the soil pH rises. This is due to increased adsorption and precipitation with soil minerals and also Zn reaction with limestone.
- Soils with a high organic matter content may have low plant availability of Zn.
- Elevated soil P concentrations may induce Zn deficiency through both chemical and biochemical reactions.
- Flooded soils and cool soils tend to induce Zn deficiency in plants. The deficiency may disappear when the soil is drained or when the soil temperature increases.

Management

- Apply inorganic foliar spray of $ZnSO_4$ (0.5%); and organic manure or compost.

3.3 Precautions in identifying nutrient deficiency and visual diagnosis

Interpreting visual nutrient deficiency symptoms in plants can be difficult. Regular plant analysis and soil testing is necessary to confirm nutrient stress. The following facts should be put into consideration when identifying nutrient stress symptoms:

1. **Many symptoms appear similar.** For example, N and S deficiency symptoms can be very alike depending upon plant growth stage and severity of deficiencies.
2. **Multiple deficiencies and/or toxicities can occur at the same time.** More than one deficiency or toxicity can produce symptoms, or possibly an excess of one nutrient can induce the deficiency of another (e.g., excessive P causing Zn deficiency).
3. **Crop species, and even some cultivars of the same species, differ in their ability to adapt to nutrient deficiencies and toxicities.** For example, maize is typically more sensitive to a Zn deficiency than barley and will show Zn deficiency more clearly. Similarly, potatoes are more sensitive to K deficiency than cereal crops.
4. **Pseudo (false) deficiency symptoms (visual disease symptoms appearing similar to nutrient deficiency symptoms).** Potential factors causing pseudo deficiency include, but are not limited to, disease, drought, excess water, genetic abnormalities, herbicide and pesticide residues, insects, and soil compaction.
5. **Hidden hunger.** Plants may be nutrient deficient without showing visual clues.
6. **Field history.** Experience and knowledge of field history provide important support when identifying the causes for nutrient stress. A farmer may notice symptoms that are different from previous field observations for the same nutrient deficiency.

3.4 Nutrient supplying potential of soils

Soils can typically contain large amounts of most essential plant nutrients, but they are rarely in the proper concentration or ratio to support high-yielding crops. Variations in soil mineralogy, effects of weathering and leaching, nutrient removal by previous harvests, and other factors often creates the need for supplemental nutrients provided as fertilizer.

The amount of nutrient applied as fertilizer is usually very small compared to the soil's native nutrient supplying potential. But fertilizer sources are generally more soluble, positioned in the root zone, and timed to meet the demands of rapidly growing plants.

The soil's ability to supply nutrients to plants is influenced by more than the amount of nutrients in the soil. The interactions between nutrients and other soil properties affect how and when those nutrients are made available to the plant. Soil texture, structure and other physical properties (such as hard layers) also influence nutrient release and availability. Soil acidity damages plant roots and may keep plants from taking up nutrients, even if they are present in the root zone.

Some nutrients are present in the soil in greater quantities than is needed to meet crop demand, but for various reasons they may not be readily available when they are most needed by the crop. Soil water plays a major role in nutrient availability either by enabling nutrient release and transport or by restricting it. A few nutrients (notably nitrate) move through the soil to the plant by **mass flow**, (i.e., dissolved in the water that moves toward and into the plant). Other nutrients slowly move to the roots by **diffusion** across a concentration gradient. Thus, as the plant removes nutrients from the soil near its roots the concentration is lowered and more nutrients move away from areas of higher concentration to equalize the concentration near the roots. A much smaller amount of nutrients may be available via **root interception**—where the root physically comes into contact with nutrients in the soil.

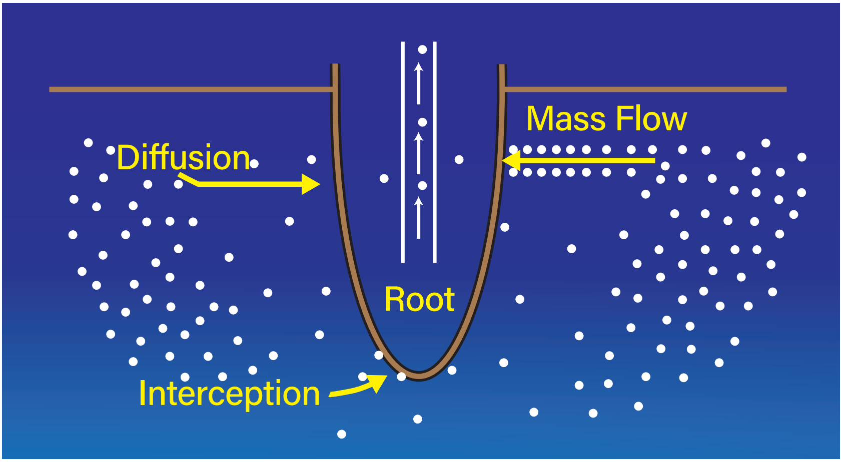


Figure 3.2 Soil nutrient movement toward the plant root by diffusion, mass flow and root interception.

As the crop grows, roots tend to move downward in the soil and explore untapped areas. However, early in the growing season the root system is limited and may benefit from a higher concentration of nutrients, such as is provided by using banded or spot-placed fertilizer applications. As the plant and root system grows, the roots can explore more of the soil and can more readily meet the plant's needs with a less concentrated soil nutrient supply.

3.5 Soil testing and fertilizer recommendations

The relative availability of nutrients in the soil before planting can be measured by soil testing. Soil test data can be used in selecting fertilizers and application rates that are appropriate for the specific needs at a particular planting site. Soil testing can also identify production areas where additional fertilizers are not needed, enabling growers to cut expenses and avoid over fertilization and potential environmental pollution.

Generally, soil test methods fall into two categories; wet chemistry (conventional methods) and scanning technologies that use non-destructive spectroscopy methods that are rapid and have a high throughput. All soil testing relies on first getting soil samples that accurately represent the field conditions. A poor sample can never provide accurate recommendations.

CONVENTIONAL SOIL TESTING IS A THREE-STEP PROCESS:

1. Nutrient extraction from the soil sample and analysis using different testing methods
2. Interpretation of test results
3. Fertilizer recommendations

Soil test values are a measure of plant-available nutrients in the soil. However, they do not indicate directly how much fertilizer should be applied. Different soil testing methods give different nutrient concentrations even for the same soil. Hence, soil testing methods need to be calibrated with field trials to give the **Soil Critical Nutrient Concentration (CNC).** Established CNC identify the degree of deficiency or sufficiency of a soil nutrient. Thus, CNC provides information on the amount of nutrient required for optimum crop yields. In assessing the plant nutrient status, it is prudent to complement soil analysis with plant tissue analysis, which is also a valuable tool for nutrient management.

Fertilizer recommendations are based on soil test results, yield target, efficiency of various application methods, the soil texture, and the amount of plant nutrients available from other sources, such as manure.

THE PROCESS OF DEVELOPING A FERTILIZER RECOMMENDATION IS STEPWISE AND INVOLVES:

1. The soil test value of the nutrient (output from soil testing)
2. The amount of nutrient required for optimum crop yields
3. The quantity of fertilizer needed to raise the soil test value above the CNC

Soil samples submitted for analysis must be representative of the sampled area. It is essential that each field be sampled in such a way that variations within the field are accurately represented. In general, fields should be divided into areas of uniform soil colour or texture, cropping history, and fertilization or manuring history. One sample should represent no more than 20 acres, even if the soil is uniform. Usually, 10 to 20 soil cores are randomly taken in a zigzag pattern across the sampled area and then combined to make up a single sample. A sampling depth of 20 to 30 cm is adequate for most nutrients.

3.6 Soil pH and soil acidity

Soil pH is a useful indicator of the relative acidity or alkalinity of a soil. The pH scale ranges from 0 to 14, and the soil is assigned a value from the pH scale to describe the acidity or alkalinity. Since pH 7 falls midway along the scale, pH values that are equal to 7 are said to be neutral. However, pH values that fall below 7 are acidic, while pH values above 7 are alkaline.

Soil acidification leads to a change in soil chemical and biological properties. Soil pH in agricultural soils commonly ranges between pH 4.5 to 8.5.

Low soil pH can cause many problems with plant growth. Excess acidity releases aluminium (Al) from soil minerals that will damage potato roots. Soil acidity also leads to reduced nutrient uptake recovery and efficiency by plants. Therefore, more fertilizer will need to be added for the same result. Low fertilizer efficiency can mean either the farmer uses the same amount of fertilizer but gets a lower yield, or the farmer adds more fertilizer to maintain the same yield. The end result is a reduction in farm income due to either increased input costs or reduced production. Maintaining the right soil pH with lime additions can minimize these problems.

Soil pH has a great effect on nutrient availability (**Figure 3.2**). For example, at pH 4.5, plant-availability of P is reduced to less than a quarter of that at soil pH 6, which means that for the same result the farmer needs much more fertilizer P.

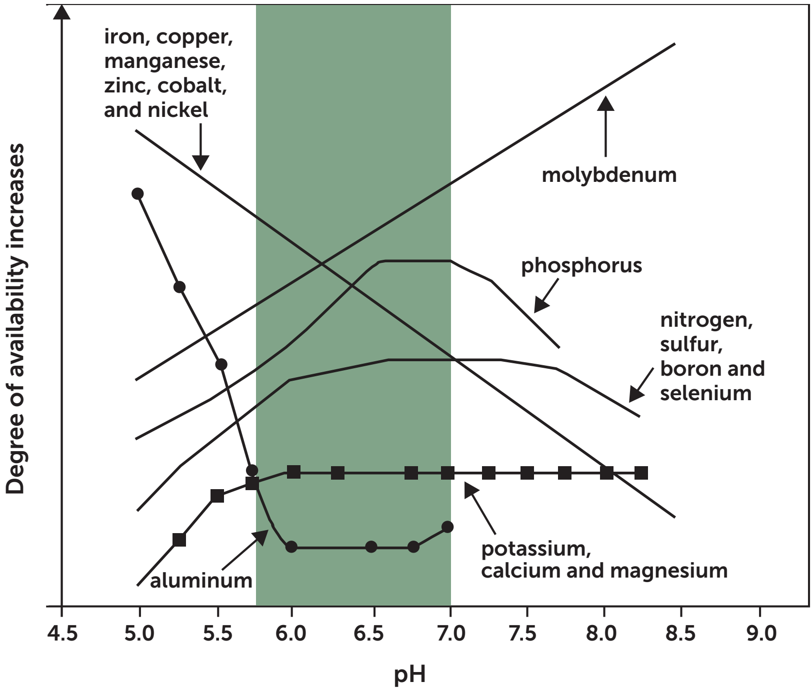


Figure 3.3. Typical effect of change in soil pH on the availability of plant nutrients. Actual effects in specific soils vary with other chemical and mineralogical properties. (IPNI. 2013)

A proper nutrient management plan must include careful monitoring of soil pH so that all of plant nutrients can be most efficiently used by the crop. For soils to support highly productive crops, they must first be in the optimum pH range.

Potatoes perform optimally at the pH range of between 5.5 and 6.5. Soil pH below 5.0 can be very damaging to plants (soil acidity syndrome) by causing nutrient deficiencies (e.g., P and Mg) and toxicities (e.g., Al, Fe, and Mn). Liming helps to raise the pH to at least 5.5 where the nutrient availability and the crop performance are optimized. **Table 3.3** show the estimated effect of soil pH on availability of N, P, and K. **Table 3.3** indicates that at pH 4.5, over 60% of these nutrients are not plant available, but at pH 7.0, pH may no longer impede their availability. The goal of the farmer should therefore be to manage pH so that soil acidity does not impede availability of nutrients to crops.

Table 3.3 Effect of soil pH on the availability of N, P, and K.

	pH 4.5	pH 5.0	pH 5.5	pH 6.0	pH 7.0
Nitrogen (N)	30%	43%	77%	89%	100%
Phosphorus (P)	23%	31%	48%	52%	100%
Potassium (K)	33%	52%	77%	100%	100%

https://www.gouldings.ie

3.6.1 *Lime and liming materials*

The best way to determine if you need to add lime is to test the soil pH. Lime is applied to acid soils to neutralize the excess acidity that causes reduced crop yields. Liming highly acidic soils could also improve the microbial activity in the soil. Earthworms are more active at improving aeration and drainage, and enabling better use of organic matter at a neutral pH (6.0 to 7.0). Liming materials are crushed carbonate rocks that contain Ca and/or Mg in forms that will neutralize soil acidity when dissolved. Addition of organic matter (manures, organic residues) into soil will enhance the buffering capacity of the soil and temporarily reduce the harmful effects of soil acidity. Common liming materials are agricultural lime ($CaCO_3$) and dolomitic lime ($MgCO_3$). Liming materials move very little in soil without incorporation. Therefore, tillage increases the effectiveness of all lime materials. This can be done by mixing them into the rooting zone (**Photo 3.1**).

3.6.2 Rate of lime required

The rate of lime required depends on the amount of pH adjustment that is required and the buffering capacity of the

Photo 3.1 *(Photo by Joses Muthamia)*

Mixing lime materials into the soil in preparation for planting in Eastern Kenya.

soil. Buffering capacity refers to the amount of lime required to change soil pH. Sandy soils and soils low in organic matter have low buffering capacities while clay soils and soils high in organic matter have higher buffering capacities. Sandy soils therefore require less lime to make a pH change, compared with the same pH change in a high clay soil.

3.6.2.1 Can over-liming be dangerous

Over use of lime can be dangerous and may create a lot of problems in the soil that include:

1. **Nutrient imbalance**
   Applying too much lime to the soil can tie up micronutrients by creating high soil pH. As a result, plant roots are unable to access adequate nutrient supplies to produce healthy plants and animals.

2. **High molybdenum (Mo)**
   Land with high levels of Mo should be kept below pH 7.0. Excessive lime can dramatically raise pH and make more Mo available to the plant, which can also induce copper (Cu) deficiency.

3.6.2.2 Estimating lime requirement

Various methods exist for estimating the lime requirements of soils of tropical regions. Cochrane et al. (1980) published the following equation for liming acid mineral soils to improve crop aluminium (Al) tolerance while taking the concentration of exchangeable soil Ca and Mg into account:

Lime Requirement ($CaCO_3$ equiv. t/ha) = 1.8 [Al-RAS (Al + Ca + Mg) ÷ 100]

where: Al, Ca and Mg are expressed as cmolc/kg soil (1 N KCl extract)

RAS = required % Al saturation of the ECEC

ECEC = $\sum$ (Al, Ca, Mg, K, Na) in cmolc/kg.

In Brazil, lime requirement is determined on the basis of Al, Ca and Mg contents of the soil and the following equation is generally used for this purpose:

Lime Requirement (t/ha) = (2 × Al) + [2 − (Ca + Mg)]

where: Al, Ca and Mg are expressed as cmolc/kg soil.

The base saturation is also used sometimes to calculate lime requirement using the following equation:

Lime Requirement (t/ha) = CEC (B2-B1) ÷ TRNP x df

where: CEC = total exchangeable cations (Ca^{2+} + Mg^{2+} + K^{+} + H^{+} + Al^{3+}) expressed as cmolc/kg

B_2 = desired optimum base saturation

B_1 = existing base saturation

TRNP = total relative neutralizing power of liming material

df = lime incorporating depth (1 for a 20-cm depth and 1.5 for a 30-cm depth).

BENEFITS OF LIMING

- Improves nutrient availability thus increasing fertilizer efficiency and decreasing the cost of fertilization.
- Improves the physical condition of the soil (i.e., better structure)
- Improves microbial activity
- Provides an inexpensive source for Ca and Mg when these nutrients are deficient
- Improves symbiotic N fixation by legumes
- Reduces the possibility of Mn and Al toxicity
- Improves root growth leading to better nutrient and water uptake

3.6.3 Organic matter and soil acidity management

Addition of organic matter is a viable option to manage problems associated with soil acidity.

- Organic matter increases the cation exchange capacity of the soil. As the base saturation increases, the relative amount of "acid cations" decreases.
- In addition, organic matter forms strong bonds, known as "chelates," with Al. Chelation reduces the solubility of Al and soil acidity. Again, if your soil is prone to Mn toxicity, it is not suggested that you add organic matter.

3.7 Fertilizer application and nutrient interactions

The plant's response to the application of a specific nutrient depends on the availability of other nutrients. The response to one nutrient is limited if any other nutrient is insufficiently available. This situation can be corrected by identifying the nutrient or nutrients that are limiting and applying the amounts needed to attain the potential yield of the cultivar in the production area where it is grown. The nutrition of a crop is a complex system and as well as under supply of nutrients over supply of certain nutrients can also have a detrimental effect on crops through antagonistic effects on other nutrients. For example, K suppresses Mg uptake, and vice versa. High amounts of NH_4 suppress K uptake. High concentrations of Ca in the soil can reduce the availability of B, Fe and Mg, whilst high concentrations of N can reduce the availability of Cu. On the other hand, high concentrations of N will increase the demand for Mg. Excessive Fe induces Mn deficiency. Heavy applications of P induce Zn deficiency in soils low in available Zn. Application of any micronutrient at rates higher than required by the plant may cause toxicity or deleterious interactions affecting the uptake of other nutrients. It is therefore important to get the nutrient balance right.

The Mulder chart below summarizes the relationships between nutrients (**Figure 3.4**).

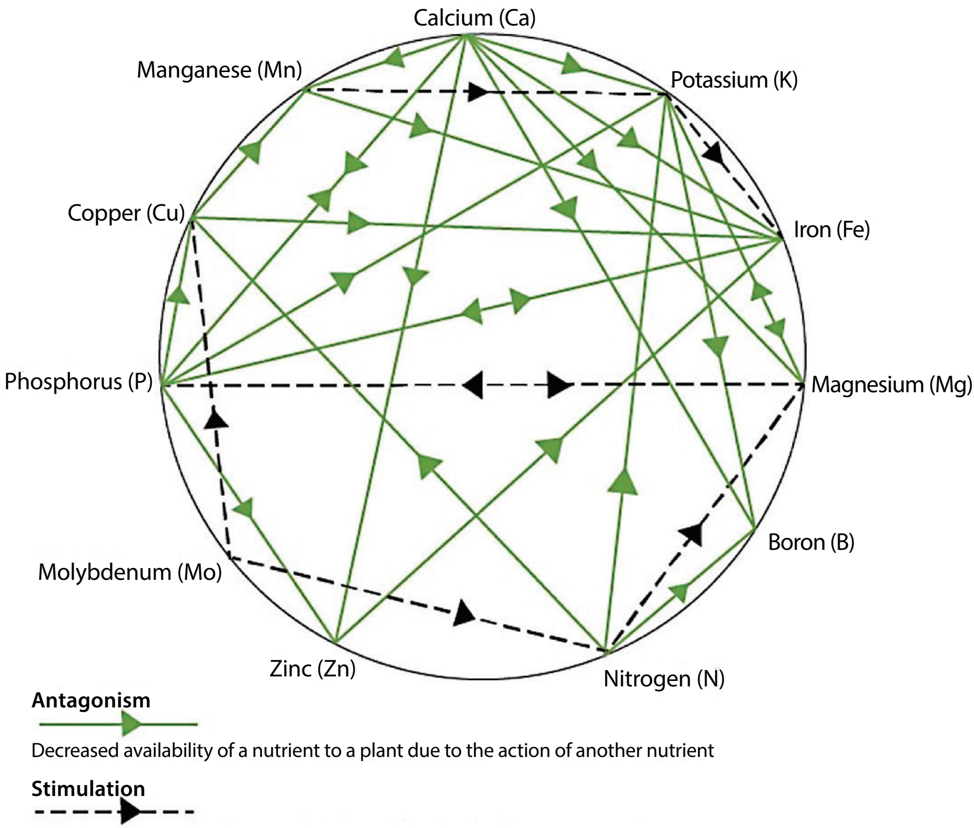


Figure 3.4. Mulder chart illustration of relationships between nutrients.
(Source: https://extension.msu.edu/newsletters)

3.8 Types of nutrient sources

Nutrients can be supplied from organic resources (also referred to as organic inputs), inorganic fertilizers (also referred to as mineral fertilizer) or a mix of the two. **Organic fertilizers** are made from living, or once-living, material such as animal waste (manure), crop residues (such as leaves), compost, and many other by-products of living organisms. **Inorganic fertilizers** are made from non-living sources such as rock deposits through industrial processes.

Using organic inputs in combination with inorganic fertilizers may increase the efficiency of fertilizer use. In other words, when fertilizers are applied in the presence of organic residues, more of the nutrients contained in the fertilizer are taken up by the crops. Unlike fertilizer nutrients, which are readily available to plants, organic inputs need time to decompose and release nutrients and are therefore a 'slow release' source of nutrients to plants. Residues with a narrow C:N ratio (e.g., legume crop residues) decompose and release their nutrient content more rapidly than materials with a wide C:N ratio (e.g., cereal straw).

The concentration of nutrients in organic resources is low and therefore much larger quantities of organic resources are required to supply a given quantity of nutrients by comparison with mineral fertilizers. For example, fresh goat manure on average contains 7 kg P/t (16 kg P_2O_5/t). By comparison, 1 t of triple superphosphate (TSP) fertilizer contains 200 kg P (460 kg P_2O_5). If the goal is to apply 50 kg P_2O_5/ha, this could either be delivered in 3 t goat manure or 109 kg TSP.

Fertilizers that contain only N, P, or K are referred to as **straight** fertilizers**.** Those containing two or three of these nutrients are sometimes referred to as **binary** (two-nutrient) or **ternary** (three-nutrient) fertilizers. The terminology multi-nutrient fertilizer can be used in reference to fertilizers that contain more than one nutrient but is most commonly used to refer to fertilizers that contain both major, secondary and and micro nutrients.

Fertilizer Products				
Powder	Crystals	Prills, Granules	Supergranules	Liquid Fertilizer
				
Example: single superphosphate, limestone	Example: ammonium sulphate	Example: urea, diammonium phosphate	Example: urea supergranules	Example: urea-ammonium nitrate

Figure 3.5. Visual appearance of some fertilizer products.

3.8.1 Straight fertilizers

Some of the most important straight fertilizers are as follows:

Urea (46% N), is the world's major source of N due to its high concentration and its usually attractive price per unit of N. However, its application requires special agricultural practices to avoid, in particular, evaporation losses of ammonia (NH_3) to the air. Urea should be applied only when it is possible either to incorporate it into the soil immediately after spreading or when rain is expected within the few hours following the application. Otherwise, some of the urea will be converted to ammonia gas and be lost to the air.

Ammonium Sulphate (AS) contains 21% N in the form of ammonium (NH_4). However, in addition to N, AS contains 23% S, a plant nutrient of growing importance. AS is preferred on irrigated crops and where S fertilization is needed. This is because there is less NO_3-N leaching from AS than AN. Less leaching losses increases N use efficiency and reduces NO_3-N pollution in groundwater and, eventually, drinking water.

Ammonium Sulphate Nitrate (ASN) contains 26% N (about two-thirds in the form of ammonia and one-third in the form of nitrate) and 13 to 15% S.

Calcium Ammonium Nitrate (CAN) with up to 27% N (equal parts of NH_4 and nitrate (NO_3^-) is one of the most common top dressing fertilizers. In addition to N, it adds Ca to the soil. CAN is less acidifying to soil than urea and ammonium sulphate.

Single superphosphate (SSP) with 16 to 20% P_2O_5 also contains 12% S and more than 20% Ca.

Triple superphosphate (TSP) with 46% P_2O_5 contains no S and less Ca than SSP. Both TSP and SSP contains water-soluble, plant-available phosphate.

Muriate of potash or potassium chloride (KCl) with up to 60% K_2O is the leading straight K fertilizer used on most crops. On crops sensitive to chloride (Cl^-) or where S is needed, potassium sulphate (K_2SO_4), with 50% K_2O and 18% S, is used. However, as with phosphate fertilizers, a major part of K_2O is applied in multi-nutrient NPK and PK fertilizers.

3.8.2 Multi-nutrient fertilizers

A large number of multi-nutrient fertilizers are offered in the Kenyan market. Some advantages of multi-nutrient fertilizers to farmers are:

- Ease of handling, transport and storage
- Ease of application
- High nutrient content
- Even distribution of nutrients in the field
- Balanced fertilization (i.e., N, P and K available together from the start and in accordance with plant requirements)
- High fertilizer use efficiency

In general, there are three distinct types of multi-nutrient fertilizers:

Mixed fertilizers or blends: simple mechanical mixtures of straight fertilizers (the mixture may not be applied homogeneously if appropriate care is not taken).

Complex fertilizers: manufactured through processes involving a chemical reaction between the constituents containing the primary plant nutrients (each granule contains the declared ratio of nutrients).

Compound fertilizers: granulated straight fertilizers or intermediates, the granules contain the nutrients in varying ratios.

Typical NPK- and NP-grades of multi-nutrient fertilizers are shown below.

NPK complex / compound fertilizers	22-22-11, 19-19-19, 17-17-17, 14-35-14, 14-28-14, 15-15-15, 13-13-21, 12-24-12, 12-12-17, 11-22-22, 10-26-26
NP complex / compound fertilizers	28-28-0, 26-14-0, 24-24-0, 23-23-0, 20-20-0, 18-46-0, 16-20-0

In addition to N, P and K, a number of grades also contain Mg, S and Ca. Some also contain micronutrients such as Fe, Cu, Zn, Mn, B, and Mo. Thus, in choosing the right grade, the farmer can provide all the nutrients requirements with a single fertilizer.

The most commonly used fertilizer for potato production in Kenya is diammonium phosphate (DAP). If DAP is used, the farmer is advised to also apply K-supplying fertilizers (e.g., sulphate of potash) at planting and to top dress with either Urea or calcium ammonium nitrate (CAN).

Other fertilizers available for potato production in the Kenya include: the top dress NPK formulation Nitrabor™ (15.4-0-0 + 25.9 CaO + 0.3 B); the basal NPK formulation Baraka Potato® (14-28-14 + S + CaO + MgO + Zn + B); and the top dress Baraka NPK® formulation (18:21:0 + S + CaO). A more comprehensive list of the most commonly used fertilizers for potato production is presented in **Table 3.3**.

Table 3.3 Common potato fertilizers available in Kenya.

Fertilizer source	Chemical formula	Nutrient composition
Macronutrients		
Urea	$CO(NH_2)_2$	46% N
Ammonium sulphate	NH_4SO_4	21% N, 24% S
Single superphosphate	CaH_2PO_4	12-18% P_2O_5, 18-21% Ca, 11-12% S
Mono-ammonium phosphate	$NH_4H_2PO_4$	10-12% N, 48-61% P_2O_5
Di-ammonium phosphate	$(NH_4)_2HPO_4$	18% N, 46% P_2O_5
Potassium chloride	KCl	60% K_2O, 45% Cl
Potassium sulphate	K_2SO_4	50% K_2O, 17-18% S
Potassium-magnesium sulphate	$K_2SO_4 \cdot 2MgSO_4$	21-22% K_2O, 10-11% Mg, 21-22% S
Elemental sulphur	S	95-99% S
Magnesium sulphate	$MgSO_4 \cdot 7H_2O$	13-16% Mg, 13% S
Gypsum (dihydrate)	$CaSO_4 \cdot H_2O$	13% Ca, 18% S
Gypsum (anhydrite)	$CaSO_4$	29% Ca, 23% S
Micronutrients		
Borax	$NaB_4O_7 \cdot 10H_2O$	11% B
Boric acid	H_3BO_3	17% B
Zinc sulphate	$ZnSO_4 \cdot 7H_2O$	22% Zn, 11% S

3.8.3 Micronutrient fertilizers

Micronutrients require special attention and care due to the narrow margin between excess and deficiency for the plant requirement. If too much of a given micronutrient (e.g., B) is applied, it may have a harmful effect on the current crop and/or succeeding crops. Special compound fertilizers can be prepared containing micronutrients along with the NPK grades for soils and crops where deficiencies are known to exist. In many cases micronutrient deficiencies are caused by low (acid) soil pH, or more often, through a soil pH that is too high (neutral to alkaline). Thus, a change in soil pH may correct some micronutrient deficiencies.

A more exact rate of application and usually also a greater efficiency are made possible through the use of spray or seed treatments with micronutrients (formulated as powders or liquids). Complexed organic compounds and chelates of Fe, Zn, Mn, and Cu will significantly increase the efficiency of applied micronutrients, particularly that of Fe, which is hardly taken up in a non-chelated form.

3.8.4 Foliar fertilizers

Foliar fertilizers contain major nutrients and also micronutrients. Foliar sprays are generally not recommended for treatment of N, P, K, Ca, and S deficiencies. It is advisable, to read and follow the label guidelines carefully for recommended rates and handling.

Foliar fertilizers are applied to, and absorbed by, the leaves and can have an immediate effect on plant growth. They may help to overcome apparent nutrient deficiencies, especially micronutrient deficiencies, and support plant recovery following stress events, such as drought. Foliar fertilization should be generally considered as a rescue treatment to add nutrients where unforeseen problems occur or soil conditions do not allow a root zone-based treatment.

Table 3.4 Fertilizer materials suitable for application as foliar sprays to correct nutrient deficiencies in potato plant.

Nutrient	Source/s	Comments
Boron	Sodium borates, Solubor®, Boric acid	Apply at growth stage 2 or 3, or 40 to 60 days after planting: repeated applications may be necessary; soil application is a more preferable option.
Copper	Copper sulphates, Copper chelates	Apply at growth stage 2 or 3, or 40 to 60 days after planting; one application may be sufficient.
Iron	Iron sulphate, iron chelates	Repeated applications are necessary to correct most deficiencies.
Magnesium	Magnesium sulphate	One application may be sufficient.
Manganese	Manganese sulphate, Manganese chelates	Effective method for correcting deficiencies: two or three applications may be necessary.
Molybdenum	Sodium molybdate, Ammonium molybdate	Effective method for correcting deficiencies; very low rates are sufficient.
Zinc	Zinc sulphates, Zinc chelates	Apply at growth stage 2 or 3, or 40 to 60 days after planting; one application may be sufficient.

Adapted from Rowe RC (1993)

3.8.5 Micronutrient Use in Potato

Certain micronutrients must be supplied for high potato yields in some soils. Zinc (Zn) and manganese (Mn) may be needed in calcareous alkaline soils. Some fungicides contain significant amounts of certain micronutrients and can be significant sources of micronutrients. For example, the fungicide *Mancozeb* is a source of Zn, and copper (Cu). Copper may be needed in peat soils but is usually sufficient in most mineral soils. Boron (B) may be needed where the soils are deficient in it. Iron (Fe), chloride (Cl^-) and molybdenum (Mo) are generally not deficient in soils that are used for potato production. The most effective application method depends upon the micronutrient, soil conditions, and the point in the growing season at which a deficiency is observed.

Generally, Zn, Cu, Mn, and B can be broadcast and incorporated into the seedbed. On calcareous alkaline soils, however, manganese should be banded or applied as a foliar spray. Foliar applications are effective for Zn, Cu, and Mn. Boron can be applied as a foliar spray, but it is not translocated from the foliage to the tubers. Repeated foliar applications are necessary to correct an iron deficiency. Application of any micronutrient at rates higher than required by the plant may cause toxicity or deleterious interactions affecting the uptake of other nutrients.

MICRONUTRIENTS AND HUMAN HEALTH

Micronutrients play a decisive role in maintaining health, because they have an essential role in cognitive growth and development, in reproductive functions and cell metabolism, and also in immune system responses of humans. Dietary deficiencies of micronutrients (i.e., hidden hunger) are considered as a global public health problem.

Iron limitation adversely distracts growth, immune function. Millions of people in developing countries especially the elderly, pregnant women, and preschool children suffer from Fe deficiency. Current studies show that Fe deficit in the first year of life is responsible for permanent effects on brain development, structure and function (Beard, 2008). Various biological functions have been attributed to Zn, since it cooperates with many enzymes and other proteins and performs critical structural, functional and regulatory roles in the body.

Agronomic biofortification involves supplying the growing crops with micronutrients through fertilization to boost the level of mineral nutrition in the edible part of crop, thus boosting the micronutrient concentration in the edible plant components.

3.8.6 Manure application

Manure can be applied anytime, but it is best added during land preparation before planting. This will improve soil moisture retention and slowly release plant nutrients during the crop growth. It is recommended to spread and incorporate manure on land after first ploughing, especially on sandy soils.

First, manure is applied in small heaps evenly distributed across the field. The manure is then spread and incorporated into the soil. This can be done during harrowing.

Farmers with access to large quantities of manure can often reduce the amount of fertilizers that they apply. When manure is band applied, it should be thoroughly mixed with soil before applying additional fertilizer and seeding.

The slow-release pattern of nutrients from manure often makes it difficult to match the crop's nutrient requirement with the availability of the nutrients. Recommendations for large quantities of manure (about 10 t/ha) imply that farmers with only a few animals may not entirely meet crop nutrient requirements with manure alone.

In scenarios where farmers have a limited amount of manure, the farmer can first apply manure, and then fertilizer, to meet the crop's nutrient demand. Better yields are possible when both manure and mineral fertilizers are applied than if they are applied independently. Manure should be well-decomposed before application. This will ensure that the manure is free from pathogens, pests and weed seed.

3.9 4R Nutrient stewardship for potato production

Understanding the nutrient demand of high-yielding potatoes throughout the growing season is crucial for correct nutrient management. Knowing the total seasonal demand and the daily nutrient requirement provides a guide for fertilization and for mid-season adjustments. Nutrient uptake in potatoes is generally most rapid during the time of the tuber initiation and tuber bulking stages. Nutrient uptake decreases later in the growing season during the tuber maturation stage.

When a nutrient deficiency is expected, consider the concept of 4R nutrient stewardship before applying a preventative or corrective fertilizer treatment. This concept helps to identify the "Right" way to meet the needs of the potato crop by considering:

1. **Right Source** of nutrient applied based on soil and crop conditions, market access, affordability
2. **Right Rate** based on the crop nutrient needs and the amount of nutrients available in the soil
3. **Right Time** in accordance with the nutrient need during crop growth stages
4. **Right Place** to maximize the access of nutrients by the crop and reduce losses to the environment

The decision-making process of implementing a 4R strategy allows farmers to consider the economic, environmental and social impacts before making any nutrient applications.

3.9.1 Right source

At planting, farmers should ensure they have the right fertilizer. Selecting the right fertilizer includes considering all major nutrients required for good potato growth and yield, especially N, P and K. In some areas, fertilizers that contain secondary and micronutrients may be required to address soil deficiencies. To determine the right source, check the nutrient composition of the fertilizer on the fertilizer bag. If organic nutrient sources are available, they should be used together with mineral fertilizers for integrated soil fertility management.

Nitrogen

Nitrogen (N) is required in high quantities at different stages of potato growth and hence getting sufficient N to the growing plant is critical in achieving high yields. Proper N management influences important properties related to tuber yield and quality—including size, grade and storage quality. Potatoes acquire N from a number of sources—all of which should be accounted for in a comprehensive nutrient management plan.

These N sources may include added N fertilizer, organic matter (including animal manure and cover crops), and inorganic N present in the soil prior to planting. All of these potential N sources should be accounted for when making decisions related to the total fertilizer N requirement. Across the region, between 100-300 kg N/ha are required for successful potato production.

Phosphorus

Phosphorus (P) is important in potato production for early plant development and rapid tuber growth. The requirement for additional P can be determined with pre-season soil tests if these are available. Fertilizers rich in P are best applied basally to provide adequate P for early growth and development of the crop. The decision to use a particular fertilizer material to supply P is generally based on availability, nutrient composition, price, ability to supply other essential nutrients, and other field operations that are occurring. Some of the fertilizers available in the Kenyan market for the supply of P include DAP, TSP, 17:17:17, and a myriad of specially designed blends such as 14:28:14, 15:9:21, among others. Mid-season application of P may be considered when the uptake of nutrients from the soil is unable to fully meet the demand of the rapidly growing crop, but this practice is not generally recommended.

Potassium

Potatoes remove very large amounts of potassium (K) in the harvested tubers (200 to 400 kg/ha). Inadequate supplies of K will result in decreased yields and poor tuber quality. There are different K sources in Kenyan market including compound fertilizers like 17:17:17 and multi-nutrient fertilizers specifically blended for potatoes. Considering that potatoes may accumulate up to 15 kg K/ha/day during tuber bulking, it is essential that adequate K supplies be maintained in the root zone.

3.9.2 Right rate

Applying the right rate of fertilizer ensures that crops get enough nutrients to achieve the required yields. Farmers should weigh the right amount of fertilizer per field before planting starts. To apply the right rate of fertilizer uniformly, farmers can use locally assembled materials such as dollop cups, bottle tops, cans etc. of different sizes that have been calibrated for different fertilizers.

Photo 3.2 *(Photo by Angela Ndanu)*

Locally assembled scoop for applying specific rate of fertilizer. Bottle caps can also be used.

Nitrogen

Although potatoes require a constant supply of N throughout out the growing season, the peak demand period generally coincides with rapid vegetative growth in the first 60 to 80 days after planting (with daily accumulation rates reaching as high as 7 kg N/ha). After this intensive growth period, N accumulation rates gradually diminish until harvest. The objective with N management is to maintain an adequate nutrient supply for the plant to achieve the optimal balance between vegetative and tuber growth.

Proper N management is one of the most important factors required for obtaining high yields of excellent quality potatoes. An adequate early season N supply is important to support vegetative growth, but excessive soil N later in the season will suppress tuber initiation, reduce yields, and decrease the specific gravity in many instances. Applying the correct amount of N requires skill and knowledge of the entire production system. Potato cultivars differ in their N requirement and there is no correct standard rate of N for all cultivars. Deep-rooting varieties with very long haulm (stalk or stem) longevity are effective N scavengers and may require lower application rates in certain circumstances compared to those with medium or short haulm longevity. As guide, the N removed by a potato crop (uptake by the whole plant) is estimated at 105 kg/ha for production of 20 t/ha and 171 kg/ha for production of 40 t/ha. The recommended N application rate should be split between basal application and top dressing. This is because N is very soluble and easily leached by rain water. Splitting N ensures its availability during the crop stages that requires it. As the risk of loss for other nutrients from soil are less significant, they should be applied at planting by spreading the fertilizer along the furrows and incorporating it into the soil before planting.

Several precautions should be taken in planning N applications. High rates of banded urea or DAP can cause ammonia toxicity, particularly in calcareous alkaline soils. Nitrogen applications 1.5 to 2 times higher than recommended rates can stimulate excessive foliar growth, leading to delayed tuber maturity, lower specific gravity, and increased problems with tuber quality.

Phosphorus

Phosphorus (P) plays an essential role in plant health and root development, which directly impacts yield and quality. The demand for P continues to increase until the middle of the growing season, with a daily demand peaking between 0.5 to 0.9 kg P/ha/day depending on the variety and yield potential. An adequate and constant supply of P during the entire growing season is required to support vine and tuber growth. An insufficient P supply results in reduced tuber size and yield. The anticipated P fertilizer requirement is best applied prior to planting, based on the results of soil testing. Since P fertilizer is not susceptible to leaching loss, it can be placed in the root zone prior to planting where it will remain during the growing season. The P requirement of potatoes is frequently higher than the P requirement of many field crops due to the high nutrient demand of potatoes and their relatively shallow root system. Generally, between 50 to 120 kg P/ha are required for potato production depending on the prevailing soil conditions.

Phosphorus fertilization at planting is generally recommended, with the application rate based on the results of soil testing or observing the previous crop performance. Additional mid-season applications may be useful when plant tissue testing indicates that P may limit plant growth and yield. The P fertilization rate should be adjusted to account for the soil properties. A history of manure application may build P concentrations to a point where little, if any, additional P fertilizer is needed.

Potassium

Since potatoes have a very high potassium (K) requirement, it is important that an adequate supply be maintained in the root zone at all times. Many important yield and quality parameters of the tuber are negatively affected if the K supply runs short, especially during tuber bulking. Pre-plant application is the most effective way to supply K. If large amounts of K are required, it is advisable to split the application into two or more applications and apply before emergence.

Potatoes require large amounts of K since this nutrient is crucial for metabolic functions such as movement of sugars from the leaves to the tubers and transformation of sugar into potato starch. Potassium deficiencies reduce the yield, size and quality of the potato crop. A lack of adequate K can be associated with low specific gravity in potatoes. During peak periods, potatoes can take up 15 kg K/ha each day. Excessively high K can result in its accumulation in tubers where it may increase tuber water content and decrease tuber specific gravity. When soils are deficient in K, it is recommended that no more than 300 kg K_2O/ha should be applied in a single application.

Potassium influences both yield and tuber quality, including specific gravity, susceptibility to blackspot bruise, after-cooking darkening, reducing sugar content, chip fry colour, and storage quality. Muriate of potash (MOP) fertilizer, particularly at high rates of application, usually results in lower tuber specific gravity than sulphate of potash (SOP) fertilizer. This problem is reduced as the interval between application and planting is increased.

3.9.3 Right placement

Fertilizer should be placed in the planting hole, or banded in the furrow, and partially covered with 5 cm of soil before placing the seed. This prevents contact between seed and fertilizer, which can affect germination. Right placement of fertilizer ensures that fertilizers are placed where growing plant roots are able to easily access nutrients.

3.9.4 Right time

Right time refers to applying nutrients such that they are most available when plants require them. Basal fertilizers containing all the P and starter N and K should be applied at planting.

Nitrogen

Plants take nitrogen in form of ammonium-N or Nitrate-N. Nitrogen especially Nitrate-N is highly soluble in water and could easily be lost from the crop root zone via leaching by rainfall or irrigation water. The leaching rates are higher in the coarse-textured soils. Leaching decreases the efficiency of nitrogen fertilizer applications, increases fertilizer expenses, and may lead to contamination of surface waters and groundwater. Based on the application and management, some nitrogen could also be lost during soil erosion and by volatilization. The goal is to supply the required N as close to the roots as practical and at the time when plants need it, thus enhance the crop uptake and reduce losses. Although this concept is simple to understand, it is not easy to achieve every year as conditions continually change. A portion of the seasonal N requirement can be applied at planting, but this N is susceptible to leaching losses during the period when seeds are getting established and just beginning to take up nutrients. Large applications of N at this time are not generally recommended. Nitrogen fertilizers are most efficiently used in split applications, with one-third to two-thirds of the total requirement side-dressed after plant emergence or applied by irrigation in several smaller applications. When applied pre-planting, the band should be placed 5 to 10 cm to the side and below the seed piece. When applied at planting, the N is commonly placed to the side, but 2 to 5 cm above the seed piece. Additional N can be placed as a side-dress application when the plants are still in the vegetative growth stage, mostly at tuber initiation stage.

A CHECKLIST OF PRACTICES FOR REDUCING NITROGEN LOSS VIA LEACHING

To avoid applying nitrogen in excess of the plant's needs and to avoid the loss of nitrates due to leaching, the following practices should be part of any nitrogen management program:

- If possible conduct soil tests to determine pre-plant fertilization rates.
- Apply the recommended nitrogen fertilizer rate in 2 to 4 splits (e.g., one quarter at planting and the other quarters as top dress
- Make fertilizer applications as close as possible to the actual time of plant demand for nitrogen.
- Schedule irrigations according to crop water use and soil characteristics. Avoid over-irrigation.
- Nitrogen fertilizers should not be applied within 4 to 6 weeks of vine killing. Applications late in growth stages after tuber development do not increase tuber yield and may reduce tuber quality, skin maturity, and the storability of the crop. Ammonia may volatilize from urea under some conditions if the material is not watered in soon after application.

Phosphorus

Since P has limited mobility in soil, it is important to place it near actively growing roots, especially during early season growth when uptake may be limited. Leaching losses of P are not significant at typical fertilization rates, but P can be lost from the surface of fields subject to erosion. Band application of P during row mark-out or at planting is generally the most effective placement of P fertilizer. The majority of the P can be applied at this time, however direct contact of the fertilizer with the seed pieces should be avoided to minimize salt damage. Placement of the fertilizer several centimetres to the side and below the seed piece is recommended. When P is broadcast, it should be applied prior to hill formation so the nutrients are concentrated where the roots will grow.

Potassium

It is important to place fertilizer K in the root zone where rapid plant uptake will be possible during times of peak demand. Potassium is immobile in soil and can only be absorbed by active, healthy roots near the soil surface. However, in sandy-textured soils with a low exchange capacity, the movement of K can be greater. If applications of K are required during the growing season, roots must be present near the soil surface in order to acquire the applied nutrients. Adequate soil moisture must be maintained near the soil surface to provide conditions for nutrient uptake by the surface roots. Broadcast application and soil incorporation of K when preparing the seed-bed is effective. Band placement of K in the furrows and covering with soil prior to placing the seed may also be sufficient to meet the K requirement when applied at typical application rates. Avoid high rates of banded K in close proximity to the seed piece. A combination of broadcast and band placement may be more appropriate if K application rates are high.

3.10 Fertilizer calculations

A reoccurring question involves the determination of how much fertilizer is required to achieve a desired crop yield goal. A series of practical fertilizer calculation examples are provided below.

Fertilizer recommendation rates may be expressed in kg N, kg P_2O_5 and kg K_2O/ha, or number of bags of fertilizer material per hectare.

An example of a fertilizer recommendation rate is 90:60:30 kg/ha - meaning 90 kg N, 60 kg P_2O_5 and 30 kg K_2O should be applied to 1 ha.

The common working formula is:

Fertilizer material (kg) = Nutrient recommendation (kg/ha) x area (ha) ÷ % nutrient of fertilizer material (expressed as a decimal)

PROBLEM #1

If the $N+P_2O_5+K_2O$ recommendation for a potato crop is 90+60+30. Determine the amount of ammonium sulphate, single superphosphate (SSP), and muriate of potash (MOP) needed for one hectare.

Solution

1. Calculate the amount of ammonium sulphate (AS) needed to satisfy the recommended 90 kg N/ha. Divide 90 kg/ha by the decimal equivalent of 20% N (0.2) in ammonium sulphate. Then multiply the quotient by the area (hectares) receiving fertilizer, which in this case equals 1.

   AS (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 90 kg/ha x 1 ha ÷ 0.2 = 450 kg ammonium sulphate

2. Calculate the quantity of SSP required to supply 60 kg P_2O_5.

   SSP (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 60 kg/ha x 1 ha ÷ 0.2 = 300 kg SSP

3. Calculate the amount of MOP required to supply 30 kg of K_2O.

   MOP (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 30 kg/ha x 1 ha ÷ 0.6 = 50 kg MOP

Solution summary

The farmer will need the following fertilizer material to meet the 90+60+30 recommendation for 1 hectare.

- 450 kg ammonium sulphate = 9 bags (assuming a bag is 50 kg)

- 300 kg single super phosphate = 6 bags (assuming a bag is 50 kg)
- 50 kg muriate of potash = 1 bag (assuming a bag is 50 kg)

PROBLEM #2

If the $N+P_2O_5+K_2O$ recommendation is 90+60+30 kg/ha, determine the amount of DAP, CAN, and MOP needed.

Solution

1. First satisfy the P_2O_5 requirement by using DAP. Divide 60 kg P_2O_5/ha by the decimal equivalent of 46% P_2O_5 (0.46) in DAP (18-46-0). Then multiply the quotient by the area in hectares.

   DAP (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 60 kg/ha x 1 ha ÷ 0.46 = 130.4 kg DAP

2. Next determine the amount of N in 130.4 kg DAP. Multiply 130.4 kg by the decimal equivalent of 18% (0.18) because DAP contains 18% N.

   = N in 130 kg DAP = 130.4 kg x 0.18 N = 23.5 kg N

   The recommendation requires 90 kg N/ha and we know that 23.5 kg N is already supplied by DAP. The balance can be supplied by CAN which contains 26% N.

3. To calculate the correct amount of CAN to meet the balance of 66.5 kg N, divide 66.5 kg N by the decimal equivalent of 26% CAN. Then multiply the quotient by the area in hectares. The quantity is 256 kg (exact 255.8 kg).

   CAN (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 66.5 kg/ha x 1 ha ÷ 0.26 = 255.8 kg CAN

4. Then calculate the required MOP using the same procedure.

   MOP (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 30 kg/ha x 1 ha ÷ 0.6 = 50 kg MOP

Solution summary

The answer in kg and bags is:

- 130 kg DAP or 2.6 bags (assuming a 50 kg bag)
- 256 kg CAN or 5.1 bags (assuming a 50 kg bag)
- 50 kg MOP or 1 bag (assuming a 50 kg bag)

PROBLEM #3

The kg per ha N+P_2O_5+K_2O recommendation is 90+60+30. Determine the amount of fertilizer product needed using 14-14-14, 16-20-0, and 20-0-0 as sources.

Solution

In this situation, the best procedure is to first use the 14-14-14 fertilizer to determine the K_2O amount since it is the only fertilizer that can provide K from the available options.

1. Divide 30 kg K_2O/ha by the decimal equivalent of the 14% potash in 14-14-14 fertilizer, then multiply the quotient by the area in hectares.

   14-14-14 (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 30 kg/ha x 1 ha ÷ 0.14 = 214.3 kg 14-14-14

   This amount also contains 30 kg N and 30 kg P_2O_5.

   Therefore, a balance of 60+30+0 remains after accounting for nutrients supplied by the 14-14-14.

= (90 N + 60 P_2O_5 + 30 K_2O) – (30 N + 60 P_2O_5 + 30 K_2O) = 60 P_2O_5 + 30 K_2O (balance)

The balance can be supplied by the 16-20-0 and 20-0-0 (ammonium phosphate) sources.

2. To get the amount of 16-20-0 required, divide the remaining 30 kg P_2O_5/ha by the decimal equivalent of 20% P_2O_5 in 16-20-0. Then multiply the quotient by the area in hectares.

   16-20-0 (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material

   = 30 kg/ha x 1 ha ÷ 0.2 = 150 kg 16-20-0

   As mentioned earlier, 16-20-0 has both N and P_2O_5. Therefore, you need to know how much N is in 150 kg 16-20-0.

3. Multiply 150 kg 16-20-0 by the % N in the material.

   = 150 kg ammonium phosphate x 0.16 = 24 kg N

   The recommendation requires 90 kg N/ha. The 214.5 kg 14-14-14 fertilizer supplies 30 kg N/ha. The 150 kg of 16-20-0 supplies an additional 24 kg N/ha. There is a remaining requirement of 36 kg N/ha.

   This balance can be met with the 20-0-0 source.

4. Determine the amount of 20-0-0 needed:

   20-0-0 (kg) = Nutrient recommendation rate (kg/ha) x Area (ha) ÷ % nutrient of fertilizer material.

   = 36 kg/ha x 1 ÷ 0.2 = 180.4 kg 20-0-0

Solution summary

Thus, to satisfy the N+P_2O_5+K_2O recommendation of 90+60+30 using 14-14-14, 16-20-0, and 20-0-0, a farmer should apply:

- 214 kg 14-14-14 = 5.3 bags (assuming a 50 kg bag)
- 150 kg 16-20-0 = 3 bags (assuming a 50 kg bag)
- 180 kg 20-0-0 = 3.6 bags (assuming a 50 kg bag)

PROBLEM #4

A farmer is advised to apply 40 kg N/ha to his crop as basal fertilizer at the time of planting. How much Calcium Ammonium Nitrate (CAN) fertilizer should he apply? How many bags of CAN should he buy from a fertilizer dealer if the fertilizer is sold in 50 kg bags?

Solution

According to the fertilizer recommendation the farmer would apply 40 kg N/ha. However, CAN contains only 21% N, meaning that the amount of CAN required is:

= 40 kg ÷ 0.21 = 190 kg CAN

One bag of CAN fertilizer weighs 50 kg; therefore, the answer is 3.8 (or 4) bags

= 190 kg CAN ÷ 50 kg/bag = 4 bags

PROBLEM #5

A farmer is advised to apply 20 kg P/ha on his 5-acre field. How many bags of triple super phosphate (TSP) or single super phosphate (SSP) should he buy? For the same P fertilizer recommendation, which type of P fertilizer (and how much) should he apply to a) groundnut and b) maize?

Solution

Remember: For P fertilizers, the % indicated on the bag refers to P_2O_5. To convert % P to % P_2O_5, multiply by 2.3.

1 ha is equivalent to 2.47 acres; 5 acres are equivalent to 5.0 ÷ 2.47 = 2.02 (or 2) ha.

A recommendation of 20 kg P/ha translates into 20 kg P/ha x 2.3 = 46 kg P_2O_5/ha

The amount of P_2O_5 required for 2 ha is equal to 46 kg P_2O_5/ha x 2.02 ha = 93 kg.

For TSP containing 45% P_2O_5 the amount of TSP required is:

= 100 ÷ 45 x 93 = 206.6 kg TSP

or 206.6 kg ÷ 50 kg/bag = 4.1 bags

SSP is preferred for legumes due its S content. SSP contains 20% P_2O_5, therefore the amount of SSP required for 2.02 ha is:

= 100 ÷ 20 x 92.5 kg = 462.5 kg

or 462.5 kg ÷ 50 kg/bag = 9.3 bags

For maize, the farmer can apply TSP, but DAP may be preferred over TSP because of its added N content.

Therefore, the amount of DAP required for 2.02 ha is:

= 100 ÷ 46 x 92.5 kg = 201 kg

or 201 kg ÷ 50 kg/bag = 4 bags

PROBLEM #6

After soil testing, a farmer is advised to apply 60 kg K_2O/ha to his banana crop. How much MOP (KCl; 60% K_2O) should he apply?

Remember: For K fertilizers, the third number indicated on the bag refers to % K_2O. To convert % K to % K_2O, multiply by 1.21.

Solution

The amount of KCl to apply is:

= 60 kg K_2O ÷ [0.6 kg K_2O/kg] = 100 kg KCl

CHAPTER FOUR

Crop Management

Good agricultural practices are essential for potato as it responds well if attention is given to weed control, ridging/earthing, water management and irrigation, disease and pest management, and extended crop rotation.

4.1 Weed control

Weeding should commence 2 to 3 weeks after planting; however, the weed pressure is an important determinant of when weeding should be done. Weeds are usually removed to prevent competition for moisture, light, nutrients, and space. If weeds are left unattended, they will lead to drastically reduced potato yield. Contact herbicides can also be used for weed control, but testing on a small plot may be advisable before applying any herbicide across the whole farm. It will also be prudent to get advice from an agricultural expert before using any herbicide, and carefully follow the label instructions.

4.2 Ridging/earthing-up

Ridging/earthing-up is done during the second weeding. It prevents greening of exposed tubers, infestation by potato tuber moth, and reduces internal brown spot caused by high soil temperatures. Ridging also cushions tubers against waterlogging in flooded fields. Proper ridging should dome the soil along the rows as the potatoes grow and should preferably be done during weeding. The final ridge should be about 25 cm high (**Photo 4.1**). Avoid ridging when the soil is too wet in order to minimize soil compaction and the spread of fungal diseases like late blight. Regular inspection of tuber development will determine when earthing-up should be stopped.

Photo 4.1 *(Photo by Jose Muthamia)*

Potato hills should be piled or earthed up to a height of 25 cm.

4.3 Water management and irrigation

Potatoes grow best with consistent soil moisture throughout the growing season. A 120 to 150-day potato crop consumes between 500 and 700 mm of water. Depletion of more than 50% of the total available soil water during the growing period often results in lower yields. Water shortage during tuber initiation, flowering, or when haulms start browning will lead to misshapen/deformed tubers. While soil should be maintained at a relatively high moisture content to maximize yield, frequent irrigation with relatively cold water may reduce the soil temperature below the optimum value for tuber formation (15 to 18°C), thus affecting yields.

The most common irrigation methods for potato are furrow or sprinkler systems. Furrow irrigation has relatively low water use efficiency. In areas with water scarcity, sprinkler or drip irrigation is preferred; especially on soils with low water retention capacity. Overhead irrigation should be done during the early hours of the day to reduce evaporation and to avoid wetting plants before nightfall. When possible, irrigate with 25 to 30 mm in one application since the soils used to grow potatoes often have a high infiltration rate and are prone to crusting. Mulching around the plant will conserve soil moisture.

4.4 Potato diseases and management

There is a strong relationship between the susceptibility of the crop to disease and a number of environmental and cultural factors. The severity of many potato diseases often increases if the plants are also stressed by heat, insufficient amounts of nutrients or water, or other adverse environmental factors. Good management of soil fertility and plant nutrition can help to suppress many diseases and minimize their effects on yield. For example, appropriate applications of N, P and K, based on analyses of soil and leaf tissue, will help suppress symptoms of potato early dying and early blight.

Regular field inspections to monitor growth and performance of the crop should be carried out. Roguing, which involves uprooting and destroying diseased plants and host weeds, reduces the build-up of pathogens in the soil and the number of infected tubers, and reduces the inoculum level in the field. It should be noted that uprooted plants should be destroyed and not be used for animal feed or composting.

The major diseases that affect potatoes and their management options are outlined below.

Late blight (*phytopthora infestans*)

Leaf and tuber symptoms of Late blight.

Late blight is a fungal disease that produces water-soaked lesions on the foliage that turn brown when dry and black when wet. These spots can also occur on the tips of the stems, which turn black and die.

On the underside of the leaf, the fungus produces a white mouldy growth that is more clearly seen at the edges of the spots.

Management

Late blight is the most economically important potato disease in Kenya. It spreads rapidly under cool humid weather through infected tubers and causes huge economic losses particularly during the long rain season.

As a preventive measure, susceptible potato varieties are sprayed with fungicide when plants are 10 cm tall. Resistant varieties like Kenya Mpya, Sherekea, Konjo and Lenana should be sprayed when the first disease symptoms are noticed. It is important to spray on the underside of the leaves.

Early blight (*Alternaria solani*)

Courtesy Simplot, Image by Jeffrey Miller

Leaf symptoms of Early blight.

Early blight rarely affects young plants. Symptoms first occur on the lower or oldest leaves of the plant.

Dark, brown spots appear on this older foliage and, as the disease progresses, enlarge, taking on an angular shape. As the spots enlarge, they may cause the entire leaf to yellow and die, but remain on the plant. Dark brown to black spots may also occur on the stems of the plant.

The disease thrives in heavy dew, and warm conditions with frequent rainfall.

Management

The disease can be avoided by observing proper field sanitation, crop rotation, use of clean seeds and roguing.

Contact fungicides are used to prevent the establishment of the disease by providing a surface coating. Systemic chemicals are usually used for curative purposes where the disease symptoms have been noticed.

Early blight Management (cont'd)

The spores and mycelia of the pathogen survive in infested plant debris and soil, in infected tubers and in overwintering host crops and weeds. They enter a tuber via wounds caused by mechanical injury or insect feeding. Lesions begin to appear 2 to 3 days after the initial infection.

Plant potato varieties that are resistant to the disease; late maturing varieties are more resistant than early maturing varieties.

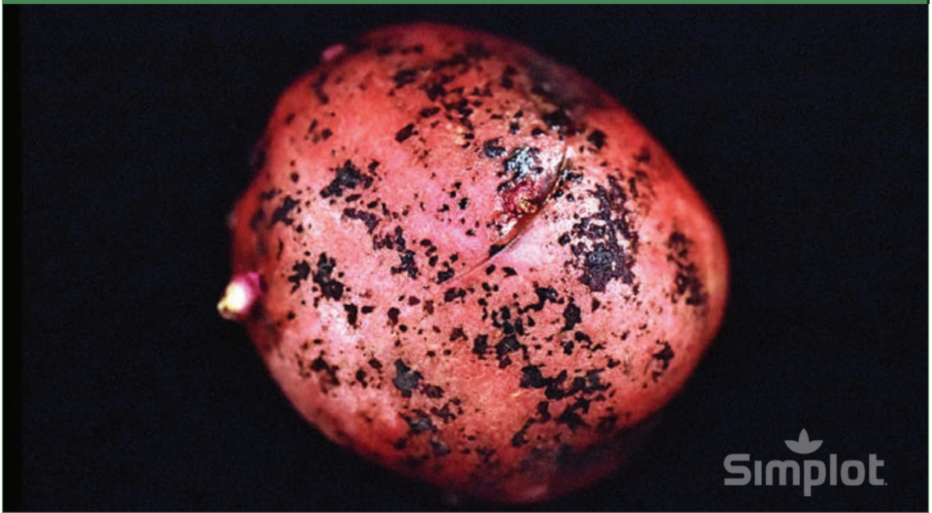
Avoid overhead irrigation and allow for sufficient aeration between plants to allow the foliage to dry as quickly as possible.

Practice a 2-year crop rotation by not replanting potatoes or other solanaceous crops for two years after a potato crop has been harvested.

Keep the potato plants healthy and stress free by providing adequate nutrition and sufficient irrigation, especially later in the growing season after flowering when plants are most susceptible to the disease.

Only dig the tubers up when they are completely mature to prevent from damaging them. Any damage done at harvest can additionally facilitate the disease.

Black scurf/Stem canker (*Rhizoctonia solani*)



Courtesy Simplot, Image by Phillip Nolte

Rhizoctonia solani **sclerotia on the surface of tubers.**

Symptoms include irregular emergence with a number of poor uneven stands, stunted growth and development of aerial and deformed small tubers.

A white mass of fungus develops at the base of the stalks particularly in dense crops.

Mature tubers have black specks that fall off with the skin when rubbed.

Management

This fungal disease is present in many soils and causes damage to many crops. The disease is common to potatoes planted next to organic matter stockpiles.

Use a crop rotation with non-host crops.

Treat certified or good quality seeds before sprouting. Pre-sprouting of seeds reduces the risk of the disease.

Fungicides are used as a seed dressing before planting, or for application on a growing crop.

Avoiding waterlogging soil.

Fusarium dry rot

Courtesy Simplot, Image by Phillip Nolte

Symptoms of Fusarium dry rot is caused by a number of species, but is generally associated with *Fusarium sambucinum, F. solani, F. culmorum and F. avenaceum.*

Dark depressions appear on the surface of the tuber. With large lesions, the skin becomes wrinkled in concentric rings as the underlying dead tissue desiccates.

Internal symptoms are characterized by necrotic areas shaded from light to dark chocolate brown or black. This necrotic tissue is usually dry (hence the name "dry rot") and may develop at an injury such as a cut or bruise.

Rotted cavities are often lined with mycelia and spores of various colours from yellow to white to pink.

Fusarium dry rot - Management (cont'd)

Pre-plant

Maintain long crop rotations to prevent build up in the soil.

Bring tubers out of cool store and to room temperature slowly to minimize potential damage at planting.

Use clean seed and equipment, and grade out infected tubers. If cutting seed, sterilize the knife after every bin/box/bag to prevent spread to healthy tubers. Do not store cut seed for longer than 10 days and keep temperatures below 16°C. Apply registered fungicides to cut seed.

Planting

Plant when seed and soil temperatures are within 5°C of each other.

Plant seed in sufficiently moist soil to promote quick emergence and wound healing.

Avoid irrigation before emergence to prevent seed piece breakdown.

Growing season

Monitor and record areas of fusarium wilt and be aware of these during harvest as they will have large amounts of spores.

Do not overwater.

Harvest and grading

Make sure tubers have good skin set before harvest.

Slow the harvester/grader speed to minimize damage. Avoid harvesting in wet conditions.

Dry tubers as soon as possible after harvest to aid in soil removal from the tubers. Do not leave tubers in direct sunlight or at high temperatures.

Apply post-harvest fungicides adequately.

Cool storage

Cure the seed appropriately before cool storage. Cool seed gradually to prevent condensation build-up on the seed surface.

Maintain adequate airflow to prevent carbon dioxide build-up. Keep storage areas clean.

If rot occurs, separate infected seed from healthy seed.

Bacterial Wilt (*Ralstonia solanacearum*)

Leaf and tuber symptoms of Bacterial wilt. *(Photos: Infonet-biovision.org)*

Plants display sudden wilting and drying in the field even during wet periods. In rapid disease development, entire plants wilt quickly without yellowing. Sections of diseased plants may wilt completely and dry up, while the remainder of the plant appears healthy.

Leaves become yellow at their bases, then the whole plant wilts and dies.

When stems are cut a brown coloured ring will be visible. When a tuber is cut in half, black or brown rings will be visible. If left for a while or squeezed, these rings will exude a thick white fluid.

Fluid exudes from tuber eyes, which results in soil sticking to tuber eyes when crops are harvested.

Management

Up-root all infected plants and tubers, with the surrounding soil, and put them in a 60-cm deep pit and cover with clean soil, or burn them. Do not put diseased plants and tubers on your compost heap.

The plants next to the diseased plants should be harvested only for home use, not for seed.

Use clean seed or tubers of tolerant varieties, bought from reliable and certified sources. Disinfect all tools with household bleach before and after use.

Rotate with crops that are not related to potato, such as maize or beans.

Plant potatoes in disease-free fields that have not been used for growing potato or tomato for at least three years.

Avoid planting in low-lying or waterlogged areas.

Plant only whole, undamaged tubers.

Weed regularly and earth-up taking care not to damage roots and stems.

Blackleg or Soft Rot (*Erwinia carotovora*)

Courtesy Simplot, Image by Eugenia Banks, left and Phillip Nolte, right

Symptoms of Blackleg and Soft Rot on plant tissue and tubers, respectively.

The disease begins with yellowing and upward rolling of leaflets which eventually wilt and die.

The disease can occur at any stage of the crop development when moisture is excessive.

Management

Use certified seeds and avoid tuber injury.

Planting at wide spacing for good aeration. Ensure adequate N and Ca during planting.

Scout fields to remove diseased plant.

Avoid furrow irrigation.

Use of fungicides can effectively control black leg.

Potato Leaf Roll Virus

Courtesy Simplot, Image by Phillip Nolte

Symptoms of Leaf Roll Virus

In primary infections, symptoms first appear at the top of the plant where the leaves roll inwards and turn pale yellow, some may develop yellow margins.

In secondary infections, the entire plant is affected all the leaves roll inwards, especially at the base of the plant.

The virus can also be spread through infected tubers and diseased volunteer plants.

Symptoms appear 2 to 3 weeks after crop emergence.

Management

Potato leaf roll virus is commonly spread by aphids. Viruses have no cure; however, control of the vectors prior to virus spread is critical.

Potato Mosaic Virus X, S and Y

Courtesy Simplot, Image by Phillip Nolte, left

Leaf and tuber symptoms of Potato Mosaic Virus

Potato virus Y (PVY) is a Potyvirus, transmitted by aphids and spread through infected tubers. It causes stipple streak.

Potato virus S (PVS) is a Carlavirus. Symptoms include a slight deepening of the veins, rough leaves, more open growth, mild mottling, bronzing, or tiny necrotic spots on the leaves.

Potato virus X (PVX) is the type member of the Potyvirus family of plant viruses. Plants often do not exhibit symptoms, but the virus can cause symptoms of chlorosis, mosaic, decreased leaf size, and necrotic lesions in tubers. PVX can interact with PVY and PVS to cause more severe symptoms and yield loss.

Management

Use disease-free seeds.

Keeping the field disease free throughout the season is the best way to control insect borne viruses. Scout regularly for obvious symptoms. Diseased plants should be removed early and haulms removed and destroyed early.

Volunteer plants can harbour insects and must be eliminated.

CHAPTER FIVE

Potato Pests and Management

5

Insect pests attack seed potato plants growing in the field tubers during storage. The most important ones include aphids, potato tuber moth, cutworms, leaf-eating caterpillars, beetle, spider mites, and nematodes.

5.1 General principles for controlling pest and diseases

To increase potato production while protecting producers, consumers and the environment, use integrated insect, pest and disease management strategies that encourage biological control.

These include:

- Planting pest and/or disease-resistance varieties.
- Plant healthy seed potatoes.
- Grow potatoes in rotation with other crops. Whenever possible, use rotations that reduce insect pest and disease problems. In general, avoid solanaceous crops like tomato and pepper as rotation choices because they are likely to share the same pest and diseases with potatoes.
- Avoid build-up of weed seeds in the soil by removing weeds before they flower and set seeds.

5.2 Crop rotation for reducing disease and pest

To minimize disease and pests, solanum-related crops should not be planted continuously in the same plot. If farmers cultivate potato every year in the same field, virus and other soil borne diseases will increase to a level to cause complete crop failure. Thus, the potato tuber from such fields are not appropriate for use as seed tubers. Land can be left fallow for at least one or preferably several seasons where possible.

Crop rotation helps in improvement of soil fertility, soil water retention, control of soil erosion, and management of weeds. Crop rotation is probably the best-known method to control bacterial wilt in potatoes. Crop rotation controls the spread of other diseases by eliminating susceptible volunteer potato crops. The development of a crop rotation plan can begin by dividing the farm into four plots and allocating a crop per season for each plot. Therefore, crops are rotated across the plots, making sure the same family of crop is not planted repeatedly. Where this is not possible, like in intensive production systems, soil sterilization by steaming, solarisation, or use of appropriate fumigants is important at the beginning of every season.

5.3 Pesticides and the environment

Improper use of pesticides in potato cultivation is a major environmental concern. The most widespread and intensive use of pesticides in developing countries is for control of late blight potato disease. Farmers in some countries spray their potato fields more than 10 times during a single growing season of 4 to 6 months to combat this disease. Pesticides are a health risk to farm families and farm workers engaged in potato production. With the emergence of new and more virulent strains of late blight, even more frequent applications of pesticides are being made, which raise the risk of harm to human health and the environment. Pesticides and other agrochemicals can be very harmful if not properly handled. They can cause detrimental health hazards to the user, consumer and the environment. Example of common health hazards associated with agrochemicals include: nausea, diarrhoea, stomach ache, nasal bleeding, vomiting, loss of sight, dizziness, and sometimes death. Agrochemicals could also lead to environmental hazards like contamination of water bodies and poisoning of important wild and domestic animals especially when they consume plants that are treated with agrochemicals.

Concern over environmental and health impacts, combined with a better appreciation of the damage different diseases and insects cause to the potato, have led to the development and adoption of alternative technologies including selection of resistant varieties and integrated disease (IDP) and pest (IPM) management techniques.

5.4 Importance and safe handling of pesticides and other agrochemicals

As indicated in the previous section, potatoes are prone to many diseases and pests, necessitating regular use of agrochemicals. These agrochemicals play the roles of (1) reducing loss of crop yield due to pest and diseases and (2) reducing loss of produce quality due to attack by pests and disease-causing pathogens. In the case of weed control, agrochemicals are labour saving relative to mechanical methods of weed control.

The most common agrochemicals used on a potato farm can be classified into four groups:

- Herbicides (for weed and herb control)
- Insecticides (for insect and pest control)
- Nematicides (for nematode control)
- Rodenticides (for rodent pest control)

The first step for safe handling of an agrochemical is understanding its composition, uses and restrictions. This can be achieved, by reading the product labels, understanding how to mix the chemicals and how to handle the chemicals during and after application. Below is a description of important steps for safe handling of agrochemicals.

5.4.1 The product label

The first step at the point of purchase and before beginning to use an agrochemical is to read and understand the details in the label. The label provides all the necessary information such as: active ingredient, mixing and application rates, first aid, disposal of containers, pre-harvest and pre-entry intervals, etc. Read the product label and follow instructions on how to handle and apply the chemical. If you do not understand the instruction, seek advice from extension agents. Ensure that you buy the necessary protective gear as recommended on the product label (cap, masks, overalls, gumboots, gloves, goggles).

The information on a pesticide label includes:

- Commercial name
- Intended use
- Net content of the container
- Type of formulation
- Ingredient(s) and concentration
- Classification – mode of action
- Registration number
- Registrant's name and address
- Directions for use
- Hazards - their degree and nature
- Special warnings
- Handling precautions
- First aid instructions
- Toxicological information

Look out for colour coding, warning symbols, pictograms, or any additional safety instructions on the label. Agro-chemicals are also classified according to their toxicity and should be used as recommended on the label of the product.

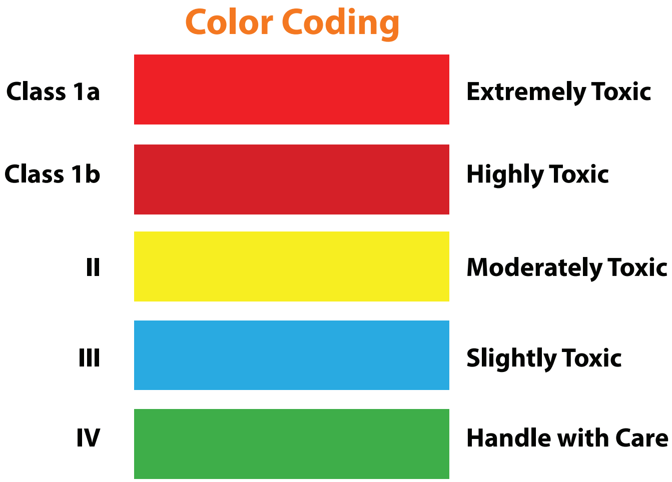


Figure 5.1. Illustration of colour coding interpretation for agrochemicals.

5.4.2 Determining the rate of pesticide to use

The appropriate quantity of pesticide to put in the sprayer depends on the calibration of the sprayer. In short, how many square metres one spray pump full of water + pesticide will cover. Always read the label for recommended dilution rate or dosage.

It is important that the amount of pesticide to be used is precise to avoid excess that could lead wastage of resources, damage of the crop and contamination of the environment. When quantity is inadequate, it is likely that the pest will not be effectively controlled and this can result in pest resistance.

Calibration of tractor/motorized sprayers

For automated systems, especially those mounted on a tractor, the application rate can be changed by modifying applicator speed, nozzle output, spray pressure and the distance between nozzle.

There are several calculation steps to determine the output of an applicator and the amount of product that should be added in the mixture. For multi-nozzle tractor mounted systems, it is important to note that the nozzle regulates the flow, and atomizes the solution in a desired pattern. Prior to calibration each nozzle on the boom should be checked to make sure that all nozzles (and screens) are of the same type. The output of each nozzle should be similar. Nozzles that have outputs 10% below the average should be checked to make sure that the orifice (or screen) is not blocked or plugged. Nozzles that have output 10% above average should be checked for damage and wear. Replace nozzles as needed with the same nozzle type and recheck the individual output. The next step to correctly calibrate a sprayer is to measure the output in volume per unit time.

EXAMPLE 1:

Calculate the output (L/min) of a sprayer that has an average nozzle output of 6 L in 30 sec. The number of nozzles on the boom is 50 and nozzles are spaced every 50 cm (50 cm on centre).

Solution

First determine how much would be delivered in 1 minute if 6 L are delivered in 30 sec. (1 minute = 60 seconds)

Sprayer output per nozzle in minutes = 0.6 L ÷ 30 sec x 60 sec/min = 1.2 L/min/nozzle

The sprayer output over the boom = 1.2 L/min/nozzle x 50 nozzles = 60 L/min

Speed of the tractor/motorized applicator

The applicator speed influences the amount of chemical applied to a given area. Tire slippage due to non-uniform terrain conditions can result in actual speeds that differ from those shown by the speedometer, and therefore speeds need to be checked on a terrain similar to that of application area. The time to drive a course is measured and the speed of the equipment is calculated with the equation:

Tractor speed = length of the course ÷ time over the course

EXAMPLE:

The course length is 60 m and the time to drive the course is 25 sec. Calculate the tractor speed in (a) m/min, and b) km per hour (km/hr).

Solution

(a) Tractor speed (m/min) = (60 m/25 sec) x 60 sec/1 min) = 144 m/min

(b) Tractor speed (km/hr) = (60 m/25 sec) x 1 km/1000 m x 60 sec/1 min x 60 min/1 hr)

= 8.6 km/hr

Determining the area covered per unit time by tractor/ motorized applicator

Based on the speed of the applicator and the width of the boom, the area in hectares sprayed in a given time can be calculated.

EXAMPLE:

Calculate the number of hectares that are sprayed in 1 minute if the sprayer has 50 nozzles on 50 cm centre spacing and the tractor speed is 150 m/min.

Solution

Area = Length x boom width

Boom width = (50 cm/nozzle x 1 m/100 cm) x 50 nozzles = 25 cm
Area covered = (150 m/min x 25 m) = 3,750 m^2/min
In hectares = 3,750 m^2/min x 1 ha/10000 m^2) = 0.375 ha/min

The most common applicators in the smallholder farming systems are the knapsack sprayers.

Steps of calibration of a knapsack sprayer

Every sprayer has a different capacity, different nozzles with higher or lower output. Also spray operators work at a different speeds and pump at a higher or lower pressure. To realize appropriate application, there is need to calibrate the spray equipment as follows:

- Measure and mark out an area of 10 m x 10 m = 100 sq.m.
- Fill the knapsack with known volume of water (e.g., 15 L of water).
- Put the knapsack on your back and start pumping, walk at a steady walking pace, spraying with the nozzle at knee height and recite the word 'one thousand' over and over again making one pump stroke per 'one thousand.'
- Spray the marked area.
- After spraying, measure the litres of water that has remained in the spray tank (e.g., 10 L remained)
- Amount used to spray area of 100 sq.m = 15 L - 10 L = 5 L
- To work out how much pesticide to measure into the sprayer is now very easy. Look at the application rate on the product label. For example, Roundup® is 1.5 L (= 1500 ml) per acre and 1 acre = 4,000 sq. meters (2.47 acres = 1 ha).

Calculating the amount of pesticide to put in knapsack sprayer

To calculate the quantity of pesticide to put into your sprayer the operator should follow the following steps:

First, calculate the volume of water needed to spray an acre.

If 5 L covers 100 sq.m

1 acre = (4000 sq.m x 5 L) ÷ 100 sq.m = 200 L

Using Roundup® at a rate of 1.5 L/acre, calculate the amount of chemical for a knapsack sprayer with a 20 L capacity as:

1. If 200 L of water is needed to dilute 1.5 L of Roundup®, a 20 L capacity knapsack will carry:

   (20 L x 1.5 L) ÷ 200 L = 0.15 L of Roundup®.

2. Since a litre is equal to 1000 millilitres the 0.15 L can be converted to millilitres for ease of measurement by multiplying 0.15 by 1000.

   1 L = 1000 ml

   0.15 x 1000 ml = 150 ml

   The farmer can also calculate the needed ml per L of water = 150 ml ÷ 20 = 7.5 ml.

5.4.3 Mixing agro-chemicals

Mixing and sprayer filling operations are the highest risk time for pesticide accidents.

- Read the label carefully and understand the instruction.
- Ensure recommended rates are followed.
- Always mix and fill outdoors to avoid pesticide fumes that can concentrate in closed area.
- Open pesticide containers with extreme care.
- In case of spillage, wash it off with clean water as soon as possible.
- Use clean water to mix chemicals.
- Use suitable equipment for measuring out chemicals.
- Never use hands as scoops or for stirring liquids.
- Add only enough pesticide to the tank for the job you will be doing.

5.4.4 Before spraying

- Check the spraying pump for any leaks, use the right nozzle for the particular activity (e.g., flat nozzle for herbicide application, the cone nozzle for pesticide and insecticide application).
- Checking nozzle for blockages, if clogged do not try to blow it out with your mouth, use a small soft twig or grass or soft brush to remove the clogs.
- Wear protective gear before spraying activities.

5.4.5 During spraying

- Put warning signs in field during spraying to alert the community.
- Do not spray near people, food or close to water sources.

- Spray in the direction of the wind.
- Walk within the rows and direct the nozzles to the targeted pest.
- Preferably spray in the morning hours before 11:00 am or late in the evening after 4:00 pm bearing in mind when the pest is most active.
- Do not spray when it is about to rain or when it is raining.
- Do not eat, drink or smoke while working with chemicals.
- Minimize talking when spraying.
- Do not touch your face or any other bare skin with soiled hands or gloves.
- Apply the pesticide evenly and in the right amounts.
- Turn off the equipment whenever you pause.
- If your co-worker shows signs of pesticide poisoning, stop the spraying immediately and begin first aid measures.

5.4.6 After spraying

- Use all pesticides in the sprayer in a day.
- Do not leave pesticide containers at the application site.
- Do not re-enter the treated area within at least 24 hours after spraying.
- Rinse the empty container at least three times pour the rinse back to the spray pump.
- Puncture the metallic agro-chemical containers to avoid re-use.
- Select a disposal site away from home and mark it properly "container disposal".
- Dispose of the containers following the guidelines on the label.
- While still dressed in protective gear, wash the knapsack in protective gear wash the knapsack and rinse it well to ensure that no residues remain.
- Pour all the washing on the bare ground.
- Do not wash away spray pumps near water sources like rivers, lakes or swamps.
- Remove the protective gear ending with gloves and wash the protective gear.
- Wash the body and change to clean clothing.
- Keep record of spray application.

CHAPTER SIX

Harvesting and Post-Harvest Management

6

Potato maturity period ranges between 3 to 4 months after planting depending on the variety. Tubers harvested while still immature tend to have low dry matter content and suffer more skin damage, which results in easier infection by fungal and bacterial pathogens. However, seed potatoes are often harvested early to avoid virus infection that may occur during the latter part of the growing season.

Tubers should be completely covered with soil to reduce greening and entry of potato tuber moth. Cutting vegetative material (de-haulming) two weeks before harvesting hardens the skin of tubers. Hardening of skin tuber reduces damage of tubers during harvest and post-harvest handling. Dug potato tubers should be stored clean and dry with mature skins free from wounds, insect pests, and diseases.

Proper husbandry and use of clean planting material can increase yields to 6 to 8 tons/acre (15 to 20 t/ha). Depending on variety and degree of maturity at harvesting, potatoes can be kept for two months before sprouting at room temperature. Mature potatoes can be de-haulmed and left in soil for 1 to 2 months.

At crop maturity, when the leaves begin turning yellow, a few plants are taken at random and checked whether the tubers have reached the required size. Often this is determined by local market requirements.

6.1 De-haulming

De-haulming involves the cutting of the haulms (stem and leaves) to allow the skin to harden and reduce damage potential to the tubers during harvest. De-haulming should be done two weeks before harvesting when the crop has attained physiological maturity and at least 50% of the haulms have started to turn yellow. This can be done using hand tools like Slashers or Pangas, or contact herbicides. Spraying herbicides can be cost effective for large-scale farms but mismanaging this practice can increase the risk of environmental damage and contaminated, poor-quality tubers.

6.2 Harvesting

Harvesting should start approximately two weeks after de-haulming when the skin has hardened and the tubers are less likely to be damaged. The potatoes can be harvested using hand tools or machines. The entire crop should be removed from the field to prevent re-sprouting of volunteer plants that can harbour pests and diseases.

The tubers should be carried to indoor storage in padded boxes or cardboard containers. Relatively cool days are preferred for harvesting. The tubers should not be exposed to sunshine for a long time. The tubers should be dried in open shade for 2 to 3 hours to help harden the skin.

THE FOLLOWING SHOULD ALSO BE CONSIDERED DURING HARVESTING:

- Harvest when the soil is dry.
- Do not expose harvested tubers to sunlight for a long time to prevent them from drying out too quickly and avoid greening of the white skin varieties, which would reduce their keeping quality and consumer acceptance.
- Avoid harvesting when the soils are wet in order to avoid pathogens sticking on tubers.

6.3 Post-harvest practices

6.3.1 After harvesting

The following care should be taken during drying:

- The harvested tubers should be dried quickly to remove excess surface moisture.
- The harvested tubers should always be dried in a storage shed to avoid tuber greening.
- The harvested tubers should be sheltered from rain and water runoff.

Up to 80% of potato tuber content is water and this needs to be maintained to avoid loss of weight and quality. A storage shed or holding area with a warm temperature is desirable prior to filling it with tubers as it promotes wound healing and further skin set. The shed area should be well ventilated to allow good exchange of air and to achieve good temperature control.

6.3.2 Sorting, grading, storage, and packaging

Sorting: is the process of separating good tubers from the damaged, deformed or diseased tubers, and other foreign materials. Sorting helps prevents spreading of diseases by removing infected potatoes.

Grading: can be done by size, shape or any other predefined quality parameter. Rejected tubers can be used for other purposes such as livestock feed and for domestic use. It is advisable that each bag is well labelled according to variety description and weight for ease of identification. Potatoes are graded depending on **size** and **shape of tuber**. Malformed tubers are removed. According to Kephis (2016) the tubers should be graded into one of the following categories:

- Ware: beyond 60 mm gauge
- Seed: 28 to 60 mm gauge
- Chatts: < 28 mm gauge

Storage: conditions should ideally be cool, dry, dark, and well ventilated to keep tubers alive, reduce deterioration through natural process of starch breakdown, reduce storage pest infestation and damage, reduce storage loses through rotting and greening, and increase the tuber dormancy period. The storage area should be sprayed with insecticides to kill tuber moth adults. Spread the tubers on crates and turn regularly to prevent spoilage. Also, you can place *Mexican marigold* or Eucalyptus leaves on the tubers to repel pests. The best temperature and humidity conditions for storage of potatoes are indicated below.

Table 6.1 Temperature and relative humidity guidelines for potato storage.

Intended use	Temperature (°C)	Relative humidity (%)
Seed purpose	2 to 4	95
Table purpose	7 to 8	95
Processing purpose	8 to 12	95

Table courtesy of the National Potato Center.

Some important guidelines for storage of potatoes are listed below:

- Store tubers in the dark
- Store each variety separately
- Inspect the tubers in storage regularly, removing those that are rotten or sprouting

Since the newly harvested tubers are living tissue and therefore subject to deterioration, proper storage is essential both to prevent post-harvest losses of potatoes destined for fresh consumption or processing, and to guarantee an adequate supply of seed tubers for the next cropping season.

For ware and processing potatoes, storage aims at preventing "greening" (the build-up of chlorophyll beneath the peel, which is associated with solanine, a potentially toxic alkaloid), and losses in weight and quality. The tubers should be kept at a temperature of 6 to 8°C degrees, in a dark, well-ventilated environment with high relative humidity (85 to 90%). Seed tubers are stored, instead, under diffused light in order to maintain their germination capacity and encourage development of vigorous sprouts. In regions, such as northern Europe, with only one cropping season and where storage of tubers from one season to the next is difficult without the use of costly refrigeration, off-season planting may offer a solution.

CHAPTER SEVEN

Marketing and Potato Business

7

7.1 Marketing

Marketing of potatoes consists of all activities involved in moving potatoes and potato products from the point of production to the point of consumption (i.e., farm to the plate). In other words, marketing involves all those activities linking producers to the consumers. Effective marketing should ensure that goods are supplied according to the demand (i.e., on time and the quantity and quality that consumers want).

Access to markets

Access to competitive markets requires establishment of both backward and forward linkages between organised farmers (suppliers) and buyers (customers). Farmers need to access other value chain support services such as market information, transport, warehousing, financing, and packaging to enable them produce the quality and quantities desired by the markets.

Group marketing

Group marketing involves pooling together products from many farmers and selling collectively. For group marketing to be effective, the farmers in the marketing group should synchronize their production operations (planting time, inputs used [e.g., seeds, fertilizers, harvesting]) and postharvest operations (sorting and grading of the product).

For smallholder farmers to access competitive markets, they should enter into group marketing/collective marketing (horizontal linkages) to attain big volumes and develop marketing contracts with large buyers or marketing facilities (vertical linkages).

ADVANTAGES OF COLLECTIVE MARKETING

- Attracts large potato buyers such as NGOs, supermarkets, large french fry outlets, relief agencies, and export market.
- Provides farmers with better bargaining power for prices, sales volume and time of delivery.
- Makes small-scale farming competitive small holder farmers can access technology, credit, marketing channels and information at a lower cost.
- Reduces costs when activities are carried out by groups due to the economies of scale (transport, grading, packaging are some of the costs that can be shared).

Contract farming

In contract farming, agricultural production is carried out according to an agreement between the buyer and farmers. It establishes conditions for production and marketing of produce for a specified time. Typically, farmer(s) agree to provide agreed quantities and quality of potatoes according to the set quality standards. In turn, the buyer commits to purchase the product and, in some cases, to support production through, for example, the supply of farm inputs, land preparation and the provision of technical advice.

ADVANTAGES OF CONTRACT FARMING

- It ensures higher production of better quality, financial support in cash and/or in kind and technical guidance to the farmers.
- Assured market for the farm produce.
- Contract farming can open up new markets which would otherwise be unavailable to small scale farmers.
- In case of agri-processing level, it ensures consistent supply of agricultural produce of the right quality, at the right time.

7.2 The farming business of potatoes

A business is a commercial activity designed to supply goods and/or services that are demanded by the market with a major aim of making profit. Farming as a business is built on the principles of improving farm production to increase profits and/or ensure sustainability of farm output. To make profits in a business, the cost of production must not exceed the income. Farmers need to understand and update business practices as technology changes.

Farming as a business requires farmers to have entrepreneurship skills that can enable them carry out farming on a commercial scale.

7.2.1 Entrepreneurship

Entrepreneurship can be defined as the capacity and willingness to develop, organise and manage a business venture along with any of its risks in order to make profits. A potato farmer can become an entrepreneur if he/she comes up with innovations that will helps him to increase the net profits. It is important therefore that farmers acquire good entrepreneurship skills to enable them access remunerative markets. Like with other crops, effective potato market development follows the 7Ps of entrepreneurship (Product, Price, Place, Promotion, Packaging, Positioning, and People) and 2Cs (Customers and Competition). For potatoes to be sold to the market, there must be people who want to buy it (the customers), at the same time, sellers must be aware of the competition on the market.

Table 7.1 The 7Ps of entrepreneurship.

Number	The P	Relation with potato
1	Product	Potato
2	Price	Price established by both parties (competitive price).
3	Place	The markets supported by storage, distribution and transportation (e,g., farm outlet, shops, store/warehouses).
4	Promotion	The way in which the target market is informed about the product and where it can be found (e.g., advertising, sales promotions, direct talks to customers).
5	Packaging	The way the product is presented to the customers. This creates impression that effects consumers decision to purchase.
6	Positioning	Product must be marketed in place where opportunities for purchasing it are high.
7	People	Marketing of potato require people to purchase and to aid in marketing.

Sources of information include: government commercial offices, NGOs, e-market apps, extension officers, media, traders, and processors involved in potato trade, etc.

7.2.2 Commercial farming

Farming as a business is based on the commitment of the farmer entrepreneur to carry out farming as an occupation with a major aim of making profits. The farmer must ensure proper business planning enterprise selection, business record keeping, and farm enterprise budgeting. For commercial farming to be a viable venture, farmers must accurately know their cost of production, margins and how to maximize profits by lowering costs of production while increasing yields.

For measurements of land area: 1 acre = 4000 square meters, 1 hectare = 2.5 acres = 10,000 square meters. Understanding the size of farm is very important for:

- Planning accurate input requirements
- Forecasting potential yield and income
- Evaluating performance (potential vs actual)

Land is the principle capital for an agricultural business enterprise and therefore it must be optimally utilised.

7.2.3 Productivity

As a commercial farmer, it is important to aim at maximum productivity as this determines the total volume of produce supplied to the market. The bigger the volume, the higher the sales and the higher the profits, holding other factors constant.

Profitability is defined as state of yielding profit or financial gain from a business activity and depends on how the farmer manages costs of production, yield and market price.

It is expressed as:

Profit = Sales – Costs of Production

7.2.4 Farming as a business

Farming as business can be viewed as the integration of **Inputs** (seed, fertilizers, pesticides, herbicides, farm equipment) and **Processes** (land preparation, planting, weeding, fertilizer application, harvesting, and output marketing) to generate a **Profit.**

FARMERS THAT ENGAGE IN FARMING AS A BUSINESS ENJOY THE FOLLOWING BENEFITS:

- Growth in income as a result of increased profit margins.
- Improved standards of living due to increased income.
- Diversity of consumed products purchased using increased income.
- Improved nutrition and household food security.
- Increased productivity and efficiency of the family farm.

Farm planning and decision making

Farm planning is an important aspect of farm business and it involves setting where the business is going (**goals**) and how to get there (**strategy**). A successful farm is not the result of chance or luck - it is the result of good planning. **Planning** is the process of thinking through what is desired and how it will be achieved. Plans must be made before any other management activities can be performed. Assessment of past, present and expected future performance are integral to the planning process.

It is important to take time to analyse past financial and production records to find out which production practices worked well which did not and identify weak spots and while planning for present consider internal (resource availability) and external (markets, economy, weather) forces on the decision-making process.

AN EFFECTIVE FARMING BUSINESS SHOULD:

- Provide products or services of value to satisfy the market in exchange for a monetary return.
- Plan, analyse the environment, and manage risk: businesses must undertake planning to continuously check what happens within and outside of the business, stay alert to uncertain events, and work to reduce potential loss.
- Conduct legal and ethical activities with a defined purpose: businesses undertake activities that conform to the laws and standards of the society in which they operate, and they clearly state what they exist to do for customers and stakeholders, including their core business.
- Record keeping: businesses should keep up-to-date records for reference in planning and decision making.
- Relationship management and continuity: businesses should develop long-term relations with other stakeholders and continue to operate even beyond the life of the founder.

Risk management

Risk refers to the probability of occurrence of hazards and shocks that impact negatively on agricultural production, trade, markets, and consumption. These could be due to weather, diseases, pests, market, and price. Risk management are the measures put in place by the farmer to avoid or minimize the negative impact of hazards and shocks. Managing risk is very important for the success of agricultural operations. While some risks can be managed through changes in farming and marketing practices, others cannot be avoided as they are natural (e.g., droughts and floods). Therefore, managers of farm businesses need to focus on managing manageable risks and take measures to reduce the negative impact of those that are uncontrollable.

Potato farming like other businesses is supposed to generate income but this is not always certain. This is because businesses operate in a rapidly changing and unpredictable environment that impacts upon the outcomes of business activities. While the physical, political, economic, social, technological, and trading environment presents opportunities for business, it also offers threats that make business risky. However, this does not stop businesses from operating. Entrepreneurs have to expect, accept and manage risks as they relate to business. An identified risk is not a threat but a management problem.

Table 7.2 Risks and Associated Mitigation.

Value Chain Level	Risk	Possible effects	Mitigations
Production	Climate change/ droughts/floods. Input shortages/in accessibility. High input costs, poor quality inputs (counterfeits), pests and diseases, theft.	Total loss or reduction in potato yield.	Adoption of climate smart technologies e.g. irrigation. Good business planning. Diversification of enterprises (crops and livestock), adoption of appropriate technologies, crop insurance.
Market	Price fluctuation, competition, poor infrastructure.	Loss of income.	Insurance, contract farming, taking advantage of established market system, collective marketing, value addition, proper planning.

Farm record keeping

This is the documentation of all the farming activities. Farm records facilitate quick reference to previous activities and this enables the farmer to make quick informed decision. Record keeping also provides useful information for assessing the performance of a business at any time. It is important for farmers to emphasize record keeping to enable them carry out financial analysis and budgeting as well as making informed business decisions.

Farm records include: human resource, finance, production, operation, storage, and marketing.

Types of Farm records

i) **Human resource records** including details of the labour force, leave calendar and profiles of the workers for the farm.

ii) **Financial records** including: (1) **invoices** issued by the seller to the buyer requesting payment for the goods and services offered. It indicates the quantity, unit price, taxes and details of the payee; (2) **payment vouchers** prepared to pay service providers after invoices have been received and verified; (3) **receipts** issued to acknowledge payments; (4) **pay in books** indicating money you have paid in the bank; (5) **cash book** containing information on money banked, received and spent.

iii) Operations records contain all farm activities as part of farming as a business. A farmer needs to design a simple comprehensive record entry/report that can be easily understood by all the people on the farm. Records must be easy to understand and written in such a way that they can easily be accessed for analysis. A **stock card** is a document in form of a card hung on the batch of food product or grain indicating the quantity of stock you have at that time. You can also have stock cards for all inputs at your farm. Keeping track of stock helps with identifying theft, guarding against wastage and unnecessary purchases, and planning for production. A **stack card** is fixed to a bag stack used to keep a tally of the number and weight of bags of grain either added or removed from the stack. A **goods received note** (GRN) is a document issued out to acknowledge receipt of goods. **Received stock ledger books** are records of the stock that has been received in the store/warehouse. **Outgoing stock ledger books** are records of stock that has been removed from the store.

iv) Marketing records document customers, price lists, details of buyers, quantities desired by the market, and product types.

CHARACTERISTICS OF GOOD RECORDS:

- They should be simple and easy to use. If your record-keeping system is complicated, it is more likely to generate mistakes.
- The financial records maintained should have appropriate level of details depending upon the type of your business. A more complex farm operation requires a more detailed system.
- A good system provides essential information in a timely manner. Make sure that your records provide essential information on a timely basis.

7.3 Value of Production

Once a crop has been harvested, the farmer (and family) can do three things: sell it, consume it, or store it. The **value of production** is the money received from the sale of produce together with the value of produce that is consumed and stored (i.e., unsold produce). It is sometimes referred to as the "value of output".

The value of sales is very easily measured by the amount of money the farmer receives. This is calculated as the quantity of production sold multiplied by the price that the farmer receives.

Value of production sold = Quantity sold x Sales price

The value of production should also include the value of unsold produce. This is produce consumed by the farm family or stored. A convenient method of valuing produce is by using the market price for which the produce could have been sold. A more precise way to measure the value of food produced and consumed by the family is to ask: *"What would we have had to pay for the food, if we had not produced it?"* However, in rural areas there is little difference between selling prices and buying prices and thus the sales value can be used as a convenient approximation. Then, the total value of production includes produce sold, produce consumed by the farmer's family and produce stored.

Value of production = (Quantity sold + Quantity consumed + Quantity stored) x Sales price

AN EXAMPLE OF VALUE OF PRODUCTION:

After the maize harvest a farmer had 50 bags of maize. She sold 10 bags of maize at $5.50 each and earned $55. She put 20 in her storage shed: 4 bags for cow feed and chicken feed, 14 bags for her family, and 2 to give to a farmer friend.

If the farmer wanted to know the value of her maize production, she would have to add together the bags of maize that she sold in the market, the bags she put in storage, and the bags she gave away, and multiply the total by the market sales price.

This would be 50 bags x $5.50 = $275

Calculating gross profit

Calculating gross profit shows farmers how much they are earning from their farm activities. Farmers are often surprised to see how much or how little is earned from far activities when they calculate gross profit for the first time. This makes gross profit calculation a good place to start, because it shows farmers where their highest costs of production are, and it motivates farmers to either reduce some of their inputs, increase yields, or increase sale prices to improve their margins.

Once a gross profit has been calculated, the figure can be used to calculate a return on investment (ROI) for a crop. This gives an indication of the profit in relation to the expense. The higher the ROI, the better the investment.

Gross profit is the profit a farmer makes after deducting the costs associated with making and selling a product.

Gross profit = total revenue – total expense. Revenue (or **sales**) is the money earned from selling farm **outputs** such as grain and stalks. **Total revenue** is the sum of the revenue earned from all outputs of a particular product. **Expense** is the costs of **inputs** purchased such as seed and fertilizer. **Total expense** is the sum of all expenses needed to produce a particular product (e.g., a maize grain or milk). This is often referred to as **cost of goods sold** (COGs). **Return on investment (ROI)** = gross profit ÷ total expense x 100

Table 7.3 Hypothetical illustration for calculating the value of produce, gross profit and return on investment (ROI).

Expenses/acre	Unit	Quantity	Unit Price (Ksh)	Total (Ksh)	Estimate value (US$)
Potato seed	kg	800	50	40,000	400
Planting fertilizer	kg	100	70	7000	70
Top dressing fertilizers	kg	100	50	5000	50
Fungicide (Rodomil)	kg	0.5	1000	500	5
Dithane M-45	kg	2	1000	2000	20
Bulldog pesticide	Litres	0.3	5000	1,500	15
Ploughing and Ridging labour	Person days	15	400	6000	60
Planting labour	Person days	10	400	4000	56
Fertilizer application labour	Person days	4	400	1600	16
Weeding labour	Person days	15	400	6000	60
Harvesting and harvest handling labour	Person days	18	400	7200	72
Total expense				**80,800**	**808**
Potato yield (total revenue)	**kg**	**8,000**	**30**	**240,000**	**2,400**

Gross profit = Total revenue (Ksh 240,000) - total expenses (Ksh 80,800) = Ksh 159,200

Return on investment (ROI) = Gross profit (Ksh 159,200) ÷ total expense (Ksh 80,800) x 100 = 197%

Gross margin of an enterprise is a measure of what that enterprise can add to farm profits.

Calculating gross margins is essential when deciding between different enterprises. If a farmer wants to know whether to continue with a certain crop or grow another, he or she could compare the gross margins of the two crops. If a farmer changes enterprise, the fixed costs will probably not change. But what will change are the variable costs and the value of production.

Using a gross margin will help the farmer to see if the change in enterprise will be profitable or not.

Gross margin = Value of production – Variable cost

AN EXAMPLE OF GROSS MARGIN:

A farmer who produces a potato crop of value US$ 10,000 at a variable cost US$ 3,000 generates a gross margin of US$ 10,000 - US$ 3,000 = US$ 7,000

When comparing various potential farm enterprises (e.g., which crops to grow), variable costs can be regarded as the costs that vary between enterprises that the farmer would want to compare. Fixed costs are those costs that do not change with the change in enterprise, they include the land rental charges that may be the same irrespective of the crop that the farmer decides to grow. Changing from maize to potato results in costs like treatments for early blight. A cost like this becomes a variable cost for potato while the land, buildings, machinery, and other costs that are the same irrespective of the enterprise, are fixed costs. Farm profit can either be calculated from the value of production or from the gross margin using the following formulas

Formula 1: ***Farm profit = Total value of all farm produce (in monetary terms) - Total cost***

where **Total cost** = Fixed cost + variable cost

Formula 2: ***Farm profit = Total gross margin of all farm enterprises – total fixed cost***

If the amount obtained by subtracting fixed costs from the total gross margin is positive, there is a profit. If the amount obtained is negative, there is a loss. Because fixed costs do not vary much with changes in production, it is almost always the case that if farmers can increase the gross margin on their farms they will also increase profits. Further, because the smallholder farmer usually has few fixed costs, the total gross margin is almost the same as total profit.

7.4 Differentiating between variable and fixed costs

Variable costs

Costs vary according to the size of the enterprise, the amount of inputs used, and the yields achieved. If the area of land under a particular crop increases or more inputs are applied, then variable costs also increase. If less land is planted or fewer inputs are used, the variable costs decrease.

EXAMPLES OF VARIABLE COSTS:

A farmer has to hire labour for weeding and harvesting. If the farmer increases the area that needs to be weeded or increases the number of times the land is to be weeded, the cost of hired labour will also increase. Similarly, the amount of labour needed for the harvest is linked to the yield. If a low yield is attained the amount of hired labour at harvest time will also be low. If a high yield is attained the labour costs will be higher. The same is true of other inputs. If the farmer decides to increase the amount of land planted to maize, the amount of seed and fertilizer applied will increase, so increasing the farmer's costs.

Fixed costs

Costs which can be termed fixed usually apply to a specific enterprise and they do not vary with changes in production. These costs include the costs of using a tractor, farm equipment and draught livestock as well as payment for permanent labour.

EXAMPLE OF FIXED COST:

A farmer has a small storeroom for fertilizer, seed, animal feed, and farm tools. Any costs associated with the storeroom (e.g. maintaining or cleaning it) are shared by all of the farmer's enterprises. These costs are not affected by production or yield. Whether production is increased or decreased, or the yield is high or low, the costs are fixed. It would be difficult to divide such costs and allocate them to the farmer's individual enterprises.

Calculating a farm's net profit

Gross profit focuses on individual farm activities. Net profit takes financial planning to the next level and covers the **whole farm**. Farmers calculating net profit must account for: **gross earnings** (the gross profit of each activity multiplied by the total area each activity uses), **secondary earnings** (revenues that are not related to individual cropping cycles, such as wage labour, or other off-farm income), **long-term expenses** and overhead expenses such as instalments for buying equipment or land, rental costs, maintenance costs, interest on loans, and taxes.

Net Profit = (gross + secondary earnings) - long term expenses

Table 7.4 shows the annual net profit calculation for a family farm.

Table 7.4 Annual net profit calculation for a family farm growing four crops and renting out a tractor.

Farm activity	Gross Profit (per acre) (Ksh)	Actual area (acres)	Gross earnings (Ksh)
Potato	159,200	0.40	63,680
Cassava	16,000	0.25	4,000
Beans	45,000	0.25	11,250
Maize	65,000	0.7	45,500
Total gross earnings			***124,430***
Secondary earnings sources			
Rental of tractor	900 per acre	50 acres	45,000
Off farm income	1,500 per day	40 days	60,000
Total secondary earnings			105,000
Total earnings (gross earnings + secondary earnings)			**229,430**
Long-term expense	**Cost**	**Life**	**Annual cost**
Purchase of a plough	100,000	7	14,285
Net profit per year (total earnings - total long-term expenses)			**215,145**

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The **African Plant Nutrition Institute** research and outreach activities focus on improving the understanding of spatial and temporal variability of nutrient needs for Africa's diverse cropping systems. APNI promotes balanced and site-specific soil nutrient management for greater crop yield and quality, and develops nutrient management strategies to improve soil health, reduce environmental footprints, and improve adaptation to climate change.

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