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MANUAL

Manual for sweetpotato pre-basic seed production using the sandponics system

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SASHA Sweetpotato Action for Security and Health in Africa

CGIAR RESEARCH PROGRAM ON Roots, Tubers and Bananas

Kenya Plant Health Inspectorate Service

ZARI Researching Soils, Crops and Water in Zambia

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Prologue

Research has demonstrated sweetpotato yields on smallholder farms are improved when they have access to quality planting material of improved varieties. Providing that access is easier said than done in the case of vegetatively propagated crops. Given the ease of farmer-to-farmer sharing of sweetpotato planting materials, willingness-to-pay in general for quality material is low. Typically, there are several rounds of multiplication of planting material after producing plantlets in tissue culture. With each round the cost per unit reduces. It is critical, if the planting material is to be of quality, that pre-basic seed, that is the first round of multiplication after hardening plantlets emerging from tissue culture, needs to be of highest quality, that is virus-free and vigorous.

The Sweetpotato for Security and Health in Africa (SASHA) collaborated with 10 sub-Saharan Africa National Agricultural Research Institutes (NARIs) to improve the management of their pre-basic seed system by fully understanding the cost of each component and developing business plans so that pre-basic seed production would be sustained whether or not a project was in place. Complementary to that effort was the undertaking of research on the technical side with the goal of lowering the cost of producing and improving the efficiency of pre-basic seed. In the past, lack of sufficient pre-basic seed has emerged as a bottleneck in the entire seed system. Adapting research protocols developed at CIP headquarters for potato, we explored whether a sandponics systems could be developed for sweetpotato in Africa. As such, a series of experiments were conducted at Kenya Plant Health Inspectorate service—Plant Biosecurity and Quarantine Station, Muguga, Kenya between 2016 and 2019. There were three objectives: (1) To optimize the nutrient media for sweetpotato pre-basic seed multiplication in the sandponics system by assessing the effect of various macro- and micro-nutrients levels required for good vine growth; (2) To determine the cost of using the sandponics system compared to the current sterilized soil based system; and (3) To compare the yields of selected sweetpotato genotypes whose pre-basic seed was multiplied by using sandponics compared to the conventional soil substrate method.

Favorable results were obtained from several studies that will result in CIP and NARIs moving towards just using the sandponics system for their pre-basic seed production. This manual provides a “how-to” guide to what is needed to set-up and manage a small sandponic unit. Diagrams and instructions are presented on how to set up the sandponics system in a screenhouse. The components of the optimized nutrient media for multiplying pre-basic sweetpotato vines under a sandponics system are presented. Key research findings showing that the vine multiplication rate (VMR) using the sandponics system increased by 21.8% compared with the conventional soil substrate multiplication method and that the cost of producing a 3-node cutting was lower by USD 0.027 in the sandponics system. Moreover, storage root yields were 23.8% higher using the sandponics system sourced planting materials compared with materials sourced from the conventional soil substrate method. Guidance is provided on how to manage the pre-basic seed production process. The rationale is that the sandponics system is a better viable alternative technology for a sweetpotato pre-basic seed business enterprise.

We intend this manual to be a practical guide for those wanting to adopt the sandponics system within their program as a major way to cost-effectively multiply pre-basic seed in most sub-Saharan African countries. We hope that by using these guidelines, there is no need to “re-invent the wheel” from scratch as the optimized system has been developed. However, we note that varieties do differ in their response within the sandponics system and further experimentation with specific varieties to maximize the efficiency of the system may be warranted.

We intend for sandponics system to be part of a broader toolkit of technologies and training that will successfully address the seed system bottleneck for resource poor smallholder farmers, so that they can access timely and adequate quantities of quality planting materials.

1. Introduction

The production of sweetpotato in sub-Saharan Africa is constrained by lack of access to high quality planting materials and improved varieties at the right time and in the right quantities. This is mainly due to infection of planting materials with sweetpotato viruses that build up over generations of use and that compromise the quality of the material. Prolonged droughts also limit the availability of seed from the previous season's crop. Insufficient planting material limit the adoption and utilization of improved sweetpotato varieties. Ensuring that farmers have timely access to adequate quantities of quality planting materials of the varieties they want starts with the availability of adequate pre-basic seed. This will then drive multiplication of quality clean planting material of new and improved varieties by trained vine multipliers.

Sweetpotato pre-basic seed production maintains pure disease-free seed through cleaning, multiplication and dissemination of cuttings from vines or 'seed'. In most sub-Saharan African countries, breeders in the national agricultural research systems (NARS) are using in-vitro tissue culture facilities to produce a limited quantity of plantlets, which are then hardened off to provide vines for in-vivo production of pre-basic seed in screenhouses. Producing pre-basic seed has traditionally been done with sterilized soil also referred to as "conventional soil substrate method". With the phasing out of use of methyl bromate in the sterilization process, sterilizing soil now has to be done with heat. However, sterilizing soil using either diesel or firewood as a fuel is expensive, unsustainable and may not achieve optimal vine multiplication rates (VMR). Multiplying sweetpotato pre-basic seed in sand with fertigation (application of nutrients through irrigation systems), also known as 'sandponics system', offers a possible opportunity to build a more sustainable production system for sweetpotato pre-basic seed. Sand is chemically inert and can be sterilized at low cost with sodium hypochlorite (the active ingredient of locally available household bleach, often sold under the brand name Jik).

Research undertaken under phase II of the Sweetpotato Action for Security and Health in Africa (SASHA) project has demonstrated that sweetpotato pre-basic seed can be multiplied more cost-effectively in a sandponics system than when using the conventional soil substrate method (Makokha et al., 2019a). The VMR in the sandponics system is 22% higher when compared with the conventional soil substrate method. The sandponics system has a high production efficiency by area with 1,021 cuttings (3-nodes each) per square meter. Consequently, the average cost of producing a 3-node sweetpotato cutting in the sandponics system, KES[1] 10.5 (USD 0.10), is 20% lower than the cost per cutting for the conventional soil substrate method, at KES 13.2 (USD 0.13), although the actual cost per cutting varies between different varieties. An additional benefit found was that the storage root yield in open fields from planting material multiplied under the sandponics system was 24% higher than the root yield from vines that had been multiplied by conventional soil substrate method. This may be due to the levels of residual nutrients in sweetpotato pre-basic seed multiplied in the sandponics system (Makokha et al., 2019b).

This manual explains the procedures involved in setting up the sandponics system and managing it to multiply sweetpotato pre-basic seed to ensure a dependable supply of high-quality planting materials.

[1] Kenyan Shilling: KES. The exchange rate in 2019 was around KES 100 per USD 1.

2. Sandponics system infrastructure

The basic components of a sandponics system infrastructure are: the screenhouse, an elevated water tank, a tower to support the water tank, water pipes, and the beds or pots filled with sand substrate.

2.1 Screenhouse

The screenhouse should be insect-proof and keep out rain water. Screenhouses with no roofs are not recommended, as the rain water will wash nutrients from the growing media, leading to symptoms of nutrient deficiencies in the vines. The floor does not need to be costly.

Since sweetpotato performs well in warm environments, screenhouses with lower roofs are preferred; normally these are warmer than those with higher roofs and appropriate for situations where the producer does not have the capacity to install heating equipment, especially in areas with prolonged cold seasons. If the structure is too warm, especially in cases where the producer cannot afford installation of cooling fans, shade netting can be placed over the roof or alternatively a screenhouse with a taller roof should be designed.

The orientation of the screenhouse is not an important factor in sweetpotato pre-basic seed production. Any orientation should be suitable provided the prevailing wind direction is considered.

More durable metal structures are recommended over wooden structures, although wood is much cheaper.

The size of the screenhouse depends on the quantity of planting material the producer wants to multiply. Detailed materials required for the construction of a simple screenhouse for sweetpotato pre-basic seed production using the sandponics system are highlighted in Table 1 using cost estimates from Kenya as an example. Clearly, that the actual cost of these materials will vary by country.

2.1.1 Recommended screenhouse management and sanitation practices:

- The design of the structure and the way it is operated should always aim to prevent insects from entering the screenhouse.
- No food should be brought into the screenhouse.
- The screenhouse operator should be adequately trained.
- The screenhouse should have a pre-chamber also known as head house, and the two doors should never both be open. Springs should be attached to the doors, so they close automatically.
- Everyone entering should wear a clean lab coat which should be kept in the pre-chamber. Only essential staff should enter the screenhouse; visitors should remain outside.
- People entering the screenhouse should not come directly from fields of sweetpotato.
- The pre-chamber should make provision for water and the following materials: Two to three clean lab coats, liquid soap, a bottle containing 2% sodium or calcium hypochlorite solution (bleach), and paper towels.
- Everyone entering the screenhouse should walk through either a tray containing calcium oxide (lime) dust, or on a mat dipped in a concentrated solution of copper sulfate or quaternary ammonia (benzalkonium chloride) or covered in sulfur powder to eliminate soil-borne spores.
- If no vines are to be touched, on entering, hands should be washed with soap and water. If vines are to be handled, hands should be thoroughly washed with soap and sanitized with disinfectant (bleach).

- Disposable gloves may also be used when many vines are to be handled. Disinfectant should be used after handling each plant.

2.2 The tank and tower

The tower to support the elevated water tank can be made of wood or metal. Metal towers are more durable, but also more expensive. The tower must be strong enough since it is going to support considerable weight, at least 2 tons. Space on the platform for the operator must be considered in the design.

As the sand in which the vines are grown in the sandponics system is an inert material, nutrients and also water need to be provided to the sweetpotato vines. This is done using a nutrient-rich solution delivered by gravity so the tank must be elevated. The size of the tank will depend on the size of the screenhouse and the number of vines to be multiplied.

The tank is accessed using a ladder. The operator will use a hosepipe to fill the tank and prepare the nutrient solution. The base of tank must be around 1.8 to 2.0 m above ground level. It is better to place the tank outside but adjacent to the screenhouse, so that better use of screenhouse space can be made and to keep the nutrient solution in a cooler place. This is illustrated Figures 1 and 2.

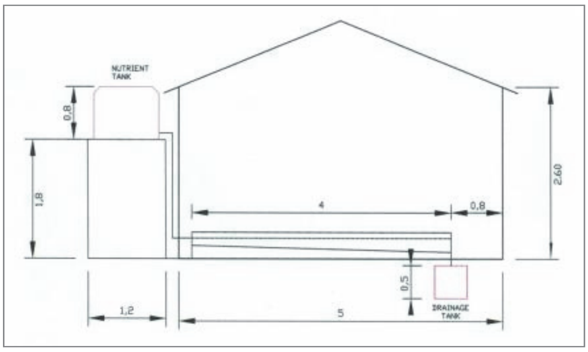

Figure 1. A diagram showing a design of sandponics system

Figure 2. An elevated tank and ladder next to the head house.

2.3 Pipes and fittings

Distribution pipes and fittings can be made of PVC (polyvinyl chloride) (Figure 3) or PE (polyethylene) (Figure 4). For nutrient/water delivery pipes, the most commonly used pipes are the black polyethylene pipes, also called HDPE (high density polyethylene). It is advisable to use pressure compensated pipes to ensure uniform delivery of the nutrient media. A diameter of 16 mm is adequate, but 20 mm are often more readily available and can also be used. Use of a plumber for the installation of these pipes is recommended. Somewhere between the tank outlet and the distribution pipe, a filter should be installed. Black canister (1/2” or 3/4") filters are useful for retaining insoluble material that comes in the fertilizers and can block the drippers. The filter needs to be cleaned regularly. A general valve should also be installed to allow the flow of nutrient solution to be shutoff, as well as secondary valves that control the nutrient solution flow in each bed.

Figure 3. PVC distribution pipes and fittings

Figure 4. PE distribution pipes and fittings

2.4 Drippers

Drippers, which deliver the water/nutrients to the vines at the required rate, are cheap (USD 0.20 each) but may not be available everywhere. Two common types are shown in Figures 5 and 6. Drippers are convenient, because they allow better control of the nutrient delivery. If drippers are not available, then control of rate of flow can only be achieved using the distribution valve, but this will not give such a uniform flow. In this case, consider the following options:

- Purchase flat pipes with incorporated drippers.
- Manually make holes in the pipes with a drill or with nails.

A diagram displaying how vines, pipes and drippers should be installed is shown in Figure 7.

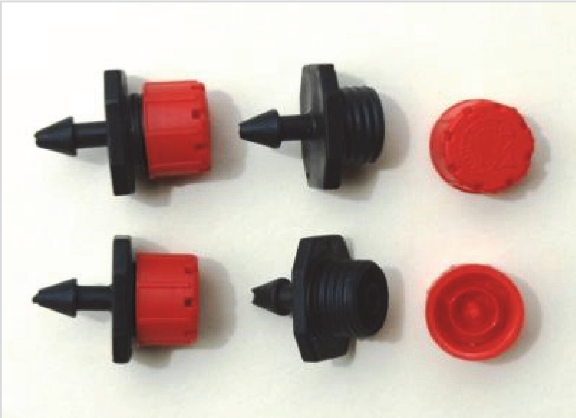

Figure 5. Drippers with a calibrated flow delivery

Figure 6. Drippers with a fixed flow delivery

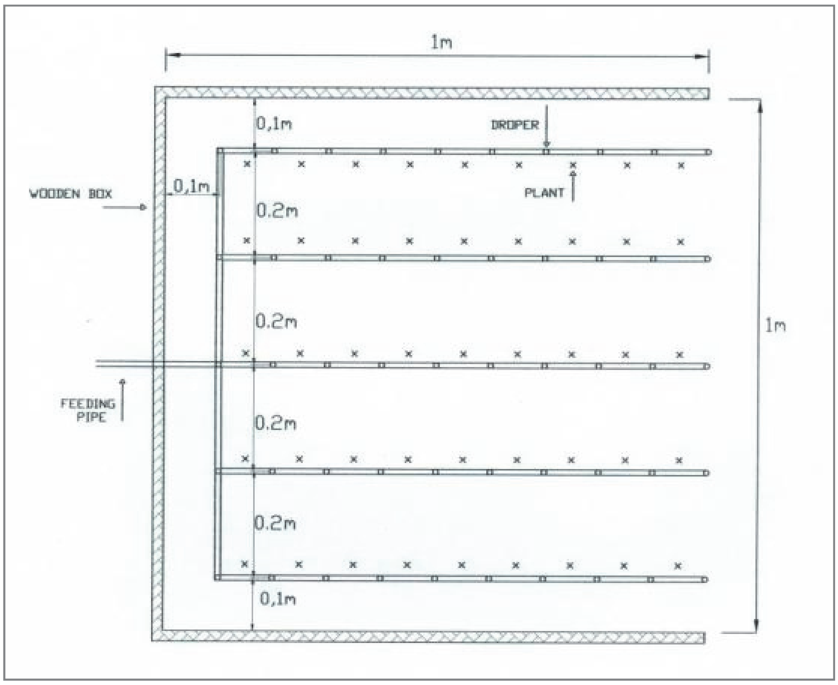

Figure 7. Pipe, plant and dripper distribution in a sand box, 1 m square

2.5 Costs

Table 1 shows a list of materials and approximate costs for a screenhouse (8 m × 10 m) using pots. The ridge height is 4.5 m and the height of the sides is 2 m. The roof and walls consist of netting stretched across the frame. Costs, based on prices in Kenya in 2018, are shown in Table 1. Actual prices will vary. The materials listed are usually commonly available in most countries. The total cost was about USD 9,695 in 2018.

Table 1. Materials required for an 8 m x 3 m pre-chamber plus an 8 m x 10 m screenhouse for sweetpotato pre-basic seed multiplication using sandponics system (2018 prices in Kenya)

	Items description	Units	Quantity	Unit price (USD)	Total price (USD)
	A. Screenhouse				
1.1	Complete metal main screenhouse frame 8 m × 10 m × 2 m under gutter × 4.5 m ridge height	m^2	80	24	1920
1.2	Complete metal pre-chamber screenhouse frame 8 m × 3 m × 2 m under gutter × 4.5 m ridge height	m^2	27	24	648
1.3	Hinged door 1.2 m wide × 1.8 m height	pieces	2	48	96
1.4	Insect netting, black 50 mesh for roof 12 m × 11 m	m^2	132	1.4	184.8
1.5	Insect netting, black 50 mesh for gable ends 9 m × 7 m	m^2	189	1.4	264.6
1.6	Insect netting, white 50 mesh for sides 3 m × 11 m	m^2	66	1.4	92.4
1.7	Insect netting, white 50 mesh for gable ends 9 m × 7 m	m^2	189	1.4	264.6
	Sub-total				**3,470.4**
	B. Civil works and concrete works/concrete floor in main screenhouse				
2.1	Digging holes for screenhouse foundation	m^3	3	6	18
2.2	Screenhouse posts foundation, concrete	m^3	1	144	144
2.3	Compacted gravel, 200 mm depth, topped with concrete screed for main screenhouse floor, 8 m x 30 m screenhouse	m^3	17.1	96	1641.6
2.4	Masonry wall foundation, concrete	m^3	2.64	120	316.8
2.5	Masonry wall up to 1 m height above ground level	m^2	44	24	1056
2.6	Quarantine channel all round screenhouse, 20 cm width x 20 cm depth	m	46	14.1	648.6
2.7	Paving slabs all round screenhouse, 20 cm square	m	46	9.4	432.4
	Sub-total				**4,257.4**
	C. Irrigation system				
3.1	Water outlets stand, ¾'' system inside main screenhouse	Units	1	300	300
3.2	Water outlet, 3/4", plus sink inside pre-chamber	Units	1	300	300
3.3	Irrigation pot dripper system including drippers, pegs, 4-way manifolds, piping & valves	Units	1	768	768
3.4	Plastic tank 2 × 1000 liters plus stand 3 m high	Units	1	300	300
3.5	Fittings, accessories and spare parts	Units	1	300	300
	Sub total				**1,968**
	Grand total				**9,695.8**

2.6 Water source

The sandponics system requires clean water free of pathogens. A dependable source of potable water is the best. Clean water that becomes turbid during heavy rains is not sufficient and should be filtered before going into the nutrient tank or alternatively it should first be boiled. Chemical and microbial analysis will provide useful information on water quality. A pH meter and an electric conductivity (EC) meter are useful tools for monitoring pH and the presence of salts in water. Water to be used in sandponics system should have a low EC, not exceeding 1 mS/cm, and the pH should be above five but below eight.

2.7 Sand substrate

Sand is available in many places across the world. Quartz and other inert materials can also be tried if they are more available. Very fine sand should be avoided as it becomes compacted and limits root development. In some areas, sand may be contaminated with heavy metals that cannot be removed by washing (Mbiri et al., 2015).

An easy test to detect salts in sand can be performed. For this about 400 ml of water is placed in a glass or plastic container and the EC is measured using an EC meter. An equal volume of sand is then placed in the container, the mixture is stirred, and the supernatant used to get an EC reading. If the EC reading of the sand mixture is the same as the EC of water, then no salts are present in the sand sample.

Chemical sterilization of sand can be done using sodium hypochlorite. Sodium hypochlorite is cheap and readily available in most places as household bleach, which is used as disinfectant and in laundering clothes. Bleach usually contains 3–5% sodium hypochlorite by weight. A mixture of 1:10 parts bleach to water should be used for sand sterilization. The substrate (sand) should be soaked for 10 minutes in the solution after which any excess bleach is removed by rinsing the sand two or three times with clean water (Figure 8). Any residual sodium hypochlorite can also be detected using an EC meter, as explained above. The rinsed sand can then be placed directly in pots or beds and left for one day before planting to allow any traces of bleach to diffuse into the air; alternatively, the sterilized sand can be left overnight on a drying rack then used the following day. If sterilized sand needs to be stored, sealed plastic bags should be used to avoid contamination.

Figure 8. Washing, sterilization and drying of sand on a raised rack

Considerable amounts of sand are used in beds. It is advisable that after six production cycles all remnants of plant materials (roots, stems, tubers) are removed by sifting the sand using a screen and subjecting it to the sterilization process as described above. The screenhouse should also undergo maintenance and sanitation procedures, waiting for two weeks after cleaning before establishing a new crop.

2.7.1 Procedure for sand sterilization using bleach (sodium hypochlorite)

Formula for diluting bleach:

Volume of bleach needed = Recommended % /100 × Final volume required

For example, if the recommendation is 10% bleach and the final desired volume is one liter (1000 ml), then the calculation is: 10/100 × 1000 = 100 ml of bleach. So, 100 ml of bleach is then added to 900 ml of water to produce a 10% sodium hypochlorite solution.

Safety recommendations should be followed, including using personal protective equipment when handling these products. The personnel should always put on gloves and safety glasses.

2.7.2 Advantages of using sand over soil substrate for multiplying sweetpotato pre-basic seed

- Sand is locally available in most places
- Sand is easily sterilized using bleach (sodium hypochlorite)
- Bleach is affordable and locally available
- Sand can be easily recycled
- It is a low risk technology
- It is versatile as it can be implemented in wooden/concrete beds, pots, crates, and even in plastic bags.
- In general, it is a cheaper and more efficient technology than using soil.

3. Vine multiplication techniques in sandponics system

A schematic diagram showing a summary flow of events during sweetpotato pre-basic seed production using the sandponics system is shown in Figure 9.

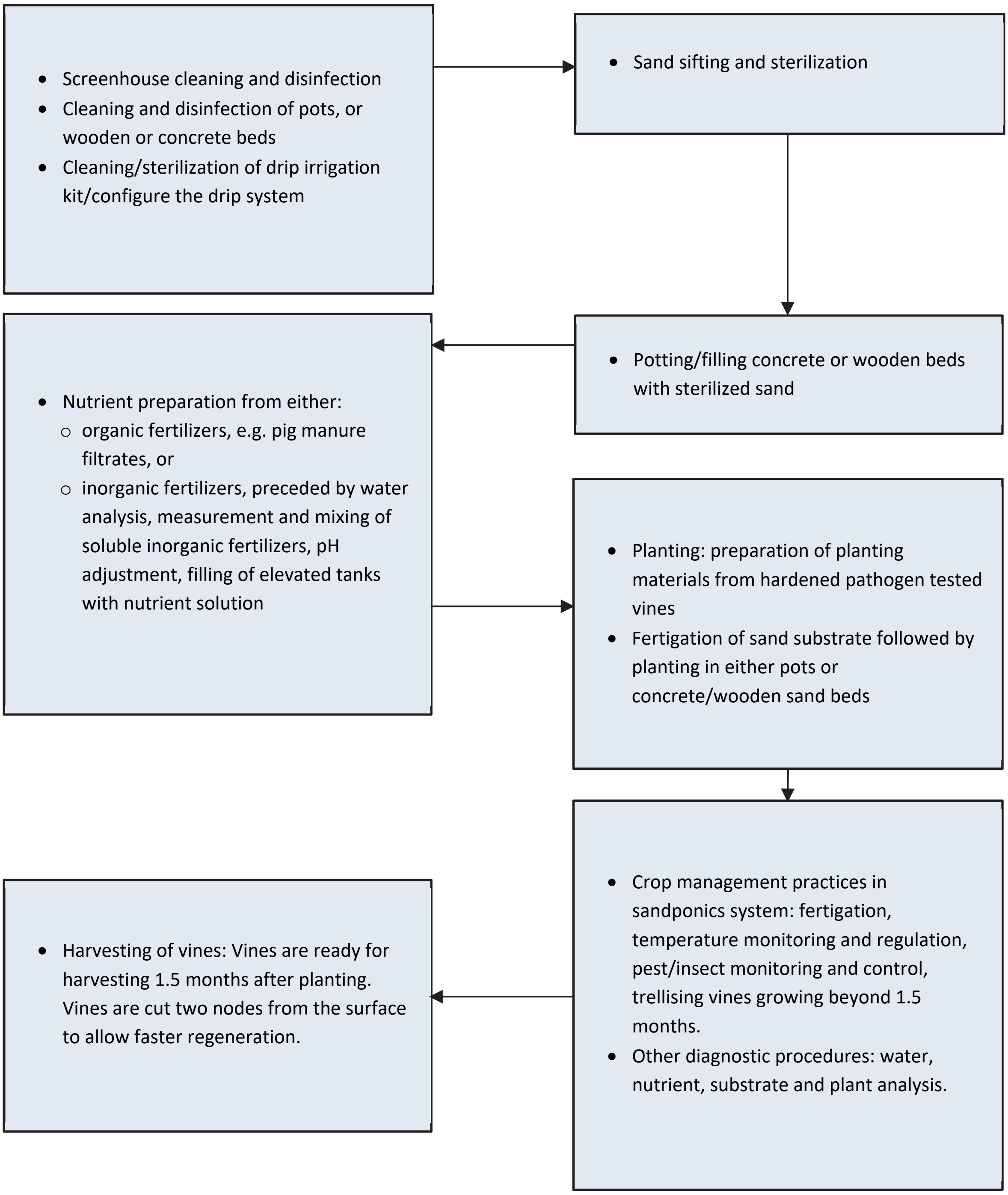

Figure 9. Schematic flow of activities during vine multiplication in sandponics system

Pots, crates, concrete/wooden beds and plastic bags of different sizes can be used to accommodate sand substrate for planting vines. Black plastic bags are, however, the cheapest option. Plastic or wooden crates lined with plastic can also be used. In our study, we used 3-liter pots perforated at the base. A plastic tray is placed under each pot. The tray is useful to avoid contamination from the surface the pot stands on and also serves as an indicator when sufficient nutrient solution is supplied during fertigation; when the nutrient solution starts dripping through onto the tray, the valves should be turned off.

3.1 Use of concrete and wooden sand beds

If sand beds are to be used, the size and design of beds should be estimated based on the size of the screenhouse. Wood is usually available in most places (Figure 10), but other materials can also be used. If wood is used, then a plastic liner is needed.

Figure 10. Wooden sand beds for vine multiplication in sandponics system

Concrete beds (Figure 11) used for conventional soil substrate method seed production can also be converted to sandponics system. For such structures, plastic lining is not needed. The length of the bed will depend on the size of the screenhouse, but the width should be 90 cm wide for easy agronomic management practices. The size of the beds should optimize the available screenhouse space, but enough space must be allowed for servicing the boxes using a wheelbarrow, for example filling the boxes with sand. Walking paths of 65 cm wide are suitable. Wet sand is heavy, so we must consider lateral reinforcements and supporting bricks. A drainage pipe should be included at one of the bottom corners of each box. For this, a one unit rise for every two units across will allow excess water or nutrient solution to drain properly. This drainage is especially important when we want to recycle our sand after harvest. The pipes connected to the drainage should connect to a common sewage system or to an adequate soak away pit.

Figure 11. Vine multiplication using sandponics system on concrete beds

4. Nutrient media for sweetpotato vine multiplication in sandponics system

Nutrient media for sweetpotato vine multiplication can be formulated from organic or inorganic fertilizers.

4.1 Organic fertilizers

Research in Zambia has shown that in areas where soluble inorganic fertilizers are not readily available, filtrates of pig manure sourced from commercial piggeries can also be used as nutrient source for sweetpotato pre-basic seed multiplication. Five gunny bags, each containing 50 kg of fresh pig manure, are soaked in 8,000 liters of water in an uncovered tank (Figure 12). The bags are churned every four days to facilitate dissolving of the soluble nutrients in the pig manure (Figure 13). When the color of the water turns dark green, usually after seven days of soaking, the pig manure filtrate is ready. It is then diluted with water by 50% (equal parts filtrate and water) for application to the vines using two overhead tanks of 1000 liter capacity each. In Zambia, each 50 kg bag of pig manure costs Zambian Kwacha (ZMK) 20 (USD 1.7) and 8,000 liters of pig manure filtrate can be used to provide nutrients for a sandponic system with 320 pots for 1 month.

Figure 12. Uncovered tank for soaking pig manure

Figure 13. Churning gunny bags of pig manure to facilitate dissolving of the soluble nutrients

A limitation with pig manure filtrates is the variation in the soluble nutrients in the pig manure, which can lead to nutrient deficiencies that occasionally can be observed on the vines. Transferring the filtrate from the soaking tank to the elevated nutrient tank by use of buckets and human labor is laborious and use of a water pump is recommended.

4.2 Inorganic fertilizers

Research conducted in Kenya determined the best combination of nutrient sources to employ in pre-basic seed production using sandponics system. Table 2 lists the macro-nutrients to be purchased and Table 3 provides details of the recommended nutrient solution.

Table 2. Inorganic salts and minerals for sweetpotato pre-basic seed production in sandponics system

Salt/fertilizer*	Formulae	Molecular weight	Nutrient supplied	Concentration (%)
Calcium nitrate	$Ca(NO_3)_2 . 4H_2O$	236	Ca, N	19, 15.5
Magnesium nitrate	$Mg(NO_3)_2 . 6H_2O$	256	N	10
Triple super phosphate	$Ca(H_2PO_4). H_2O$	252	P	20
Magnesium sulfate	$MgSO_4.H_2O$		S	26
Microsol B			B	2.5

***Supplier in Kenya:** Amiran Kenya Ltd. Ca is calcium; N is nitrogen; P is phosphorus, S is sulfur, B is boron.

Table 3. Nutrient solution used for sandponics system sweetpotato pre-basic seed production

Nutrient	Concentration*
Calcium	200 ppm
Nitrogen	200 ppm
Phosphorus	60 ppm
Sulfur	120 ppm
Boron	0.3 ppm

*Recommendations based on Makokha et al., 2018

4.2.1 Calculating nutrient concentrations from inorganic fertilizers

In this manual, the concentration of nutrients is expressed in parts per million (ppm). It is important to know the molecular weights of nutrient sources and the percentage concentrations of the nutrients. To calculate the optimal rates of nutrients, apply the formula below:

Concentration (ppm) = solute mass in milligrams (mg)/volume in liters.

For example, to determine 200 ppm of calcium in 250 liters of water:

Calcium (Ca) nitrate (15.5% N, 19% Ca) fertilizer is the source of Ca. To get 200 ppm of Ca in 250 liters of water, you will need to dissolve a certain amount of calcium in 250 liters of water, therefore;

200 ppm Ca = *x* mg of Ca/250 liters of water;

***x* mg of Ca = 200 ppm Ca × 250 L of water = 50,000 mg of Ca = 50 g of Ca**

So, when 50 g of Ca is dissolved in 250 liters of water, it gives 200 ppm of Ca.

But Ca does not exist as a single element. It exists as a compound, in our case hydrated calcium nitrate ($Ca(NO_3)_2 . 4H_2O$) is the source of Ca, which contains 15.5% N and 19% Ca. We, therefore, need to calculate the amount of hydrated calcium nitrate containing 50 g of Ca:

Thus (19/100) × *x* g of $Ca(NO_3)_2 . 4H_2O$ = 50 g of Ca = 263. 2 g of $Ca(NO_3)_2 . 4H_2O$;

This means that 263.2 g of $Ca(NO_3)_2 . 4H_2O$ (15.5% N, 19% Ca) contains 50 g of Ca. When dissolved in 250 liters of water, the resulting solution contains 200 ppm of Ca.

To be more accurate, a water analysis report will help to adjust nutrients and precisely prepare optimal concentrations. The example which follows shows how to prepare a nutrient solution using the results of water analysis obtained from KEPHIS, Muguga, Kenya (Table 4).

Table 4. Water composition and adjustment of nutrient solution for sweetpotato pre-basic seed multiplication using sandponics system at KEPHIS-PQBS, Muguga, Kenya (2018–2019).

	N	P	Ca	S	B
Water composition	0.91	0.059	4.29	1.86	<0.01
Recommended concentrations	200	60	200	120	0.3
Adjusted concentrations to account for nutrients in the water	199.1	59.9	195.71	118.1	0.3

4.2.2 Nutrient preparation from inorganic fertilizers

To prepare a nutrient solution for 250 liters, refer to Table 5 and the steps outlined.

Table 5. Nutrients required for a 250-liter solution for sweetpotato pre-basic seed production using sandponics system

Nutrient	Nutrient source	Concentration (ppm)	g/liter	g/250 liters	Calculations
Calcium	Calcium nitrate $Ca(NO_3)_2 . 4H_2O$ (15.5% N, 19% Ca)	200	1.03	257.5	200 ppm Ca less 4.29 ppm supplied by water = 200 – 4.29 = 195.71 ppm 257.5 g of $Ca(NO_3)_2$ which also comes with 159.7 ppm of N leaving N still needed = 200 – 159.7 = 40.3 ppm
Nitrogen	Magnesium nitrate $Mg(NO_3)_2 . 6H_2O$ (10% N, 10% Mg)	200	0.4	100	40.3 ppm less 0.91 donated by water = 39.4 ppm of N = 100 g $Mg(NO_3)_2$
Phosphorus	TSP (46% P_2O_5)	60	0.3	75	60 ppm of P less 0.059 ppm donated by water = 60 – 0.059 = 59.94 ppm = 75 g of TSP
Sulfur	$MgSO_4 . 7H_2O$ (98.7% MgSO4)	120	0.45	112.5	120 ppm less 1.86 ppm donated by water = 120 – 1.86 = 118.14 = 112.5 g of $MgSO_4$
Microsol B	(2.5% B)	0.3	0.012	3	0.3 ppm = 3 g of Microsol B

* Adjust the pH using 0.1 M phosphoric acid

Preparation procedure:

1. Weigh 75 g of triple superphosphate (TSP) granules, place in a 50-mesh insect-proof net and then soak in a bucket of one liter of warm water overnight (it takes time to dissolve). The following day squeeze net until all granules disappear.
2. In another bucket containing 10 liters of water, dissolve the following fertilizers, one at time:

Calcium nitrate	257.7 g
Magnesium nitrate	100.0 g
Magnesium sulfate	112.5 g
Microsol B	3.0 g

3. Mix contents of both buckets and adjust the final volume to 250 liters of water in an elevated tank connected to the drip kit.
4. Adjust the pH to 5.7 by pH meter (for example the HI98107 pH meter, Hanna Instruments Ltd, UK) and 0.1 M phosphoric acid.
5. Measure the EC using an electrical conductivity meter. It should not exceed one mS/cm. If the EC exceeds one mS/cm, add some water to bring it down.

5. Screenhouse cleaning, disinfection and potting

5.1 Cleaning

Cleaning the screenhouse at the end of a cropping cycle is part of a good integrated pest management program. Growers can use low-cost ways to get rid of current pests and disease issues and to prevent carry over into the new cycle. Success requires a combination of removal of the previous crop, cleaning up, disinfection, screenhouse preparation, and sanitation procedures.

Prior to crop removal, the grower should do an assessment of the current insect and disease problems in the crop. If diseases or insects are present, a control program should be implemented prior to crop removal to try to eliminate them to reduce the risk of spread later when removing the crop debris.

The irrigation kit should be turned off to dry out the planting material. The grower should remove the crop debris from the screenhouse and bury the debris at least 30 cm deep in hole located at least 10 m away from the screenhouse. Avoid placing crop debris near the screenhouse as this provide excellent opportunities for insects and diseases to move back into the screenhouse. Care should be taken to remove all plant materials from the screenhouse, paying extra attention to debris such as vines and leaves on wires, screens and pipes.

An insecticide treatment should be applied to control insects currently in the screenhouse. Use fogging equipment to achieve the best results as the smoke will reach all the crevices and corners. Increase the temperature to at least 20^{o}C and close all doors to seal off the screenhouse during this process to achieve maximum results. Put up sticky traps in the screenhouse after completing the insecticide treatment to monitor whether all insects have been eliminated and to detect any new insect occurrences.

After removing the previous crop, clean the irrigation lines by flushing with fresh water, then with either nitric or phosphoric acid at a pH of 1.6–1.7 (70% acid mixed at a ratio of 1:50 with water) for 24 hours. This will get rid of any mineral precipitates in the lines. Next, rinse with fresh water to flush the acid from the lines. Soak nozzles in acid solution to dissolve any mineral precipitates and rinse well with fresh water. Wash the entire structure with a food-safe detergent solution to remove oily residues from the screenhouse and covering materials. Remember to also wash down the head house floors and walkways.

5.2 Disinfection

Flush your lines and tanks with disinfectant using either 10% bleach or hydrogen peroxide at a rate of 1000–3000 ppm, then flush with fresh water. Disinfect the drippers and nozzles with 10% bleach overnight and rinse with water. The grower should give the screenhouse time to dry between washing and sanitation to avoid any chemical reactions between the disinfectants and the detergent. The operator should ensure adequate ventilation during product application. The head house and all walkways should also be disinfected at the same time as the screenhouse is sanitized. Pots, trays, tools and equipment should all be disinfected after being cleaned.

5.3 Potting

Pots should be sterilized by soaking in 10% bleach for 10 minutes, rinsed three to four times with tap water and allowed to dry. The sterilized pots (Figure 14) should each be filled with 5.5 kg of sterilized sand and each placed on a plastic tray along the drip lines.

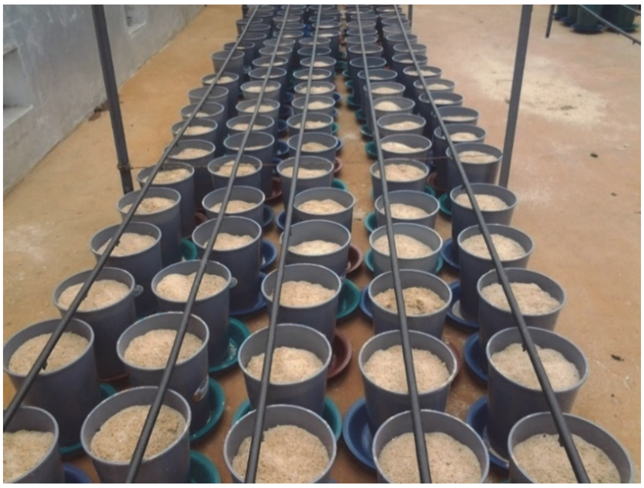

Figure 14. Pots filled with sterilized sand

6. Preparation of planting materials and planting

Sweetpotato is propagated from vine cuttings. The cuttings are selected from disease-free and true to type tissue cultured plantlets that have been hardened in the screenhouse. The ideal cuttings should have three nodes (Figure 15), i.e. bumps where leaves appear. Cuttings should be taken from vines that are old enough (at least 6 weeks) to provide material without causing excessive damage. Stems that have an equal amount of carbohydrates and nitrogen should be selected; this is assessed by bending vines where you would have cut. Vines are ideal if they bend into a 'V'. If they snap, then the cuttings are too woody, while if they bend into a 'U' then they are immature.

Note: *Sterilize everything that is going to be used in the preparation and harvesting of planting material, including secateurs, by flaming and dipping in 10% chlorine bleach or 70% ethanol; then rinsing with distilled water. Dry them with paper towels. Surface sterilize hands between samples using 70% ethanol.*

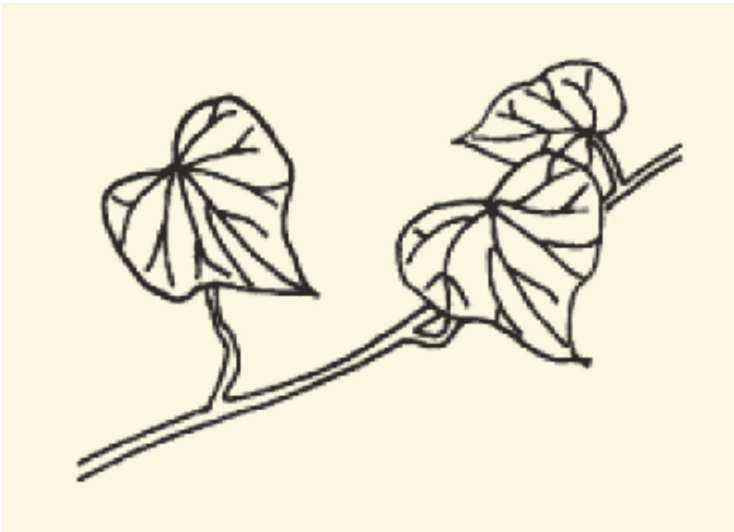

Figure 15. Preparation of cuttings for planting (a three node cutting constitutes a unit of planting material).

Source: *Stathers et al., 2013.*

6.1 Planting vines in sandponics system

Fertigate the pots by turning on the drip kit valves one hour before planting. This ensures adequate percolation of nutrient solution into the sand substrate and avoids exposing cuttings to moisture stress. Remove all leaves from the cuttings and insert 10 per pot. Two nodes should be buried under the sand with one node left above the surface (Figure 16).

Figure 16. A newly planted crop (A) and (B) vines growing in pots on sand substrate

7. Crop management practices

7.1 Fertigation of vines

Fertigation of vines is done by use of drippers. An elevated tank containing nutrient solution and connected to each bed in the screenhouse allows the distribution of nutrients by gravity through surface pipes and drippers, as described in sections 2.2, 2.3 and 2.4. Normal drip lines can be used, although pressure compensated drip lines are preferred since they allow even distribution of nutrients in all the pots. If a drip irrigation kit cannot be afforded, a watering can be used to fertigate the vines. However, using a watering can is time consuming and some nutrients go to waste. Vines should be fertigated until nutrient solution leaks out on the trays under the pots. The grower can install a tensiometer (Irrometer is a popular brand) in one of the pots to monitor moisture content and schedule suitable fertigation frequency (Figure 17). Here we used the tensiometer SR 12'' model (Irrometer Company Inc., CA, USA). The tensiometer will increase precision as to when to fertigate the vines. Alternatively, the grower should observe vines and fertigate when vines exhibit the first signs of wilting. Irrigation using tap water should be done after every two fertigations to avoid accumulation of salts that injure vines. (Note that to do this the nutrient solution should be emptied from tanks, filled up with tap water and vines irrigated until water adequately starts seeping below the pots.)

Figure 17. Installed tensiometer

7.2 Temperature management

The optimum temperatures range for sweetpotato vine growth ranges from 22 ^{0}C to 30 ^{0}C, although they can tolerate temperatures as low as 18 ^{0}C and as high as 35 ^{0}C. In places where electricity is accessible, the structure can be installed with automated heat controllers, sensors, and cooling air extractor fans to maintain an optimal temperature range around 26±4 ^{o}C. HOBO™ data loggers can also be installed to monitor temperature and help in trouble shooting anomalies in temperature variations. Alternatively, if the grower is not able to install the heat controllers and air extract fans, rolled plastic drapes can be attached at each side of the screenhouse. These can be rolled down during cold weather conditions and rolled up when temperatures rise.

7.3 Insect and pest management

Insects are vectors for sweetpotato viral disease transmission. The screenhouse for pre-basic sweetpotato vine multiplication should always be insect free. Insect proof all places of potential entry, including windows, doors, and walls, and regularly check for insects and mites. Hanging sticky insect traps in the screenhouse (the yellow strips in Figure 18) helps to control and detect presence of insects. Spray fortnightly with an insecticide taking care to choose products that are effective and alternate between different products in the spraying program to prevent resistance buildup. Moreover, occasionally flood the surface of the screenhouse with water to kill pests.

Figure 18. Hanging yellow sticky traps in screenhouse

7.4 Trellising

Vines should be supported to grow upwards using sisal twine. Trellising (Figure 19) increases vine yields, resulting in more material for sale by the grower. During the dry season, when root production activities are limited, demand for vines will be low. However, more vines will be available at the onset of rains due to trellising, which is an advantage to the grower.

Figure 19. A trellised crop in sandponics system

7.5 Harvesting of vines in sandponics system.

Vines should be harvested 6 weeks after planting (Figure 20) when the grower is practicing ratoon[2] (crop cycle) harvesting, or later if trellising. Harvesting should be done early in the morning or late in the afternoon to avoid excessive evaporation, wilting, and transplanting shock. During harvesting, start from the tip of the vines, cutting portions of 20 to 30 cm (at least 3 nodes) long. The operator should avoid cutting vines right down to ground level: leave about 15 cm (at least two nodes) at the base of the plant to ensure faster regeneration. The cut vines should be left in the shade for at least 2 hours (Figure 21) before packing to make them floppy (wilt) and occupy less space during transportation.

Figure 20. Harvesting of vines in sandponics system

Figure 21. Harvested vines

[2] Ratooning is the process of making several sequential vine cuttings. Usually after cutting the vines, the vines will re-grow, particularly if they have been fertilized.

8. Other crop management practices

8.1 Diagnostic testing procedures in sandponics system

The grower should get into the habit of routinely sampling and having tested the water source, nutrient solution, sand substrate, and crop. Interpretations and recommendations based on assay results are designed to assist the grower to avoid crop losses and reduced yields (Jones, 1983).

8.1.1 Water analysis

Water that is available for making a nutrient solution or for irrigation may not be of sufficient quality (i.e. free from inorganic as well as organic substances) to be suitable for use. The only way to determine what is in the water is to have it assayed. Knowing what is in the water will determine whether it is acceptable with or without treatment and whether adjustments are required to compensate for constituents that are present (Table 4). If a sample is to be collected for a laboratory analysis, it is best to contact the laboratory beforehand to obtain their recommended sampling procedure.

8.1.2 Nutrient solution analysis

Errors in the preparation of nutrient solution are not uncommon. Hence, do remember to check on the final nutrient concentrations prior to use by taking a sample of the prepared nutrient solution for lab analysis. To cut down costs incurred on analysis, large quantities of nutrient solution should be prepared and can be stored in extra tanks to be loaded later in the elevated tanks at appropriate time. Knowing the nutrient composition of the nutrient solution allows for adjustments to be made to compensate for the 'crop effect', not only for the current crop stand but for the future ratoon crop as well. Nutrient analysis prior to use increases precision of nutrient supply to ensure good crop growth and optimal vine yields.

8.1.3 Nutrient analysis of the growth medium

Nutrient analysis of plant growth medium is an important part of the total evaluation of the nutrient status of the medium-crop system. When coupled with a plant analysis, it allows the grower to determine what nutrient stresses exist and how best to bring them under control. A comprehensive laboratory analysis is more valuable as a means of pinpointing possible nutrient problems than just a determination of the EC. Composite samples of the growth media should be randomly sampled from pots/benches or troughs and taken in the lab for a complete nutrient analysis. A test of the sand substrate measures the accumulation of salts that will significantly affect the nutrient composition of the nutrient solution being fertigated. By knowing what is accumulating in the growth medium, it becomes possible to alter the nutrient solution composition, with the idea of reducing the rate of salt accumulation while partially utilizing those elements already present in the medium.

8.1.4 Plant analysis

The objective of a plant or leaf analysis is to monitor the nutrient content of the plant to ensure that all the essential elements are being supplied in sufficient quantity to satisfy the crop requirement, as well as to avoid imbalances and excesses. Growers can use visual observation to detect for nutrient deficiencies and excesses in growing vines (Figures 22 and 23). Table 6 shows nutrient deficiency symptoms for the five most important elements that support sweetpotato vine growth. However, many symptoms of nutrient stress are quite similar and can fool even the best-trained grower or advisor. In addition, some stress conditions can be due to the relationship between or among the elements; this may require more than just a minor change in the nutrient solution formula to correct them. For optimal vine yields, the grower should develop a routine of sampling and analysis a week before harvesting (5 weeks after planting). A grower faced with a suspected essential element deficiency or imbalance should verify the suspected insufficiency by means of plant (leaf) analysis. Without a specific test result, a change could be made which would only further aggravate the problem. The seventh to ninth open leaf blades from the shoot tip should be sampled from randomly selected vines to form a composite sample for laboratory analysis.

Figure 22. Vines affected by excess nitrogen

Figure 23. Sulfur deficient vines

Table 6. Optimized nutrient media for multiplying sweetpotato vines in the sandponics system

Element	Optimal application rate (ppm)	Source	Nutrient deficiency symptoms
Nitrogen	200	Calcium nitrate, Magnesium nitrate	Stunted vines with minimal expansion of leaf area. Reddening of basal leaf edges advancing to younger leaves.
Phosphorus	60	Calcium triple phosphate	Yellowing of older leaves spreading from discrete interveinal patches affecting half of the blades.
Calcium	200	Calcium nitrate	Chlorosis, curling, cupping and distortion of younger growing apical leaves. Vines exhibit detrimental effects of root rot.
Sulfur	120	Magnesium sulfate	Yellowing of middle growing leaves succeeded with entire yellowing of the whole plant.
Boron	0.3	Microsol B	Chlorosis in the apical leaves spreading to the basal foliage in the later stages of growth. Necrosis in the symptomatic leaves at advanced stage of vine growth, death of severely affected leaves, apical buds, eventually leading to premature vine senescence.

Source: Makokha et al. (2018)

9. Economic benefits of using sandponics system

Use of sandponics system has many benefits and is a cost-effective technology. Research conducted by International Potato Center between January 2018 and March 2019 shows a 22% higher vine multiplication rate for sandponics system compared to the conventional soil substrate method of vine propagation. Table 7 compares the number of pre-basic vines produced under the sandponics system compared to the conventional soil substrate method of vine propagation.

Table 7: Comparison of sweetpotato pre-basic vine production under sandponics system and conventional soil substrate method over six harvests at KEPHIS-PQBS, Muguga, Kenya (2018–2019).

Days after planting	Vine multiplication rate		t	p
	Sandponics system	Conventional soil substrate method		
42	27.6±1.2	28.3±1.3	-0.8	0.4
84	28.2±1.6	20.7±1.2	7.5	<.0001
126	35.9±2.4	25.7±1.7	6.9	<.0001
168	34.8±2.6	22.4±1.8	7.8	<.0001
210	36.3±3.1	31.6±2.3	2.4	0.02
252	41.4±3.3	35.1±2.4	3.1	0.002
Average	**34.0±1.1**	**27.3±0.9**	**9.6**	**<.0001**

Source: Makokha et al. (2019a)

The cost of producing one sweetpotato node in sandponics system was on average KES 0.9 lower compared to the conventional soil substrate method, although cost varies between varieties (Table 8). In addition, the cost of sand (KES 3.5 per kg in Kenya) is significantly cheaper than the cost of soil (KES 20 per kg).

Also, evidence indicates that planting material multiplied by the sandponics system go on to have higher yields of storage roots than vines multiplied using conventional soil substrate method, when grown in the open field. Table 9 shows that storage root yield of the same varieties produced using vines from sandponics system was 23.8% higher compared to storage roots produced from vines generated by the conventional soil substrate method.

Table 8. Average cost (KES) of producing one sweetpotato node in sandponics system compared to the conventional soil substrate method for four sweetpotato varieties for a trial conducted at KEPHIS – PQBS, Muguga, Kenya (2018–2019).

Variety	Sandponics system	Conventional soil substrate method	Positive saving
Ejumula	3.3	4.5	1.2
Kabode	3.9	5.0	1.1
Irene	2.4	3.1	0.7
Gweri	4.4	5.0	0.6
Overall (all 4 genotypes)	3.5	4.4	0.9

Exchange rate 1 USD = KES 100 for the year 2019

Source: Makokha et al. (2019a)

Table 9. Means for vine survival, storage root yield, number of storage roots, foliage weight and root dry matter content for sweetpotato pre-basic seed sourced from sandponics system and conventional soil substrate method for a trial conducted at Kenya Agricultural and Livestock Research Organization, Kiboko, Kenya (2018).

Vine multiplication system	Vine survival (%)	Storage root yield (tha^{-1})	N°. of storage roots/plant	Fresh foliage yield (tha^{-1})	Storage root dry matter content (%)
Sandponics system	98.4^{a}	33.4^{a}	3.4^{a}	16.8^{a}	26.8^{b}
Conventional soil substrate method (soil)	94.3^{b}	26.3^{b}	2.6^{b}	13.2^{b}	27.3^{a}
p value	0.003	0.004	<.0001	0.01	0.03
LSD (5%)	2.7	4.6	0.3	2.7	0.5

Different letters within the same column denote significant difference at $p \leq 0.05$

Source: Makokha et al. (2019b)

10. Limitations of using sandponics system for sweetpotato vine multiplication

There are four major drawbacks to using the sandponics system. These are:

1) Personnel need specialized training.
2) Since it is a new technology, many factors are still not fully understood, and must be answered through further research
3) In many locations in sub-Saharan Africa, soluble inorganic fertilizers are not readily available.
4) Sweetpotato performs well in warm environments. In cooler locations, having to use expensive heating equipment will significantly increase production costs.

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