2 Crop health

2.1 Introduction

The first principle of Integrated Crop Management (and of Integrated Pest Management) is "*Grow a healthy crop*." The main requirement for obtaining a healthy crop is to maintain a healthy soil and use healthy seed. Consecutively, we have to implement cultivation practices adequately and timely in accordance with the specific growth stages of the crop. A healthy crop is able to defend itself against pest and disease attack and to compensate for any damage, in order to finally give a satisfactory yield for the farmers.

2.2 A healthy soil

The soil is the place where plants live in and feed from. A fertile soil is characterized by a loose texture, a composition rich of nutrients and organic matter, a high water-retaining capacity, and a high activity of living organisms. Soil consists of the following main elements:

- *Mineral matter* (30-48%), i.e. sand (relatively large granules), loam (medium-sized granules) and clay (small granules). Soil type is determined by the proportions of these three minerals.
- *Organic matter* or humus (2-20%), i.e. plant and animal material at several stages of decomposition. A soil rich in humus has a dark brown color and a loose structure. The total decomposition of organic matter results in water, gases and nutrients, which can then be absorbed by plants.
- *Water* (20% on average) containing soluble nutrients.
- *Air* (30% on average) with varying composition of gases depending on the depth in the soil. The closer to the surface, the more the composition resembles that of the open air.
- *Living organisms*, such as animals (earth worms, insects), plants, fungi and bacteria. Fungi, bacteria and several animals play an important role in the decomposition process of organic matter in the soil. A dead organism

in the soil will be decomposed over time to become humus. Humus is organic matter with simple chemical structures that will be further decomposed to become nutrients, water and gas.

A body of sand or clay can only be called “soil” if it contains organic matter and living organisms. In most soils, we can find the highest concentration of organic matter and living organisms in the top layers. This is because the major influx of dead plant and animal material comes from above the soil and the decomposition process starts on the soil surface. Plant roots absorb nutrients and water most actively in the rich and loose top layers of the soil. The deeper this loose layer, the better is the soil's capability to support a healthy plant growth.

2.2.1 Soil nutrients

Soils contain a variety of chemical elements. The elements needed for plant growth are called nutrients. Some nutrients are absorbed in relatively large amounts (macro nutrients), others in relatively small amounts (micro nutrients). Macro and micro nutrients are given in the following table:

Macro nutrients		*Micro nutrients*	
Type	*Code*	*Type*	*Code*
Nitrogen	N	Ferro (iron)	Fe
Phosphorous	P	Manganese	Mn
Potassium	K	Chlorine	Cl
Sulfur	S	Zinc	Zn
Calcium	Ca	Molybdenum	Mo
Magnesium	Mg	Boron	B
		Cobalt	Co
		Copper	Cu
		Silicon	Si

Manure and compost contain all the types of nutrients mentioned above, since these organic fertilizers derive from plant material. Inorganic, mineral fertilizers usually contain only one or two nutrients, for instance urea contains nitrogen, TSP contains phosphorous and KCl contains K and Cl. N, P and K are the nutrients absorbed by crops in the largest quantities.

Availability of N, P and K in the soil comes from various sources. The table below shows the average amount supplied by various sources, including natural sources and some common types of fertilizers, for tropical areas:

Source		*Content*		
		N	*P*	*K*
Soil (kg/ha/year)		100-170	6-7	90-290
Rain water (kg/ha/year)		50	uncertain	9
Air, dust (kg/ha/year)		Uncertain	3-60	60-900
Compost		0.4%	0.2%	0.7%
Manure:	Cow	0.4-1.7%	0.2-0.5%	0.1-0.5%
	Chicken	1.0-6.3%	0.8-2.6%	0.4-2.7%
Inorganic fertilizer:	Urea	45%	-	-
	TSP	-	46%	-
	KCl	-	-	50%
	NPK	15%	15%	15%

In cases where farmers have limited availability of labor and livestock, farm manure cannot provide the total amount of N, P and K to support a satisfactory yield, and additional sources of nutrients have to be found. Generally, farmers in many irrigated areas in Asia apply only urea and TSP, thereby only providing N and P nutrients to the soil in an inorganic form. Inorganic nitrogen can easily be absorbed by the plants, but it can also be easily lost from the soil through evaporation, running off and leaching. Additionally, by only providing N and P, the other nutrients not provided through fertilizer will be extracted by the plants from the soil reserve. Sooner or later, the soil will become exhausted of these nutrients. Their deficiency will become a limiting factor for plant development. Crops will no longer be able to produce high yields, despite increasingly high application rates of urea and TSP.

2.2.2 Availability of nutrients for uptake

Nutrient uptake by plants depends on both the supply in the soil and availability. A high supply does not necessarily imply a high uptake. Different types of nutrients and fertilizers show a different behavior in soil and water:

- Farm manure and compost contain elements that are for the greater part in organic form at different stages of decomposition. Nutrients are released slowly whenever they reach the stage of total decomposition. In contrast, inorganic fertilizers contain elements in mineral form, meaning that just like salt they dissolve relatively easily. Release, and hence uptake by the plants, can happen immediately after application, as soon as the nutrients dissolve in the ground water. Because of the slow release of nutrients from organic fertilizers, they are best applied as basal fertilizer, so that the nutrients will be available when the crop needs them.

- Nitrogen dissolves very easily in water, and when dissolved it easily becomes gas and evaporates. Therefore, N is easily lost to the environment, because of washing off through surface water, leaching through ground water, or evaporation from the soil surface. Studies have shown that on wet paddy lands mostly only 40% of the applied urea is available for absorption by the plants.
- Phosphorous hardly dissolves in the water, and it cannot evaporate. Therefore, P is not easily lost from the soil. However, P adsorbs easily to soil particles of both mineral and organic matter, particularly to clay minerals. This makes it difficult for the plants to absorb P, unless the soil is saturated with P and more P becomes available in the ground water. When TSP is applied to P-deficient soils, only about 10% of an application will be available for uptake by plants. On the contrary, P-saturated soils will release about 90% of an application. The easy adsorption of P to soil particles and its slow release forces us to apply TSP as a basal fertilizer, so that P will be available when the plant needs it. Increasing the organic matter content of the soil will support the availability of P for the plants.
- Potassium dissolves relatively easily, although not as fast as N. It also easily adsorbs to mineral soil particles, particularly clay minerals, but not as strongly as P. K cannot not evaporate. The adsorption of K to soil particles keeps it from excessive washing off and leaching, although a certain proportion may be lost depending on the application method and water management practices. On average, about 50% of K applied through inorganic fertilizers will become available for the plant uptake, while the remaining 50% will leach out, wash off or be adsorbed by soil particles. Soils with a high organic matter content can release K for plant uptake more easily. Since K is important for storage root formation, which takes place at 4-7 weeks after planting, half of the K fertilizer application rate is

best applied as a basal fertilizer. To prevent excessive loss of K through leaching and washing off, the other half should be applied at a later stage.

2.2.3 Maintaining soil health

Soil preparation by means of hoeing or plowing aims at turning over the topsoil. Plant residues and fertilizers that have been applied on the soil surface are put under the soil, so that they decompose faster. In addition, the oxygen content of the soil increases, which favors the development of bacteria decomposing the organic matter, and the compacted parts that have been trampled become loose again. Particularly for wet paddy lands that have been inundated, soil preparation is very important to make the soil appropriate for the next crop.

The use of heavy machinery, such as tractors, for soil preparation tends to compact the sub-soil. The inevitable result is that the development of animals, bacteria and plant roots in the soil are disfavored.

In addition to soil preparation, the supply of organic matter and nutrients in such a way that it balances the removal of nutrients through harvesting, is very important to maintain soil fertility. Each crop absorbs nutrients from the soil that will be lost from the ecosystem when the harvest is taken out. Different crops absorb nutrients in different proportions. Sweetpotato, for instance, being a root crop absorbs more potassium (K) but less nitrogen (N) and phosphorous (P) than rice does. In certain areas, we may have to apply some additional amount of K fertilizer on sweetpotato crops, whereas to support rice development in the same field enough K may already be provided by nature, e.g. from volcanic ash circulating in the air. The golden rule is that we should provide as many nutrients through fertilization as we expect will be extracted from the ecosystem by the crop we are cultivating. We should remember here that most nutrients can only be provided by organic fertilizers, such as farm manure and compost, and not by inorganic fertilizers.

2.2.4 Enhancing soil fertility

Deteriorated soils can only recover when substantial amounts of organic matter are given. The following sources of organic matter can be used for this purpose:

- *Farm manure*, i.e. the excrements of any kind of livestock, often mixed with leftovers of feed. The manure should preferably be ripened for 1-2 weeks before applied to a crop.
- *Compost*, i.e. decomposed plant material, for instance from kitchen and garden waste, or crop harvest residues.
- *Mulch*, i.e. a ground cover of dead or live plant material, such as rice, straw, weeds or a leguminous cover crop.
- *Green manure*, i.e. an intercrop that does not compete with the main crop and preferably can fix nitrogen from the air. The green manure crop should be trimmed regularly after which the cut parts are left as mulch on the soil surface or incorporated into the soil.

2.3 Healthy seed

Clean and healthy seed is the basis for obtaining a healthy crop. Sweetpotato is propagated through vegetative planting material, hence carrying the risk of transmitting pests and diseases to the next generation. This weakness can be overcome by means of thorough seed selection. To be able to select healthy seed, farmers have to know the symptoms of pests and diseases on the sweetpotato vines and roots. Sweetpotato diseases that spread through seed are viruses and scab, whereas insect pests include stemborer and sweetpotato weevil.

2.3.1 Diseases

A. *Scab* is a fungal disease the symptoms of which start with the formation of small brown spots on the veins of the leaves and the stem. At later stages, the brown spots cover the whole plant, leaves become curled and the tip of the vine heavily deformed. Scab can cause yield loss of more than 50%. The disease is supposed to start attacking the plants at the stage of storage root formation. When we use sweetpotato cuttings with scab symptoms as seed, the next crop will have scab, too. A picture of symptoms of the scab disease, and more information, is given in Section 5.3.

B. *Viruses* are transmitted to plants by sap-sucking insects, for instance aphids, whiteflies and mites. The growth of a virus-infected plant is hampered, because the plant has to spend too a lot of energy to multiply the viruses, instead of maintaining its own metabolism. Heavily virus-infected plants can be detected by their stunted growth and/or yellow leaves of irregular shape, depending on the type of virus infecting the plant. Section 5.3 contains more information on and pictures of virus symptoms on sweetpotato plants. A sweetpotato plant with symptoms of virus infection should immediately be destroyed and never be used as seed. Viruses will remain in the cutting and cannot be removed, they multiply, and are a source of infestation to other plants.

C. Several kinds of *root rot* can be found on planting material, both storage roots and cuttings. The germs of the root rot diseases can stay alive in the soil for many years. When sweetpotato cuttings are taken from the stem base near the soil surface, it is likely that the disease is transferred to the next crop, particularly if soil particles stick to the cuttings.

2.3.2 Insect pests

Most insects infesting sweetpotato seed can directly be detected by their eggs, larvae or adults on the cuttings. The main insect pests of sweetpotato that can be spread through seed are:

A. *Sweetpotato weevil*. The eggs are laid on the leaves and stems, and preferably on older leaves. The majority of weevils in a field (70-90%) can be found in the area from 15 cm under the ground to 10 cm above the soil surface. This means that cuttings taken from the vine tips are likely to contain very few weevil eggs. The use of healthy storage roots without weevil damage symptoms can also help to produce sweetpotato cuttings that are free of weevils.

B. *Sweetpotato stemborer*. The eggs are laid on the leaves. After hatching, the larva crawls to the stem base and eats its way inside the stem. The vines of plants with heavy stemborer damage should not be used for seed. Clean seed can be produced by planting healthy storage roots in a seedbed as explained below.

2.3.3 Production of healthy seed

There are several methods to obtain healthy sweetpotato seed:

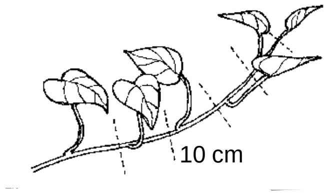
A. *Pest and disease free vine cuttings.* Vigorous plants without symptoms of pest and disease damage are selected in a crop that is about to be harvested. The first and second tip cuttings provide the best seed and are likely to contains least pests.

B. *Seedbed preparation.* New, clean seedlings can be produced from storage roots in a seedbed. Cleaning up seed is necessary when the level of pest and disease attack is high and few healthy plants are left in a field to provide seed for the next crop. Healthy storage roots are selected from plants that produced a high yield, and planted in a seedbed located far away from other sweetpotato crops. When the vines have grown long enough, they are cut at the stem base and planted directly in the field. When large amounts of cuttings are needed, rapid multiplication should be done as explained in point C below.

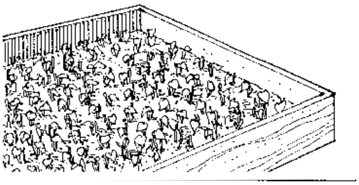
C. *Rapid seed multiplication:*

⇨ Vines growing from healthy storage roots in a seedbed are cut when they have reached a length of about 30 cm.

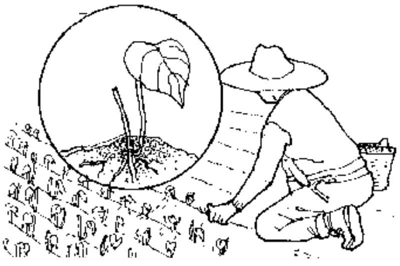
⇨ Each vine is cut up in single-node cuttings of about 10 cm (although the length of nodes depends on the variety). The leaf is kept on each cutting. The tip of the vine is discarded.



⇨ A seedbed is prepared with a mixture of loose, humus-rich soil and rice hull ash. The single-node cuttings are planted at a high density in the seedbed with the node positioned under the soil.



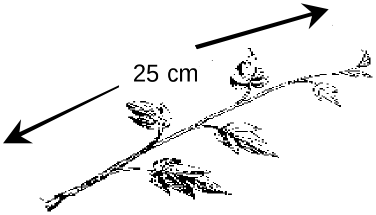
⇨ The seedbed is regularly watered and should not become dry, especially not during the first five days after planting.



⇨ After 10-15 days the seedlings have developed enough roots and are ready to be transplanted to the field. The seedlings should be removed from the seedbed with care to avoid damage of the roots. Transplanting should be done in the morning or in the late afternoon to avoid excessive evaporation, wilting and transplanting shock.

2.3.4 Seed selection

Healthy seed is selected by, first, detecting healthy, vigorous mother plants, free of pest and disease symptoms. The top 25-35 cm of the vine is the best part to be used as seed. This part most easily recovers from cutting and planting shock, and it grows faster than the lower parts of the vine. In addition, the tip is more likely to be free of sweetpotato weevil and stemborer eggs.

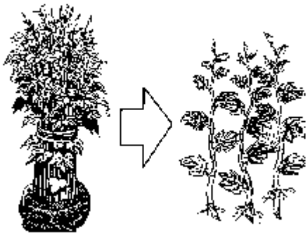


A tip cutting

A second method for seed selection, called positive selection, implies the use of cuttings from plants that produced a high yield. These plants are likely to be free of viruses, and therefore chances of virus transmission to the next generation through seed is very small.

2.3.5 Seed storage

Planting of sweetpotato cuttings is preferably done as soon as possible after they are cut and selected. However, this may not always be possible, for instance when it is too hot and the sunshine is too bright, when the field is not ready yet, or because of any other constraints. Cuttings can be kept for a maximum of seven days. In order to preserve the food reserves in the stem, most leaves on the cuttings should be removed, leaving only a few leaves at the tip. Then the cuttings are tied in bundles with their bases covered with a wet cloth or sack. The bundles are kept in a cool and shady place. During the storage period, roots may develop at the base of the cuttings. The cuttings should then be carefully planted with the roots.



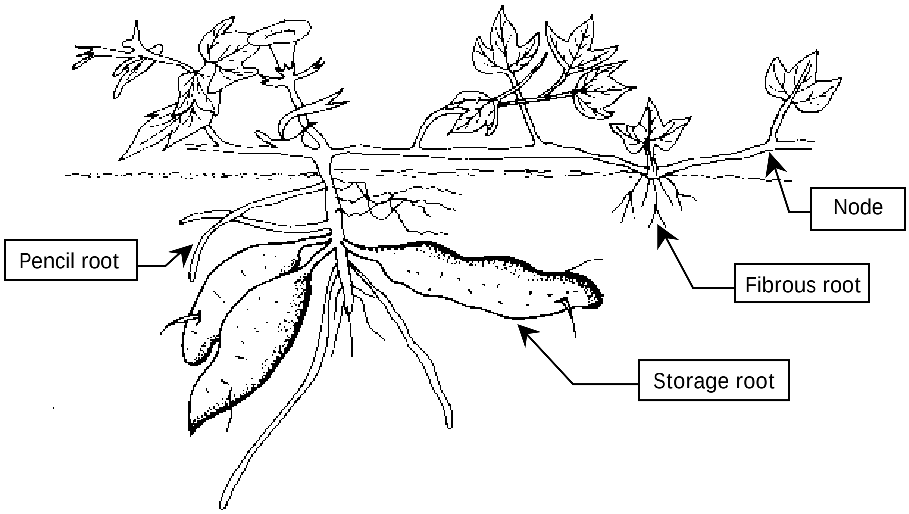
Bundle of cuttings for storage

2.3.6 Planting of cuttings

Experiences from research and farmer practice have shown various conditions that should be paid attention to when planting sweetpotato cuttings, to favor crop establishment:

A. *The length of the cutting.* An average cutting length of 25 cm is considered appropriate for most varieties, although some varieties were reported to produce better when longer cuttings (40-45 cm) are used. The conditions of the field may also influence the relation between cutting length and crop development, and farmers should conduct experiments to find out for themselves which is the best length under the prevailing conditions and varieties they use.
B. *The number of nodes under the ground.* Cuttings with 2-3 nodes (5-7 cm) under the ground have produced higher yields than those with 5-6 nodes (12-15 cm) buried. Farmers' experience shows that better yields are achieved if about one-third of a cutting of 20-25 cm is placed under the ground.
C. *Planting distance.* Most sweetpotato varieties tend to produce a lower yield per plant, but a higher yield per hectare, when we plant them at a higher density. The most appropriate planting distance for most varieties that are currently grown is considered six plants per meter of ridge when one row is planted on a ridge. The width of the ridge can range from 60 to 120 cm, depending on the conditions of field and the composition of the soil. Wider ridges are likely to give a higher yield per plant, but a lower per hectare yield. The optimum planting distance in a field should be determined through experimentation.

Soon after planting, sweetpotato cuttings form young adventitious roots that, depending on the soil conditions, develop into either thick or thin roots. Under favorable conditions, thick roots that grow from the nodes will form storage roots (see picture below). Under dry compacted conditions, young thick roots begin to enlarge, but this is soon stopped and they turn into pencil roots. Under unfavorable conditions of high nitrogen and low oxygen levels, and at the internodal areas, thin roots are formed that develop into fibrous roots, or sometimes into pencil roots.



To be able to form storage roots, young thick roots require favorable conditions, including a loose moist soil with an adequate level of oxygen and a sufficient but not excessive level of nitrogen. The number of young thick roots that will develop into storage roots is determined during the period between 4-7 weeks after planting. In that period the crop should not experience drought.

2.4 A healthy crop

2.4.1 The development of sweetpotato

The development cycle of sweetpotato from crop establishment to harvesting the storage roots takes place in three phases within a time span of 100-150 days. The growth duration depends on the variety and on the environmental conditions. The three phases of a variety maturing in four months under tropical conditions are presented below:

Week	Development phase		Characteristics
0	I	Initial phase	• Planting
1			• Fast growth of young roots
2			• Slow growth of vines
3			
4	II	Intermediate phase (storage root initiation)	• Initiation of storage root development
5			• Fast growth of vines
6			• Large increase in leaf area
7			
8	III	Final phase (storage root bulking)	• Growth of vines ceases and finally stops
9			• Rapid bulking of storage roots
10			
11			
12			• Transportation of substances from leaves to storage roots
13			
14			• Reduction of leaf area because of yellowing and falling
15			
16			
17			• Harvesting

Storage root formation may begin as early as four weeks after planting, and on average between 4-6 weeks, depending on the variety and the environmental conditions. Favorable conditions during the first month after planting are of vital important for storage root initiation and will determine the number of roots on a plant. At seven weeks after planting, 80% of the storage roots have already been formed, and between 8-12 weeks after planting the plant will stop forming new storage roots. After that, all energy is devoted to the bulking of the storage roots. When many storage roots are formed on a plant, the weight per root is normally low, while few roots per plant normally results in big roots.

Vine growth of a healthy sweetpotato crop, in which all requirements for maximum development are fulfilled, is extremely abundant. Normal levels of pest and disease attack will neither result in considerable loss, nor will the crop suffer from nutrient deficiency symptoms. Although parts of the leaves may be eaten by certain pests, such as leaffolders, tortoise beetle and grasshopper, a healthy plant is able to compensate for such damage. Vine growth normally reaches a maximum half way through the final phase. At that stage the foliage of the crop looks most lush. After that, vine density decreases, because the plant uses more and more energy to fill the storage roots rather than to form and maintain the leaves. Moreover, the substances produced in the leaves are transported to the storage roots. Vines attacked by pests are no longer replaced. The leaves become old, yellow and fall off.

2.4.2 Sweetpotato requirements

There are some requirements for a sweetpotato crop to grow well. Those include a healthy place to live (soil and environment), a sufficient supply of nutrients and water, and no extraordinary level of pest and disease attack.

Although sweetpotato can grow in almost any type of soil, in most areas it thrives best on sandy loam soils. Heavy clay soils often produce low yields and low quality roots of irregular shape, because storage root formation is hampered in the hard, sticky soil. Light sandy soils carry the risk of high weevil infestation when the soil is washed away by rain and roots become exposed. A very wet soil at the time of harvest can cause a high incidence of root rot, hence a reduced marketable yield and reduced opportunities for storage.

The nutrients most needed by sweetpotato are potassium (K) and nitrogen (N). Other important nutrients are phosphorus (P), sulfur (S), magnesium (Mg) and iron (Fe). The roles of these nutrients in the sweetpotato plant, the amounts absorbed by the plants, and the amounts that have to be supplied to a field are as follows:

Nutrient	Function in the plant	Content in sweetpotato	Supply to the field
K	– Accelerates the growth of the leaves – Supports the formation of storage root, increases the number of storage roots – Increases the weight of storage roots – Reduces the negative effect of excessive P applications – Plays a role in the protein formation – Plays a role in the formation of well-shaped storage roots – Enhances resistance against diseases – Increases vitamin A content	5-6 kg K per ton of storage roots	80-200 kg K/ha
N	– Component of chlorophyll that plays a role in the absorption of sunshine – Component of proteins, increase the protein content of storage roots – Stimulates leaf growth – Enlarges the size of leaves and storage roots	3-5 kg N per ton of storage roots	30-90 kg N/ha
P	– Plays a role in important chemical processes – Stimulates root development – Stimulates storage root development	0.6-1 kg P per ton of storage roots	0->100 kg P/ha
S	– Plays a role in important chemical processes – Component of proteins – Component of plant hormones	little	Usually enough from natural sources
Mg	– Component of chlorophyll – Plays a role in important chemical processes, e.g. the formation of proteins	little	Enough from natural sources
Fe	– Component of chlorophyll	little	Enough from natural sources

The need of sweetpotato for potassium is relatively high, like in other rootcrops. Not only should we pay attention to the appropriate amount of potassium, but also to the ratio between potassium and nitrogen to be supplied. If the plant absorbs a lot of nitrogen to form proteins, but it has insufficient potassium to support this formation, the substances to form the proteins will accumulate in the leaf sap and can cause poisoning to the plant.

The best bulking of storage roots takes place when N and K supply are at a ratio of about 1:3.

Sweetpotato is able to make efficient use of phosphorous and can absorb it relatively well from the soil. In fields where sweetpotato is rotated with rice or other crops that are given substantial amounts of inorganic P fertilizer, normally no additional inorganic P needs to be given to the sweetpotato crop. Perhaps only in the case of loam soils of low organic matter content, P fertilizer may need to be applied.

Plants need nutrients not only for their growth, but also to enhance their resistance against diseases. For this purpose particularly K and P are very important. In comparison to human beings and animals, plants are more vulnerable to diseases when they experience nutritional disorders. When the nutrient supply is insufficient or unbalanced, plants will easily suffer from disease and pest attack, or stress caused by environmental factors.

2.4.3 N, P and K deficiencies

If a plant experiences deficiency of a certain nutrient, it will show certain symptoms, mostly on the leaves but its whole growth pattern might be affected. Each nutrient shows specific deficiency symptoms. If a farmer can recognize the specific deficiency symptoms, he or she will know what to do when the symptoms occur on the plants. Deficiency symptoms of the main nutrients on sweetpotato plants are presented in the pictures and tables below.

(Photographs by J. O'Sullivan)

Symptoms of N deficiency
• Leaves become light green to yellowish • Reduced growth of the vine • Old leaves become reddish at the edges, yellowish in the middle, and finally reddish to brown all over • Stems of old plants become reddish • Short petioles • Symptoms develop from the base of the plant to the top

Symptoms of P deficiency
• Leaves are dark green to bluish with purple veins • Reduced vine growth • Small storage roots of irregular shape • Purple color on the storage roots is more obvious

Symptoms of K deficiency
• Short vines with short internodes and small leaves are the first symptoms • Leaves are of a darker color (dark green), especially at the edges • Short and pale petioles • Small, shiny brown spots emerge on the leaves, first on the bottom of the leaves and on old leaves • Old leaves become yellowish or reddish, starting at the top of the leaves and developing via the edges to the leaf base • Plants wilt faster and leaves easily fall off • When experiencing heavy deficiency, the whole leaf becomes yellow except the leaf base and the leaf tissue just next to the veins that become dark green • Low number of storage roots • Storage roots are long and thin • Storage roots are more easily infected by root

2.4.4 Other nutrient deficiencies

Deficiencies of other nutrients can cause the following symptoms on the sweetpotato leaves:

- Yellowing between the veins.
- Yellowing of the total leaf area.
- Leaf edge becoming brown and dying off.

2.4.5 Water deficiency

Sweetpotato is relatively tolerant to drought compared to other crops. However, water shortage, especially at the stage of storage root initiation and for prolonged periods of time, can strongly reduce the capacity of the plants to produce a good yield. The number of storage roots will decrease and roots will be mostly small. Direct symptoms of water deficiency include wilting of the leaves and ceased growth. Water shortage also makes the plants more susceptible to insect pest attack, and to cracking of the storage roots.

2.4.6 Nutrient toxicity

Most nutrients can cause toxicity in plants when applied in excessive amounts. Too much nitrogen fertilizer causes the vines to grow lushly, but initiation and development of storage roots is hampered. At excessive N applications, sweetpotato plants will not flower, although it should be remembered that not all sweetpotato varieties produce flowers. Potassium toxicity is seldom a problem. Sweetpotato is fairly tolerant to acidity of the soil.

2.4.7 Symptoms of virus infection

Plants showing symptoms like stunted growth, curly leaves, and/or changed leaf or vein color are likely to be infected by a virus disease. Viruses are usually transmitted by leaf-sucking insect, such as aphids (see Section 5.3). These symptoms should not be mixed up with nutrient deficiency or toxicity symptoms.

2.5 The regenerative capacity of plants

2.5.1 Leaf damaging agents

Several kinds of pests and diseases can cause damage to the leaves of sweetpotato. Among the insect pests we can find types that suck the leaf sap, while others consume whole parts of the leaf. The leaf-sucking insects have long mouth parts that they can inject into the leaf tissue to suck the plant sap. This way of eating does not only cause damage to the leaves in the form of many small holes, but also results in a loss of the substances produced by the leaf for its growth. If there are many of these mostly small insects on a leaf, the leaf dies off. Examples of the leaf-sucking insects are aphids, leafhoppers, whiteflies and mites.

Leaf-eating insects can be divided into those biting parts of the leaf, such as grasshoppers, hornworms and tortoise beetles, and those scraping tissue from the leaf surface, for instance leaffolders and thrips. The way of eating depends on the shape of the mouth of an insect. Both ways cause a direct loss of green tissue for the plant which has to be compensated by growing new leaves.

Diseases also damage the leaves, because they cause spots on the leaf's surface, thereby reducing the green area. The leaf tissue of the spots is dead and does no longer function. When the number of spots on the leaves becomes abundant, the growth of plant will be disturbed and the plant becomes stunted. A very common disease in sweetpotato causing considerable loss is the scab disease.

2.5.2 When can plants compensate for damage?

Generally, sweetpotato has a high capacity to compensate for pest and disease damage on the leaves, since under favorable conditions the foliage is very lush and vines grow very rapidly. When the plant is healthy, a certain level of damage will not result in economic loss, because soon after the damage has occurred the plant forms new leaves and compensates for the damage.

This ability for compensation, however, depends on the severity of the damage, the development phase of the plant, and the environmental conditions determining crop health. The most sensitive development phases are the initial and intermediate phases when crop establishment and storage root initiation occur, which cover the first seven weeks after planting. If there are a lot of pests that damage the leaves during this period, the yield may be affected. The compensation capacity of a certain variety under certain conditions can be tested in an artificial defoliation experiment.

2.6 Plant nutrition

Plants need various nutrients as food, the most important of which are:

- Nitrogen or N.
- Phosphorous or P.
- Potassium or K.

As was discussed in Section 2.2 (A healthy soil), N, P and K are available in the soil, in irrigation water and in the air. We have to apply additional fertilizer when we cultivate crops intensively, and exhaust the natural reserves of these nutrients. Organic fertilizers such as farm manure, compost and green manure are preferred to replenish these reserves. At high production levels, however, the (often limited) amounts of organic fertilizers available may not provide sufficient amounts of N, P and/or K, and additional inorganic fertilizers or ash may have to be used. Some other important nutrients absorbed by the crops are sulfur (S), calcium (Ca), zinc (Zn) and magnesium (Mg). Generally, these nutrients are sufficiently available in the soil, particularly when a field is often treated with organic fertilizers.

As learned in Section 2.4, we can see from a plant's appearance whether it suffers from a nutrient deficiency. After we have diagnosed the deficiency and analyzed the need for action, we can correct the problem by applying the appropriate type of fertilizer. The need for action will depend on the severity of the problem, the growth stage of the crop, and the expected benefit to be gained from the practice in relation to its cost. It is, for instance, normal that sweetpotato crops suffer from nitrogen deficiency, showing yellow leaves, at the end of the season.

2.6.1 Types, composition and prices of fertilizers

Organic fertilizers are the best food for plants since they contain all the nutrients needed by the plant. A weakness is that their nutrient content is relatively low compared to inorganic fertilizers (see table below). We need to apply a huge amount of manure, for instance, to provide the nutrients needed to support a high yield in intensive cultivation systems, however the availability of manure is often limited. Additional inorganic fertilizer can then provide a solution. Inorganic fertilizers commonly available are urea (45% N), TSP (46% P) and KCl (50% K).

In order to determine ecologically and economically sustainable fertilization levels in a field, we have to consider not only the composition of the different fertilizers, but also their price and the labor and transportation costs needed to purchase and bring them to the field. The table below shows that about two sacks or 100 kg of cow manure are needed to obtain one kg of pure nitrogen plus all other nutrients including 0.8 kg of P_2O_5 and 0.4 kg of K_2O P. The same amounts of N, P and K can be obtained from 5.2 kg of inorganic fertilizer. With the prices prevailing in Indonesia in 1997[1], the total amounts of inorganic fertilizer would have cost Rp. 2,480, in comparison with only Rp. 700 for the two sacks of cow manure. The savings would even be higher if we use chicken manure, of which we would need only 33 kg costing Rp. 660, as compared to 7 kg of inorganic fertilizer for a price of Rp. 3,427. After taking into account the labor and transportation costs we can determine which option is most

[1] US$ 1.- was equivalent to Rp. 2,250.

economical. In view of sustaining soil fertility, organic fertilizer is definitely much better than inorganic fertilizer.

Fertilizer type	*Content (%)*			*Price*	
	N	P_2O_5	K_2O		
Cow dung	1.0	0.8	0.4	Rp. 350/sack (50 kg) ⇒ Rp. 700 for 100 kg of manure containing 1 kg of N, 0.8 kg of P_2O_5, 0.4 kg of K_2O and other nutrients.	
Chicken dung	3.0	3.9	1.9	Rp. 1,000/sack (50 kg) ⇒ Rp. 660 for 33 kg of manure containing 1 kg of N, 1.3 kg of P_2O_5, 0.6 kg of K_2O and other nutrients.	
To substitute the nutrients contained by: *We need:*				*100 kg of cow manure (Rp. 700)*	*33 kg of chicken manure (Rp. 660)*
Urea	46	-	-	Rp. 400/kg (1 kg N = Rp. 870)	(1 kg N = Rp. 870)
TSP	-	46	-	Rp 650/kg (0.8 kg P_2O_5 = Rp. 1,130)	(1.3 kg P_2O_5 = Rp. 1,837)
KCl	-	-	50	Rp. 600/kg (0.4 kg K_2O = Rp. 480)	(0.6 kg K_2O = Rp. 720)
TOTAL				Rp. 2,480 for 5.2 kg of fertilizer	Rp. 3,427 for 7.0 kg of fertilizer

2.6.2 Amount of nutrients needed by sweetpotato

The nutrient contained in sweetpotato leaves and storage roots is more or less constant. Therefore, we can calculate the approximate amount of nutrients absorbed by a crop when we know the yield. This means that we have to apply a high dose of fertilizer if we expect a high yield, but can economize when the environment does not have the potential for high production. The amount absorbed by the crop is not equal to the amount we have to apply. We should consider the natural reserve available, on the one side, as well as losses due to adsorption, evaporation, washing off and leaching, on the other side. Generally, less fertilizer, particularly urea, can be applied during the rainy season than during the dry season, because the yield potential is lower when the sky is often cloudy.

To calculate the exact amount of nutrients needed by a crop to support a certain yield level is very complicated, if not impossible. We never know the exact reserves in the soil and the amounts provided by natural sources, nor can we predict the exact behavior of the fertilizers in the soil and ground water to estimate the proportion absorbed by the plants. Research done by scientists and farmers shows some important lessons that provide basic guidelines to determine fertilizer application rates under certain conditions:

- Large amounts of nitrogen keep the leaves of sweetpotato lush and green, but result in small storage roots. Too much nitrogen can even cause poisoning in the plants.
- Sweetpotato needs a relatively large amount of potassium, particularly at the stage of storage root initiation. Potassium deficiency can cause other nutrients not to be used optimally, and results in few and small storage roots.
- Sweetpotato develops best when N and K are available in the soil at a ratio of 1:3.
- Sweetpotato makes efficient use of phosphorous and can extract it well from the soil. Usually, P fertilizer does not need to be applied to sweetpotato when organic fertilizer is given and the crop is grown in rotation with rice or other crops that are given inorganic P. Exceptions are cases in which the soil has serious P deficiency and for loam soils with low organic matter content.
- Organic fertilizers provide all the important nutrients needed by the crop and should always be used in as large an amount as available. The possible amount of additional inorganic fertilizer should be adjusted to the organic fertilizer applied.

2.6.3 Time of nutrient application

The faster the growth of a plant, the greater its need for nutrients. Sweetpotato vines grow fastest during the intermediate phase of storage root initiation, which is between four and eight weeks after planting. During this period, all nutrients should be available in balanced concentrations in the ground water. Particularly potassium should not be deficient during this period, since it plays an important role in determining the number of young thick roots to become storage roots. This is the reason why we have to give part of the potassium fertilizer as a basal application to ensure adequate availability from week four onwards.

Organic fertilizer releases nutrients slowly, and, therefore, should be applied as a basal fertilizer. The supply of nitrogen from organic fertilizer and natural sources is normally enough to support the vine growth during the initial and intermediate phases of crop establishment and storage root initiation. During this period, the plants form a dense foliage and rapid vine growth continues during the first part of the storage root bulking phase. The beginning of the bulking phase, when vine growth is at its maximum speed, is the most appropriate moment for additional K and N application, if needed.

Phosphorous is easily adsorbed to soil particles and is only slowly released for plant uptake. Therefore, we should apply P fertilizer at the moment of soil preparation, to make sure that enough P is available when the plants need it during the phase of storage root initiation and bulking.

2.6.4 Sweetpotato fertilization guidelines

Based on the principles described above regarding nutritional requirements and application time, very general guidelines are presented here for fertilizer application rates. It should be remembered that these guidelines were developed in Indonesia, under tropical, irrigated, and relatively fertile conditions with a high yield potential (20-50 tons/ha). Therefore, these guidelines should not be considered a standard recommendation, but need to be adjusted according to prevailing yield potential, soil composition and fertilization history, environmental and socio-economic conditions.

Fertilization guidelines as applied in the ICM FFS in Indonesia, targeting for a yield of 40 tons/ha, include the following application rates:

Fertilizer type	Basal application at soil preparation (kg/1,000 m^2)	Second application at 50-60 days after planting (kg/1,000 m^2)
Cow manure	400	-
TSP	-	-
KCl	5	5
Urea	-	10

The rate of 400 kg organic fertilizer per 1,000 m^2 is considered the minimum amount to be supplied seasonally to arable lands to sustain soil fertility. If chicken manure is used instead of cow manure, nutrient supply is supposedly sufficient, and additional inorganic fertilizer may not be needed unless a higher yield than 40 tons/ha is expected. It is recommended that more organic fertilizer than the minimum of 400 kg/1,000 m^2 is used whenever available and feasible with regard to labor and transportation, thereby proportionally reducing the additional amounts of inorganic fertilizers. To determine the most suitable fertilizer application rate in a certain field, farmers should conduct a series of experiments and find out for themselves. Factors to consider when determining possible treatments include soil fertility, cropping pattern, availability of organic and inorganic fertilizers, labor and capital.

2.7 Vine lifting

Most sweetpotato varieties are characterized by a growth habit of long vines creeping over the soil surface. If the soil is moist and the stem touches it, roots will grow from the nodes. These roots can form storage roots, but only very small ones that are not marketable. Water and nutrients supplied to these useless roots are therefore wasted, and will result in total yield loss. This waste can be prevented by lifting the vines so that the roots growing on the stem nodes are cut off and will not continue to grow. Vine lifting implies that the vines are only uplifted to disconnect the roots from the soil. They should not be turned over because they may cause rotting of the leaves.

Farmers in certain parts of India were reported to lift the vines every 3-5 days after the field was irrigated. However, this involves a lot of labor while root growth on the stems does not necessarily happen after irrigation, and will depend on how long the soil remains wet and to what extent the stems touch the soil. Indonesian farmers were found to conduct vine lifting 1-2 times during the rainy season, whereas during the dry season the majority (64%) did not do it at all. During the dry season, they did not find many roots to be formed on the stems, because the soil surface is dry most of the time.

Experiments done by Indonesian farmers show that vine lifting at a frequency of more than once during a season only results in a higher yield when the soil is often moist, allowing roots to grow on the stems. Vine lifting during any season should, therefore, not be a routine practice, and is only recommended after root growth on the stem nodes has been observed. During routine field observations, especially after the crop is 60 days old and maximum vine production has been achieved, farmers should pay careful attention to root formation on the stems. Based on these observations, they can decide whether labor investment in vine lifting is worthwhile or not.