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Yams for Livelihoods

Manual for Clean Foundation Seed Yam Production using Aeroponics System

Maroya Norbert, Morufat Balogun, Beatrice Aighewi, Jimoh Lasisi, and Robert Asiedu

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Cover photo: Dr Norbert Maroya showing top seed companies in Nigeria the aeroponic system for basic seed yam production at IITA, Ibadan, Nigeria.

Contents

Figures

Appendix

Abbreviations and Acronyms

ASH	Adapted screenhouse for aeroponics
BIP	Business incubation platform
TIBS	Temporary Immersion Bioreactor System

Acknowledgement

The authors would like to thank the IITA staff working at the Farm Management Services for their assistance in the construction and the day-to-day maintenance of the aeroponics screenhouse and power house. We are particularly grateful to Engineer Bamidele Buraimoh and Martins Akeredolu for their significant contributions in the construction of the aeroponics system and the installation of the solar power facility. We are also grateful to Mr Igbaifua Wilson and his team for their assistance in the building of the double-ceiling screenhouse to reduce heat.

Importance of planting materials in yam production in West Africa

Yam (*Dioscorea* spp.) plays a very important role in the food security and livelihood systems of at least 90 million people in West Africa. It is cultivated mostly in the Derived and Southern Guinea Savanna. It is traditionally propagated by tuber, the edible part, with very low multiplication rate (less than 1:10 compared to 1:200 in some cereals). The major priority problem with seed yam is the competition between seed and food uses as the tuber can be used for both. The non-availability and high cost of clean seed yam are the most critical constraints to increasing yam production and productivity in West Africa (Nweke *et al.,* 2011).

Yam production and its values

Across the region, seed yam availability is insufficient to meet demand; this, limiting productivity and entry of new producers. The scarcity and high cost of clean (healthy) seed yam planting material is currently recognized as one, if not the single most critical constraint to increasing yam production and productivity in West Africa (Akoroda, 2010; MEDA, 2011). FAOSTAT data on production ranked cassava as the first crop with up to 41 and 15 million tons annually produced respectively in Nigeria and Ghana. However, in terms of production value (income to farmers) yam is far ahead of all the other five key food commodities (maize, rice, cassava, sorghum, and millet). In fact, the production value of cassava, maize, sorghum, millet, and rice represent 50%, 18%, 18%, 13%, and 11%, respectively of the yam, in Nigeria.

Seed yams are expensive (Ironkwe 2005), accounting sometimes for as much as 63 % of total variable production cost. The low rate of multiplication and alternative use of the tubers as food makes seed yam very expensive. The tubers are also bulky to transport (Manyong *et al.* 2001; Agbaje *et al.,* 2005), and the problem of low multiplication rate is worsened by the extended growth cycle and dormancy period. Hence, yam production revolves quite repeatedly around the use of mixed genotypes, pre-infected seed yam and farmlands, causing a build-up of an array of fungal, bacterial and viral diseases, and pests (Balogun *et al.* 2014; Winch *et al.* 1984) leading to 50 to 90% yield reduction. Consequently, there is significant demand for clean seeds in a market-driven seed system and 50–70% of production costs are spent on purchase of seed yam (Agbaje and Oyegbami 2005; Coyne *et al.* 2010).

Current seed yam propagation methods

Traditionally, the production of seed yam as an integral part of ware yam production is widely practiced throughout the yam belts of Nigeria and Ghana. The practices can be placed into two distinct subgroups, namely sorting and "milking". At harvest, the tubers are sorted by size (small, medium, and very large ones are retained as seed yam, table yam, and ceremonial yam, respectively).

In the "milking" technique (Okigbo and Ibe, 1973; Okoli *et al.,* 1982), tubers are harvested at about two-thirds of the time into the growing season without destroying the root system, providing early ware yam for consumption. The parent plant produces new small tubers before senescence, which are used as seed yam for the following season. The milking practice represents a significant investment by the farmer. First, there is a yield loss by harvesting the main tuber before senescence when maximum yield is attained (Onwueme 1977), followed by increased labour use from harvesting the same crop twice. These additional costs explain the very high cost of seed yam. Other methods of seed yam production include the minisett technique that was developed almost 30 years ago by NRCRI and IITA. This technique is well documented in a training manual Aighewi *et al.* 2014.

Building an aeroponics system (AS) for seed yam production 2

What is an aeroponics system?

An AS is a method of growing plants in a soilless environment with very little water. Its basic principle is to grow plants in a closed or semi-closed environment without the use of soil or an aggregate media by spraying the plant's roots with a nutrient rich solution (mist environment). This technique of growing plants without soil was first developed in the 1920s by botanists who used the original aeroponics to study plant root structure (Barker, 1922). The AS is composed of three main parts (screenhouse, boxes with their piping system, and the power house).

Figure 1. The aeroponics boxes planted with yam plantlets inside screenhouse showing feeding pipes.

The international union of soil-less culture defines aeroponics as "a system where roots are grown continuously or discontinuously in an environment saturated with fine drops of nutrient solution." In 2014, a working paper titled "Seed yam production in an AS: A novel technology" was developed Maroya *et al.,* 2014.

Carter (1942) was the first researcher to study air culture and described a method of growing plants in water vapor to facilitate examination of roots. Went (1957) named the air-growing process in spray culture as "aeroponics." Aeroponic is derived from the Latin words of 'aero' (air) and 'ponic' (work). In aeroponics, the plant's roots dangle mid-air with only the stems held in place. The way nutrients and water are delivered also demonstrates the efficiency of the system. Atomizing nozzles ensure the most effective delivery of nutrients since they turn the water into a fine mist. Plants absorb nutrients through their roots by osmosis; a selective absorption of compounds through cell walls. Roots can absorb nutrients more easily as they are delivered via the mist.

Figure 2. An inside view of the aeroponics box with yam plants growing and producing tubers.

The AS optimizes root aeration giving the plant stem and root systems access to 100% of the available oxygen in the air which promotes root growth

Construction of screenhouse adapted to the aeroponics system

One of the determinant factors to be considered before building an AS for yam is the availability or construction of a screenhouse of reasonable height and size. Any existing screenhouse can be used to establish the system, but the size of the boxes should be adapted to the dimensions of the entire AS. When starting from scratch, it is advisable to have a design that gives the specifications of the screenhouse and the power house (Figure 4) based on the desired capacity.

Figure 3. Picture showing young yam plants (left) and mature plants (right).

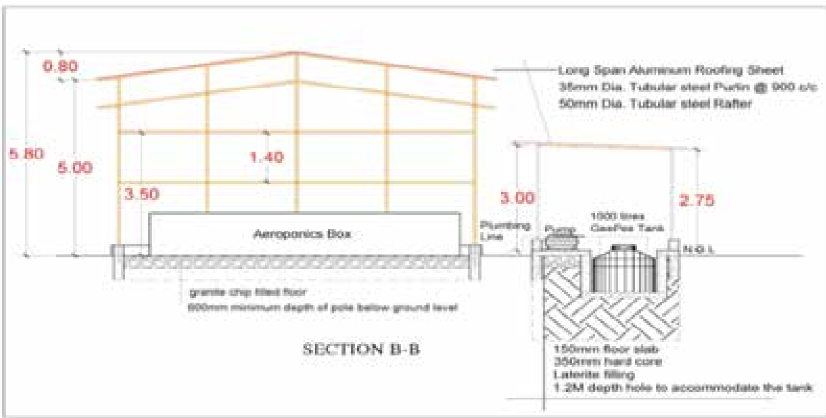

Figure 4. Design of the lateral section of the double ceiling screen house and the power house.

Figure 5. Screen house ground foundation work with the framing.

In West Africa, the height, length, and width of the screenhouse are important, especially for yam, to avoid the challenges of excessive heat within the structure and to accommodate the maximum number of boxes possible. The ideal situation is to build a screenhouse adapted to the number and size of the boxes planned for the AS. The Yam Improvement for Income and Food Security in West Africa (YIIFSWA) project YIIFSWA project is promoting the construction of a double-ceiling functional aeroponics screenhouse (Figures 5, 6 and 7) with the following dimensions: length = 24 m, width = 8 m; and height = up to 6 m; and with appropriate ground work for foundation, solid structure, anti-aphid net, and appropriate entrance foyer to the screenhouse.

Figure 6. Full establishment of the solid structure for a double ceilings screen house type.

Figure 7. Global view of completed aeroponics screen house with double ceilings.

Materials used for the construction of a double-ceiling functional aeroponics screenhouse are listed in Appendix 1.

Building of aeroponics boxes inside the screenhouse

After the construction or adaptation of the screenhouse, the most important structures to be built within are the boxes and their piping system.

YIIFSWA is promoting the AS of 10 boxes for research institutions (4.8 m x 1.2 m x 1 m) at 20 cm from the screenhouse gravelled ground floor to the bottom of the boxes. Each box is made of four tables of 1.2 m x 1.2 m with 49 plants per table. For business, the dimensions and the number of boxes can be increased only by reducing the alleyways. The items used to build the 10 boxes and the power house are detailed in appendix 2.

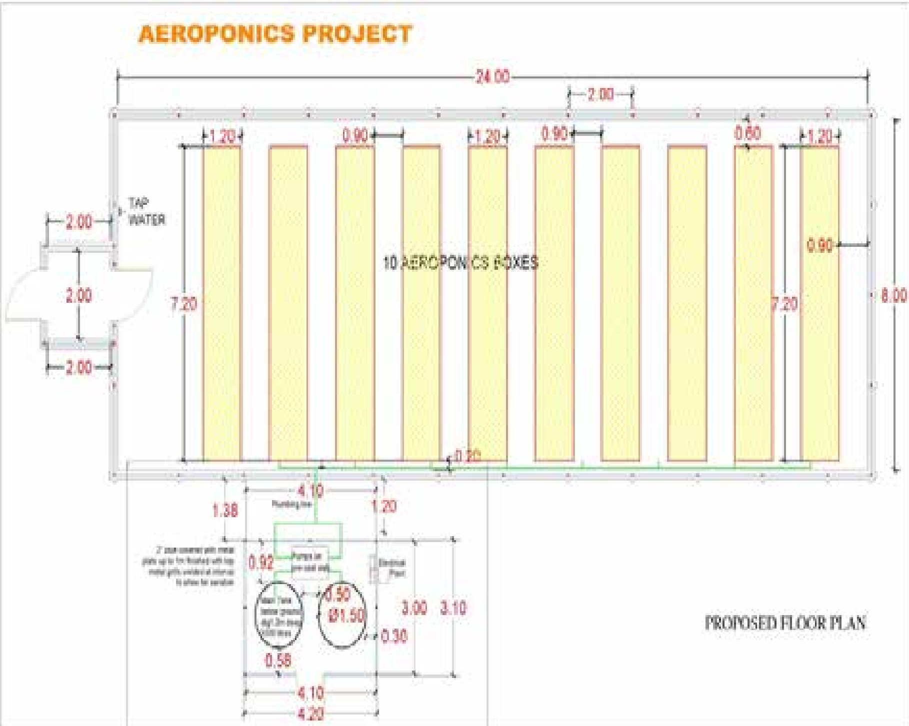

Figure 8. Schematic drawing view of AS boxes in screenhouse and the adjacent power house.

a. Dexion shelve stands

This is used for building the enclosure of the boxes. It is assembled and fastened together by the angle guide plate, bolts, and nuts after cutting into different required sizes for length, width, and height. In the absence of a Dexion shelf, a slotted angle iron is recommended.

Figure 9. Construction of the aeroponics boxes frames using Dexion shelve.

b. Styrofoam

Also known as polystyrene sheet, Styrofoam is a plastic from petroleum product. It is an insulating material that provides enclosure to isolate each box and provides mechanical support to the structure. Two types of Styrofoam are used for the AS. The one used for the body of the box has 35 or 30mm thickness while the top of the boxes are covered with Styrofoam of 50 mm thickness cut into pieces of 1.2 m X 1.2 m corresponding to the four tables per box as per figure 10A.

The Styrofoam is cut exactly in various sizes to fill the external parts of the frame of the boxes. Four root growth inspection windows, also used for tubers harvesting, are created at each lateral side of the boxes (lateral sides of each table). So each table has two windows making a total of eight windows per box Figure 10B.

Figure 10A. Aeroponics boxes with four tables and planting holes.

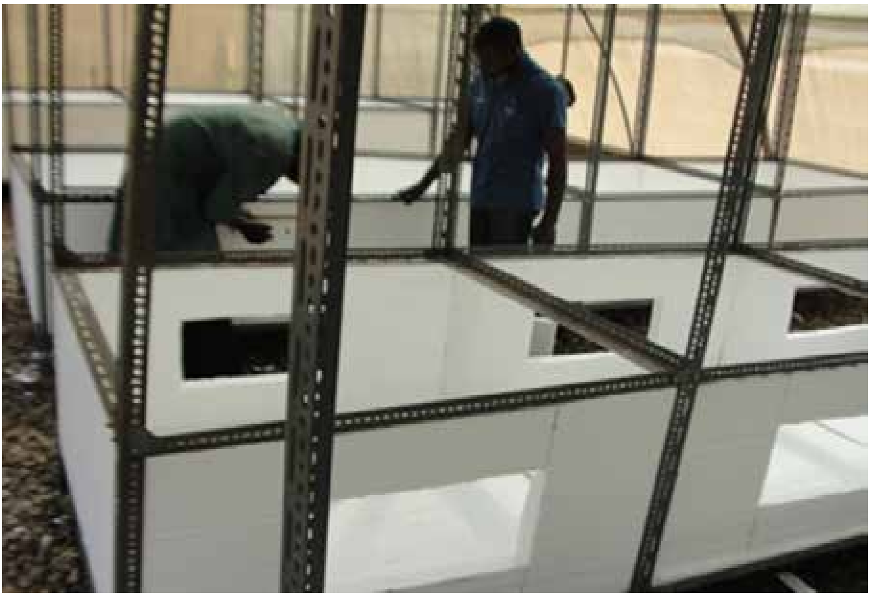

Figure 10B. Construction of the body and windows of aeroponics boxes using styrofoam.

Figure 11. Perforated box' covers that serve as the upper face of tables (left) and down face in right picture.

The top styrofoam sheets are perforated into the required number of holes (36 or 49) to accommodate the required plant density. Perforations at 20 cm x 20 cm will give 36 planting holes while at 17 cm x 17 cm will give 49 planting holes as per figure 11.

c. Plastic sheets

For the aeroponics boxes, three types of plastic sheets are used. This is also part of the protecting and filling material used in covering up the entire Styrofoam sheet within and outside the boxes.

The 500-micron black plastic sheet is used to cover the entire inside and outside of the boxes to avoid any admittance of sunlight into the rooting system of the plants and to avoid nutrient leakages.

The 200-micron white plastic sheet is used to cover the entire external top of the boxes to make it transparent and allow less heat concentration on the plant.

The 200-micron black plastic sheet is used to cover the entire internal top cover of all boxes and the inspection/harvesting window.

d. Piping network

Different sizes of pipes, valves, fittings, and plumbing accessories are used to connect all boxes to the power house. There are three categories of pipes for a functional and efficient AS.

Figure 12. Styrofoam fully covered with black plastic sheet outside the box (left) and inside (right).

- The medium size pipe (white in the figure 13) is used for pumping the nutrient solution from the underground tank for feeding the plantlets in the boxes of the aeroponic system.
- The larger size pipe (green in figure 13) is used to collect the nutrient solution back from boxes after use by the plants into the nutrient tank in the power house.
- The smallest pipe is the pressure pipe located centrally inside the length of each box (Figure 14) to hold the misters for feeding the plants.

Figure 13. Piping in the power house (left) and pipes for feeding the plantlets in the boxes (right).

e. Misters

The misters/sprayers are connected to the smallest pressure pipes, and create a fine mist of the nutrient solution in a hydro-atomized droplet size to deliver nutrients to the plant rooting system. The misters are positioned at equidistance in each box.

Figure 14. Picture of misters (left) and the central pipe with misters (right).

Construction of the power house

The powerhouse is the source of energy for running the AS and feeding plantlets throughout their growth and development. It is composed of:

- Two nutrient tanks of 1000 L each (capacity can vary 500 to 200 L);
- Two water pumps of one horse power each (power can also vary depending of the number of boxes to spray);
- Two filters attached to the pumps; and
- One electrical/electronic control panel.

The power house built and promoted by YIIFSWA measures 4.2 m (length) x 3.1 m (width) x 3m (height). Depending of the size of your screenhouse, the number and dimension of the boxes the power house dimensions can be modified to meet the specific requirement.

Figure 15. Left picture are tanks of 1000 l buried and right is the mason work of the power house.

Figure 16. Fully completed power house ajascent to the aeroponics screenhouse.

a. Nutrient tanks

The two tanks are installed below ground level so that the lower part of each box is above the upper portion of the tanks. This allows easy flow back of the nutrient into the tank through the returning line. The second reason why the tanks are placed underground is to maintain the nutrient solution at cool temperatures.

b. Water pump

Two one-horse water pumps are used to transfer the prepared nutrient solution from the tank through the feeding pressure pipe to the misters that do the spraying. One pump feeds the plants of the 10 boxes at a time for 15 minutes at 15 minutes intervals. This interval allows the nutrient solution to return to the tank for re-use. All the boxes are installed to slope towards the power house and the tanks so that the returning nutrient solution flows back into the tank by gravity.

c. Filters

Two filters are positioned and connected through the pressure pipes to filter the nutrient solution immediately after the water pump. The primary function of the filter is to trap any foreign particles within the nutrient tank and along the pipe line connections.

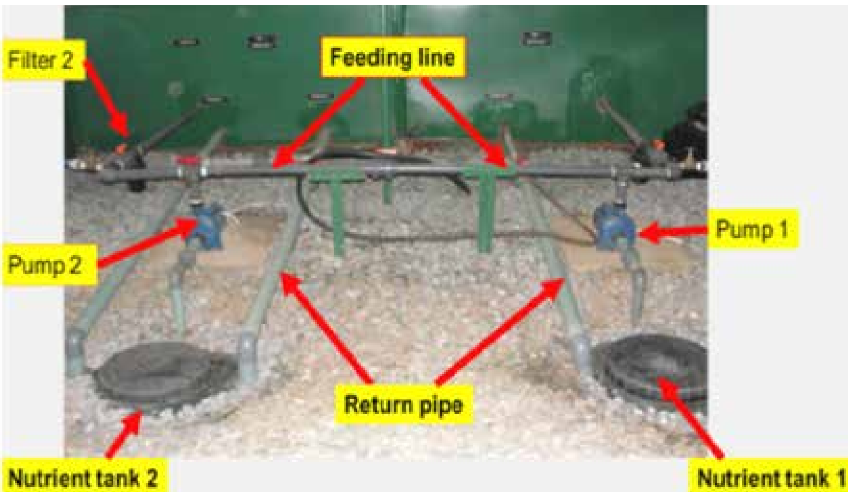

Figure 17. Equipment of feeding system inside the power house.

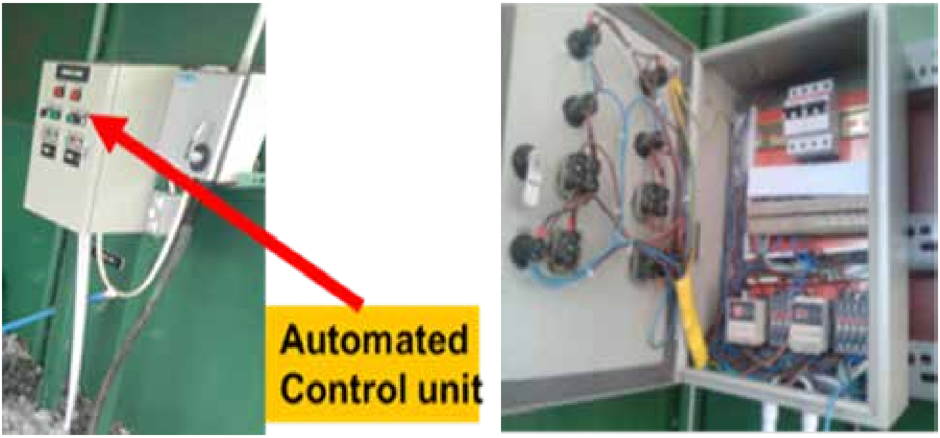

Figure 18. Automated control panel of the power house with the timers linked to the pumps.

d. Electrical control panel

The electrical control panel contains the contactors, circuit breakers, push buttons, and digital timers. It is used to automate the powering system of the AS depending on the setting of each of these elements, especially the timers.

As per the detailed descriptions above, the four types of skilled workers are needed to work together to build a functional AS: a welder, plumber, electrician, and carpenter.

Management of AS for seed yam planting materials production

3

The AS is an automated electricity-powered system. The system is established and set to run on its own for 24 hours a day and seven days a week. However, it needs daily control and checks both in the screenhouse and in the power house. Electricity may not be a challenge at IITA because of regular supply, but in locations where supply is irregular, alternative sources of supply are necessary.

Video reference
Aeroponics: growing yams in the Air (https://www.youtube.com/watch?v=lCwyPG1P9JY)

The management of the AS starts with preparation of the nutrient. After this, regular checks of level of nutrients in the tanks, is necessary as well as maintenance of hygienic conditions in the entire system. This is to ensure that adequate amounts of nutrient solution is being used by the plants and that the misters are not blocked by residues during nutrient recycling.

Preparation of the nutrient solution and quality control

Quality of water used for nutrient preparation

Water quality is a very important factor that should be taken into consideration when preparing the nutrient solution. The water should be analyzed before use in nutrient preparation. The initial pH of water before mixing in the nutrient is important as very low pH (acidic) will inversely affect the final pH of the nutrient solution. It is also advisable to know the chemical used to treat the water as it can affect the nutrient balance and availability to plants.

The quantity and type of water treatment chemical will be used to adjust the quantity and quality of nutrient solution preparation. The normal pH for portable drinking water is between 6.5 and 7.5 while low pH will suggest the presence of heavy metals. The mineral elements of water should also be taken into consideration before preparing the nutrient solution.

The colour, cleanliness or clarity of water is also important. If there is sand or dust sediment in the tap water, it is important to allow the water to run for some time (open tap for water to flow out). If this does not work, and there are no other options, fill containers with water, allow it to settle before carefully using the supernatant for analysis of the water and then prepare the nutrient solution

Type and quantity of fertilizers

The elements and quantities used to compound the nutrient solution are given in table 1.

Table 1. Type of fertilizers and dosage used in AS for seed yam production.

No	Type of Fertilizer designation	Nutrient	Quantity used	Volume of water
1	Ammonium Nitrate (NH_4NO_3)	N	272.7 g	800 L
2	Calcium Nitrate ($Ca(NO_3)_2 4H_2 0$)	N & Ca	193.5 g	
3	Potassium Sulphate (K_2SO4)	K & S	120.0 g	
4	Triple Super Phosphate	P	130.4 g	
5	Magnesium Sulphate ($MgSO_4$)	Mg & S	98.3 g	
6	Fe-EDTA	Fe	5g	
7	Boron	B	0.6g	
8	Mn EDTA	Mn	2.2	

The above elements are for preparation of the nutrient solution as follows:

a. Weighing of fertilizers:

During measurement/weighing of fertilizers, the scale must be placed on a flat surface and balanced figure 19. It should also be cleaned before and after every use and stored back into its container.

b. Bowls or containers for fertilizer measurement

The containers must be clean and washed after each use. When placed on the scale, the scale should be tarred at zero before any nutrient is poured inside the container. Ensure that there is no water in the container used for measurement. The container should be at the center of the scale and the spoon should not touch the container when pouring in the nutrient. The spoon must be cleaned after every chemical measurement.

c. Dissolving nutrient

Each nutrient component should be dissolved separately as combining chemicals could make them react and form crystals, salts or gas that are not desired causing some nutrient to be unavailable to the plant. A strainer should be used when pouring dissolved nutrient into the tank to avoid debris or insoluble particles from entering the tank. (Note: Wash strainer before and after each use.)

d. Storage of nutrients

It is advisable to stored nutrients in airtight containers in a cool dark place to avoid reactions. Ensure that the containers are closed properly, especially for the hygroscopic compounds.

e. Volume of nutrient

Only clean water from the tap should be used for dissolving nutrient and not an old or used nutrient solution. Once all nutrients have been dissolved, the solution can be filled up with water to reach the required volume. A 1000-L tank (figure 20) is filled with 800 L of water. Small quantity of the measured water is used to dissolve the fertilizers separately before it is poured into the tank.

Specific fertilizers are recommended for use in the AS because they easily release nutrients that can be captured by the plant rooting system as they hang in air. Many types of fertilizers have been tested in the AS at IITA-Ibadan.

Some fertilizers (i.e., triple super phosphate and potassium phosphate) are easily dissolved in hot water.. The pH should be recorded after preparation of the nutrient mix. This is important because it determines what nutrients will be available to plants. If the solution pH is above or below the recommended range (5.5–7.0), nutrients may not be soluble (absorbable by plants) or they may be so soluble that they become Phytotoxic (toxic to plant). Therefore, a plant may show signs of nutrient deficiency or toxicity even when the correct amount of fertilizer is applied to that plant. The different types of fertilizers and dosage used at IITA-Ibadan (treated water) are listed below.

Note: Ensure that monitoring of the contents of the tank is done regularly and is not disrupted by public holidays, and as much as possible have another tank of nutrients on stand-by.

Four different types of nutrient solutions in 500-L tanks were tested in four units (Figure 21) of single box AS using three yam varieties. Each tank was filled up to the 400 L mark. The nutrient composition included different quantities of minerals (i.e., N, P, K, Ca, S etc.).

The nutrient experiment results revealed varietal differences as in figures 22 and 23 in its suitability for optimal production of leaves, tubers, bulbils, and new branches, among others. In addition to the varietal difference, the type of planting materials used [two-node vine cuttings and Temporary Immersion Bioreactor System (TIBs) plantlets] influences the performance of the varieties. It is advisable to test different compositions of locally available fertilizers with the yam varieties and the type of planting materials to determine the most appropriate fertilizer composition.

Figure 19. Weighing of specific quantity of fertilier in respective container.

Figure 20. Power house showing an opened 1000-L tank with the nutrient pumping pipe.

Figure 21. Experimental power house for testing four different nutrient compositions.

Figure 22. Growth of yam on experimental boxes of four different nutrient compositions.

Figure 23. Different types of fertilizers used and their effect on plants per box.

Planting of aeroponics boxes

After fully setting up of the AS components, an effective test running of the system with water is done to assure full functionality. Ensure that the plantlets or vine cuttings are ready before preparation of the nutrient solution, which should be prepared before planting.

Sources of high quality plantlets for aeroponics

There are two types of planting materials used for the AS. These include: 1) the 2-node vine cuttings from hardened and potted bioreactor plants (Figure 24 left picture); and 2) hardened well-grown plantlets from TIBS (Figure 25). In case of shortage of planting materials, well-developed potted plants of single-node generated from plants of TIBs are also used. IITA is using the SETISTM type TIBS with twin flasks; the top flask contains the plantlets (50 to 150 plantlets) and the bottom flask contains the nutrient solution. The two containers are linked with inlets and outlets for airflow under pressure and allow intermittently feeding of the plantlets when they are immersed in nutrient solution at regular intervals.

TIBS plantlets should be handled with care when removing them from containers for hardening because they are fragile and could be easily injured. After three weeks in hardening, the plantlets can be planted in aeroponics tables. Spraying should be done carefully so that the root system is not exposed as this could make them prone to drying. Also, the plantlets or the two-node vine cuttings should be well developed and long enough to pass through the 50-mm thick Stylofoam on top of the table and have the roots or the lower node within the box exposed to the mist of the nutrient solution. Whatever the density used per box, one should plant one plantlet or two-node cutting per hole. After planting, lift the cover of the planted table and check (figure 25) to assure that the rooting system or the lower nodes are well exposed to the mist.

After planting, it is advisable to protect the newly planted box against heat or direct sunlight for at least the first two weeks. This is done by covering the top of the boxes with shading materials like reflective nylon as in figure 26 with. After this period, the rooting system of the two-node vine cuttings will be fully established and the TIBs plantlets would have produced new leaves (see figure 26).

Management of the power house

The power house is a very sensitive area of the aeroponics system and requires much attention to ensure that all works well. Any new equipment or material has to be installed or set up only by a specialist. The power

Figure 24. Two-node vine cuttings in AS at planting (Left) and two weeks later (Right).

Figure 25. Hardened well grown plantlets from TIBS planted in AS.

Figure 26. Newly planted AS with plantlets from TIBS and protected with reflective material.

house is the source of energy for feeding and survival of the plantlets in the boxes. The following activities are needed to be done every morning.

i. Checking of the level of the nutrient solution in tanks

If the level of the nutrient solution is below a quarter of the tank capacity, a new nutrient solution should be prepared. If the second tank is empty, it should be filled up with clean water (colourless, odourless water with pH around 6.8 – 7.2 and preferably 7.0).

Before preparing the new solution, the tank must be properly cleaned. Cleaning of the tank is usually done by two workers who are fully dressed in protected outfits. When the tank is to be washed, one person enters the tank to remove any remaining solution, while the other stays outside to provide assistance. The entire exercise should be done carefully to avoid the introduction of contaminants into the system.

If the level of the solution is around or above half of the tank, the pH of the solution, as well as the electro conductivity (EC), the total dissolved solubles (TDS), and the temperature of the solution should be measured. These are usually done three times a day (8:00 am, 1:00 pm, and 4:00 pm).

If the pH drops below 5.5, the solution should be changed or pH should be adjusted with potassium hydroxide (KOH) when the level of the solution is still high. If the volume is above half, one should be very careful about the composition of the nutrient solution. If the pH is dropping very fast without equivalent reduction in the volume of the nutrient solution, it is probably that the acidic fertilizers used as source of nitrogen (namely ammonium nitrate, ammonium phosphate, ammonium sulphate, etc.) is in excess. If this happens, consider a reduction of the ammonium components and replace if necessary with a nitrate source.

ii. Replacement of the nutrient solution

When replacing the nutrient solution, one should carefully observe sanitary rules and regulations. The first operation when replacing the solution is to discard the remaining nutrient and thoroughly wash the tank.

Three reasons why the nutrient must be changed.

- When the volume of nutrient solution remaining in the tank is too low and the pump is used continuously, it will pump air into the pipes. Hence when the volume becomes too low the solution should be discarded.
- When the pH has reduced to <5.5 or the electrical conductivity (EC) has increased to above 1,500μS discard the remaining nutrient solution. Do not prepare fresh nutrient while there is still leftover nutrient in the tank as the high concentration of the residual nutrient will affect the pH of the freshly-prepared nutrient. If the volume in the tank is above half and you are very sure that you still have enough nutrients in the solution then you can raise the pH of the nutrient solution to around 6.5 by adding potassium hydroxide (KOH) or potassium carbonate.
- The nutrient solution is muddy either due to the presence of plant debris from yam roots, rotten tubers, or dusts that have settled at the bottom of the tank. These will contaminate the nutrient solution.

Figure 27. Overall wear for cleaning the nutrient tank before renewal of feeding solution.

iii. Setting of the timer

There are two types of timers: the digital timer (the preferred type for the AS) and the manual timer with teeth each representing 15 minutes. When the tooth is pushed in, it is 'OFF' and when it is out, then it is 'ON' and the nutrients are spayed in the AS chamber. The manual or analogue timer used in one of the AS at IITA-Ibadan is set for two periods: 6:00 AM to 5:00 PM (15 minutes 'ON' and 15 minutes 'OFF') and 5:00 PM to 6:00 AM (15 minutes 'ON' and 30 or 45 minutes 'OFF'), depending of the period of the year. The digital timer is used in the solar powered AS located at the Business Incubation Platform (BIP) at IITA-Ibadan. With the digital timer there is no flexibility for automated day and night settings.

iv. Maintenance of filters

The filters should be checked and rinsed on Mondays. They should be washed and cleaned on Fridays to go through the weekend. However, after every harvest of tubers or when roots' debris settled down in the tank or in suspension in the nutrient solution, the filters need to be cleaned. One should ensure that the filters are rinsed or washed prior to any major holiday.

Any other maintenance work (i.e., pipe or box dripping, electrical challenge, etc.) will need intervention of specialized workers (plumber, electrician, welder, carpenter, etc.). It is very dangerous and hazardous for the aeroponics system technician to start manipulating the system to solve specialized worker problems. The filters should be checked and rinsed at set intervals. At IITA, they are checked and cleaned every Monday and Friday. However, after every harvest of tubers or when it is observed that debris from roots have settled at the bottom of the tank or suspended in the nutrient solution, the filters should be cleaned.

Any other maintenance work (i.e., pipe or box dripping, electrical faults, etc.) will need the intervention of a skilled technician (plumber, electrician, welder, carpenter, etc.). It is inappropriate, for example, for the AS technician who is responsible for mixing the nutrient solution and maintaining plants in the AS to act as a specialist and try to resolve other issues for which she/he has no competence.

Management of the screenhouse

The management of the aeroponics screenhouse starts with the strict observance of set sanitation rules and regulations always. The aeroponics screenhouse must be treated like a laboratory in terms of sanitation. It could be dangerous to overlook these rules and then use the 'fire fighter approach' to resolve issues when they arise. Any observation that the plants are not developing well as expected should be investigated immediately and solve the cause of the problem rather than simply address its symptoms.

Basic rules to observe to maintain good sanitation in the aeroponics screenhouse

1 Never open both doors into the aeroponics screenhouse at the same time.

2 All materials that are not for immediate use in the screenhouse should be placed in an appropriate store outside the area where plants are grown.

3 Before opening the second door, ensure that the first door is closed. Hands should be disinfected with 5% sodium hypochlorite or 70% alcohol.

4 Before entering the screenhouse compartment where plants are grown, the sole of shoes should be dipped in the disinfectant solution by the entrance door.

5 Visitors to the AS should not touch the plants, tables' support, and the boxes, and signs inside the screenhouse should always be observed. Technicians should always be ready to assist visitors to the facility.

6 Only the technicians should handle the plants only when they have earlier washed and disinfected their hands with alcohol.

7 Staff should always wear laboratory coats (appropriate dressing) to enter the screenhouse for safety.

8 No food items are allowed in the screenhouse.

9 Minimize entry into the aeroponics screenhouse by keeping the entrance door under lock.

Disinfectant solution for footwear at the entrance

- This should be prepared weekly at a set time or after receiving many visitors into the aeroponics screenhouse. The disinfectant can be prepared with any of the following compounds.
- 5 g of copper sulphate dissolved in 10 L of water (using more of the chemical to obtain a higher concentration is a waste) and
- 1 L of sodium hydroxide (household bleach) in 9 L of water.

Checking and maintenance of the aeroponics boxes

- The first thing to do on entering the AS screenhouse is to rapidly check the plants in each of the 10 boxes to see if there is any irregularity that needs attention. While checking the plants it is advisable listen to the sound of the misters as they spray to detect possible irregularities.
- The boxes should be cleaned regularly and before any major planting operation with sodium hydroxide (5%). .
- Clean the top of the boxes (tables) with 70% alcohol prior to planting. This cleaning should be maintained every two weeks and can be done weekly during harmattan (dusty) period.
- Put the twines for staking in place before planting so that plants are not disturbed during growth. If plants are not twined on the ropes, their development may be slowed down due to limited exposure of leaves to light. Young plants should be directed to twines.
- Sprinklers or misters should be checked to ensure they are functioning properly. Faulty mister can be detected by the abnormal noise of the spray.
- The holes drilled into the tables are large enough to accommodate plantlets, which are held in place by a piece of foam. The foam also serves to cover the hole and prevent sunlight from entering the aeroponics boxes. It is important to note that sunlight will induce sprouting of new stem from the rooting node in the boxes. This reaction makes it very necessary for holes without plants to be closed since they could be a source of light entering the boxes. Other advantages of preventing light in the boxes are:

- Elimination of the growth of algae and spirogyra within the boxes.
- Tuber formation takes place in dark condition.
- Absence of shoot growth within the box.

- In each box, verify if the returning nutrient is flowing normally out of the box through the piping system into the tank. Also, check the point of exit of the box with the returning pipe and remove any blockage.
- When the pump is running one should check the misters to ensure that each mister is functioning normally.

Heat control in the AS and sanitation rules within the power house

All the rules listed under management of the screenhouse are observed for sanitation.

Heat control inside the screenhouse

The easier method of controlling heat inside the screenhouse is to spread a shade net (60 to 80%) over plants. When using the shade net, one should be careful about having sunlight inside the screenhouse. The temperature change pattern during the day should be studied to develop a schedule for closing and opening the shade net inside the screenhouse. Avoid frequent opening and closing of the shade net. In addition, it is important to control the heat by watering the floor of the screenhouse and using fans and heat extractors to move hot air from inside the screenhouse. Experts are trying to find more efficient ways to address challenge of having the high temperatures inside the screenhouse.

Heat control of the nutrient solution

Presently, the only solution being used to reduce the temperature of the nutrient solution is to put iced blocks made with the nutrient solution into the tank. During the hot period, the iced blocks can be made in advance and stored in a deep freezer within the power house. It is possible to find other options that will be more effective to reduce heat during the hottest period of the year (December to March).


Figure 28: Control of heat in screen house with shade nets, fans, extractors and misters.

Sanitation rules within the power house

Since the reservoir of nutrient solution is found in the power house, proper sanitation is very important to avoid contamination of the solution. All the materials used should be cleaned and disinfected regularly. The following are possible sources of contamination.

During preparation of nutrient solution: poor water source, unhygienic conditions during the weighing fertilizers (dirty containers, spoon, duster, etc.), unclean containers used to dissolve the fertilizers, technician's hygiene, etc.

The nutrient tanks: Unnecessary opening of the tanks could introduce contamination into the system.

Cleaning the nutrient tank: For now the nutrient tank is cleaned by the technicians. One goes down inside the tank to perform the cleaning. Sometimes the cleaning is done by moping the remaining solution in cleaning by adding distilled water and later 70% alcohol and used effectively the mope. Make sure that there is no more plant debris and no solution in the tank. We have not yet identified the best way to clean the nutrient tank.

Clothing materials and food items: If the power house serves other functions such as offices space, care should be taken to avoid contamination through food and clothing. Food should neither be eaten in the power houses, nor stored in the deep freezer where the nutrient solution is stored. The same applies to drinking water. Apart from being sources of contamination, eating and drinking or storing food with nutrient solution could pose health and safety hazards for staff.

Data collection in aeroponics system

Two types of data should collected in the AS and analysed to help improve the system; data collected in the screenhouse and from the power house.

In the screenhouse the data collected are related to planting events e.g. dates of planting, and variety planted per hole, per table and per box, data on plant growth (plant height and number of leaves) plant replacement, harvest of tubers, bulbils or single node vine cuttings, etc. Temperature and relative humidity of the screenhouse should be recorded at set times thrice daily (morning, afternoon and evening). Records should be taken on symptoms of diseases (anthracnose, fungal or virus diseases, etc.) or pests (mealybug, etc.). Data collected in the power house are related to the nutrient solution quantity of each fertilizer used, pH, temperature, Electro-Conductivity (EC) and the Total Dissolved Soluble (TDS), and the volume of remaining nutrient are taken three times daily. All interventions in the AS system should be recorded.

Harvest of planting materials in aeroponics

4

There are three types of planting materials that can be harvested from the AS. These are tubers, bulbils, and vines.

Harvest of mini tubers in aeroponics boxes

In early research work on aeroponics, tubers were usually harvested every four months. During the first four to six months of canopy development tuber production is low. After the first harvest the nutrient solution is changed with a new fertilizer enriched with potassium. The number of tubers per plant, the tubers weight per plant, and the average weight per tuber varied with the genotype and the age at harvest.

A total of 1527 tubers were harvested from 486 plants of nine genotypes with an average weight of 34.8 ± 1.5g per tuber and average of 3.1±0.1 tubers per plant. The highest number of tubers per plant (20) was recorded by TDr 95/18544.

Figure 29. First generation of tubers formation inside the AS box from vine cuttings.

From early studies of yam propagation in the AS, it was observed that the average weight of tubers per plant was 109.3 ± 6.6 g, and the highest weight of tubers per plant (1048.6 g) was recorded by TDa 2014. On the other hand, when considering the performance of the yam genotypes in aeroponics, the average number of tubers per plant was linked to the genotype and varied with the age of plants within the genotype.

Figure 30. Well developed tubers from mature plants in AS box.

At 13 months, the number of tubers per plant was 1.8±0.1 for TDr 97/00917, 3.0±0.7 for TDr 89/02665, and 5.1±0.3 for TDr 95/18544. These numbers of tubers per plant changed to 6.3±0.2 for TDr 95/18544 at 16 months and to 4.0±1.0 for TDr 97/00917 at 32 months. The same values were recorded for the tuber weight per plant and it was dependent on canopy development.

In terms of size, the general average length of tuber was 9.8 ± 0.7 cm and the average diameter is 4.0± 0.1.Harvesting should be done carefully to avoid bruising and wounding At harvest, one should be careful and tubers should be harvested one by one. Each tuber harvested is weighed and recorded.

All the tubers harvested should be labelled with the name of the variety, the number of tuber harvested, and the weight of each variety. Harvest of tubers is a very delicate operation, which should be done without removing all the feeding roots from the principal stem. The roots should be maintained so the plant can continue growing and produce more propagation materials.

Figure 31. Very long tubers (over 70 cm) growing inside the AS box.

Figure 32. Breeder seed yam tubers harvested from TIBS plants in AS.

At harvest, the tubers from the aeroponics system are treated with a mixture of fungicide and insecticide (7 g Mancozeb and 2 ml Karate in 1 L of water) and exposed to air dry under shade.

The labeling is very important at harvest. The following information are included in the label: Variety name; date of planting; date of harvesting; number of tuber harvested; weight of each tuber; number of hole; table number; and box number.

Harvest of bulbils from plants in aeroponics

Bulbils are aerial tubers produced by some plants. Within a variety, as much as 25% of the plants could produce bulbils, and up to 73% of plants of the variety TDr89/02665. A plant can produce up to 150 bulbils per plant. Both D. alata (water yam; Figure 33c) and D. rotundata (white yam; Figures 33A & 33B) can generate bulbils. The bulbils are formed at the nodal points and have many types. Some of the bulbils start growing while still attached on the plants, with their rooting system in air (figure 33A), while others develop exactly like tubers (Figure 33B).

Figure 33A. Well developed bulbils of white yam showing roots and shoots in AS.

Figure 33B. Two types of aerial tubers of white yam developing with roots.

Figure 33C. Bulbils of water yam growing and producing new leaves while still attached to the mother plants.

The bulbils are planted to produce plants and can be stored for a long period before planting. Bulbils have less pest and disease challenges in storage compared to tubers.

The harvest of bulbils can be done at any time. However when they are producing roots and shoots they should be harvested as soon as possible. If bulbils not harvested early enough, the mother plant as well as the bulbils will dry up.

Single-node vine cuttings from plants in aeroponics

Before developing the AS for yam propagation, the single-node vine cuttings was the technique used for yam multiplication. With these vine cuttings taken from plants growing from tubers or from true seeds in the field, the technology provided a maximum of 60 single-node vine cuttings Per plant and the percentage of cuttings that eventually produced roots and new leaves was less than 5 %. However, using vine cuttings of the varieties TDr 95/19177 and TDr 95/18544 from the AS, 98 % of cuttings rooted, while more than 90 % produced new leaves. These results were later confirmed for 12 yam varieties.

Figure 34. AS single-node vine cuttings of many yam varieties growing in nursery.

To obtain single-node vine cuttings start by cutting the lateral branches from the main branch(es). Put the cut vines in a disinfectant solution in a bucket. After cutting the lateral branches, the main branches are cut from the top leaving about 10 to 15 cm vine in place to allow re-growth. Each of the cut branches is then cut into pieces with only one node using a sharp implement. The single node cuttings should be dropped immediately in water or disinfectant solution to avoid drying. Plant the single-node cuttings immediately in plastic bags that are filled with a mixture of 50% carbonized rice husk and 50% sterilized top soil. The planting should be done under shade in a nursery. After three to five weeks the cuttings will develop into seedlings with roots and shoots ready for transplanting to the field.

The number of single-node cuttings per plant is very variable with genotype and age of the plant, and generally increases with increase of the period of growth of the plants.

The following pictures (Figure 35 to 38) of canopies are at different development stages and correspond to different number of vine cuttings that could be obtained per plant. Sometimes, it may be better to wait for a heavy canopy before cutting the vines, because more leaf area encourages more growth. However, in case there is already 'forest' (heavy canopy) in aeroponics (Figure 38), cutting of branches should be done with extreme care because the vines become intertwined and will be difficult to separate. Forcing them apart will entail loss of leaves, which are essential for successful rooting.

Video reference

Development on yam aeroponic (https://www.youtube.com/watch?v=C6Jf7F4aNwI)

Figure 35. At this stage of development each plant will give less than 100 single-node cuttings.

Figure 36. At this stage of development, 200 and 250 single-node cuttings can be harvested per plant.

Figure 37. At this stage (forest) each plant will generate on average 300 single node cuttings.

Figure 38. At the 'big forest' stage which is not encouraged, each plant can give over 400 single-node cuttings.

If the rooting system inside the boxes is too much it may need to be trimmed after harvest of the vines as per figures 39A and 39B.

Figure 39 A. Over grown yam roots inside the box of AS with forest yam plants.

Figure 39B. Tubers and roots inside the AS after trimming away the excess roots.

Field planting of harvested planting materials from aeroponics

5

Planting of mini tubers

Similar to normal yam tubers, the mini or micro tubers from aeroponics are planted only after their dormancy is broken. The mini or micro tubers are planted whole when their size is below 30 grams. Bigger tubers are cut into setts of approximately 25-30 g after breaking dormancy. The tubers harvested in aeroponics system from TIBs plantlets are pre-basic seed tubers (breeder seed). After transplanting, they produce basic or foundation seed tubers. These can be transplanted in field on ridges at a density of 1 m x 0.25 m or in plastic pots of 10 L each filled with sterilized top soil.

Figure 40 A. Micro tuber from AS (below 5 g) that have broken dormancy and ready to be planted.

At all stages of handling, proper labelling of varieties must be done to avoid mix up. It it recommended to store mini and micro tubers from AS in cool and dry place or in a AC room.

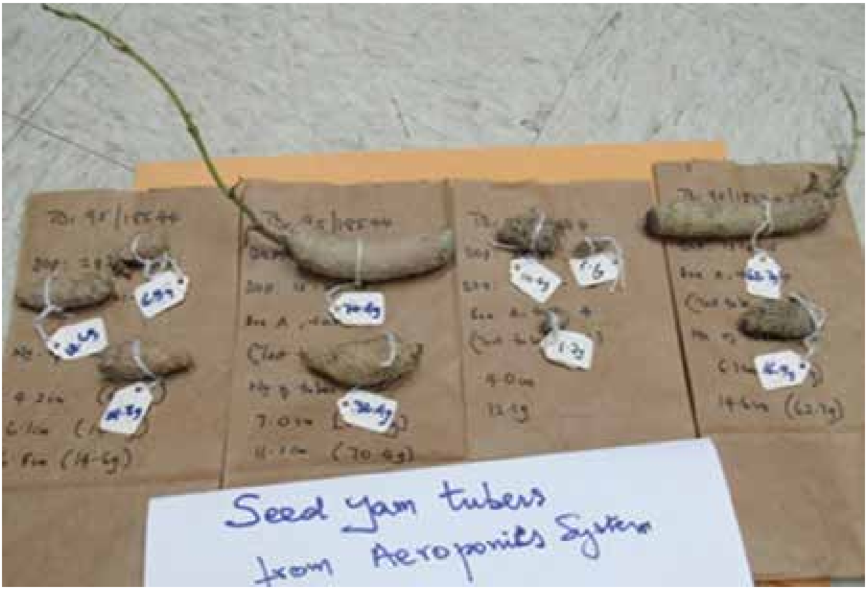

Figure 40 B. Different sizes of tubers from AS (including macro & mini tubers) that have broken dormancy.

Figure 40C. AS tubers of over 100g that have broken dormancy and ready for planting.

The information on the label should include variety name, date of planting, date of harvesting, number of tubers and weights of tubers at harvest and any other information that may be deemed necessary. Also, more information should be recorded in the field notebook including origin of the material planted, weight, treatment, etc.

Planting of bulbils

During the growth of yam plants in aeroponics, different types of bulbils are produced. It is advisable to remove the bulbils found in the rooting system with new leaves. Plants with the bulbils should be harvested. Since the number of bulbils produced is usually few, it is suggested that they should be planted in pots. The planting of bulbils is the same as tubers. The main difference, though, is that bulbils are only planted whole.

Figure 41. Newly developed bulbils from AS plants showing their respective growing point.

Figure 42. Bulbils of water yam harvested from AS and ready to be planted in field.

Planting of single-node vine cuttings

The single-node vine cuttings spend 3-4 weeks in the nursery to pre-root before they are transplanted in the field. The land should be well prepared and where its fertility status is in doubt, poultry manure should be applied before harrowing, followed by ridging. The planting density is determined by the distance between ridges (0.75 m or 1.0 m). The distance recommended between plants is 0.25 m. This will give a planting density of between 40,000 and 53,333 plants per hectare. Previous results showed that at least 92% of the transplanted vines developed and produced tubers successfully.

Figure 43. Single node vine cuttings in nursery bags ready to be transplanted after 4 weeks.

Figure 44. Field transplanting of rooted single node vine cuttings at the density of 1m x 0.25m.

Figure 45. One month after field planting of pre-rooted single node vine cuttings under irrigation.

Figure 46. Two months after field planting of single node vine cuttings under irrigation.

Figure 47. Tubers harvested from single-node cuttings at three to four months after field planting.

Figure 48. Different sizes of tubers harvested from single node vine cuttings after 6 months in field.

Conclusions and recommendations

6

The YIIFSWA Project’s single-node vine cuttings findings on aeroponics at IITA-Ibadan were used to develop this manual on foundation seed yam production. It is important for users of this manual to know that these results were obtained only after two years of experimentation with only five varieties of white yam and two varieties of water yam. This manual will be updated as soon as more data are collected.

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Appendix 1.

Materials Estimates for the Construction of Aeroponics Screenhouse for seed yam

S/N	Materials	Quantity
1	Roofing nylon	2
2	Screen net	1
3	Grip strip single	20
4	Grip strip double	40
5	Infill	20
6	Bolt & nuts	300
7	2″ Galvanized pipe	50
8	11/2″ Galvanized pipe	30
9	1″ Galvanized pipe	5
10	Anti-hot spot	24
11	Concrete block 6″	600
12	Cement	50
13	Sand	10
14	Granite	10
15	Sewing of net (tailor)	
16	Mason, Welder or/and carpenter	
17	Grading and levelling of location	
18	Labour staff	
19	Transport of materials and staff	
20	Supervision	
21	Per Diem (accommodation & food)	
	Total	

Appendix 2.

Materials estimates for Construction of Aeroponics System Including Power House

S/Nos	Description	Quantity
1	20 mmX1/2” PE Cap End	10 Nos
2	20 mmX1/2” PE Pressure Pipe	50 meter
3	20 mmX1/2” PE Elbow	10 Nos
4	20 mmX1/2” PE Adaptor	10 Nos
5	25 mmX3/4”X20mm/1/2” Tiger Reducing Bush	20 Nos
6	25 mmX3/4” PE Adaptor	22 Nos
7	25 mmX3/4” PE Pressure Pipe	8m/24’
8	25 mmX3/4” Stop Cock valve	2 Nos
9	25 mmX3/4” Tiger Elbow	2 Nos
10	25 mmX3/4” Tiger Nipple	4 Nos
11	25 mmX3/4” Hose Brass Tap	3 Nos
12	Mentus green PPR Pipe 25mmX4.2M (12feet)	30 length
13	1’X3/4”(32mmX25mm) tiger reducing bushing	12 Nos
14	50 mmX25mm Tee Tiger	12 Nos
15	$1^{1/2''}$X50mm tiger pressure Pipe of 20feet each	6 Nos
16	$1^{1/2''}$ X50mm Tiger socket	8 Nos
17	$1^{1/2''}$X50mm Tiger Plug	2 Nos
18	$1^{1/2''}$X50mm Tiger Elbow	10 Nos
19	$1^{1/4''}$X45mm Hose clip	12 Nos
20	$1^{1/4}$”X45mm union waste	12 Nos
21	$1^{1/4}$X45mm (flexible drain pipe)	6 meter
22	$1^{1/2''}$X50mm Tiger Tee (direct)	4 Nos
23	$1^{1/2''}$X50mm Tiger Union Connector	4 Nos
24	$1^{1/2''}$X50mm Tiger Nipple	6 Nos
25	75 mmX3” PVC Pipe of 12feet in length	8 Nos

Appendix 2 contd.

S/Nos	Description	Quantity
26	75 mmX3” PVC Elbow	6 Nos
27	75 mmX3” PVC Plug	2 Nos
28	75 mmX3” Union PVC Connector	2 Nos
29	75 mmX3” PVC Tee	3 Nos
30	75 mmX3” Ball Cock	3 Nos
31	1”X32mm Tiger pipe	6 Nos
32	1”X32mm Stop cock	2 Nos
33	1”X32mm Tiger tee	4 Nos
34	1”X32mm Tiger Elbow	10 Nos
35	1”X32mm Tiger union collector	3 Nos
36	1”X32mm Tiger nipple	4 Nos
37	1” X 3/4” (32mmX25mm) Tiger Elbow	4 Nos
38	1” Thread Tape	18 Nos
39	Masking Tape	5 Nos
40	1” X 32mm Tiger Plug (for two tanks)	6 Nos
41	Abro Gum	2 Nos
42	Storage Tank 1000Liters	2 Nos
43	$1^{1/2''}$X 50mm Ball cock Valve	3 Nos
44	$1^{1/2''}$X 50mm Brass foot Valve	2 Nos
45	$1^{1/2''}$X 50mm Plastic Water Filter	2 Nos
46	Water Pump	2 Nos
47	Misters	120 Nos
48	25mmX3/4” Ball Cock valve	10 Nos
49	500 Micron Nylon Black	L/B(30MX7M)
50	200 Micron Nylon Black	L/B(151MX96M)
51	200 Micron Nylon White	L/B(11MX6M)
52	9” block	160 Nos

Appendix 2 contd.

S/Nos	Description	Quantity
53	Sharp Sand	5 tons
54	3/4”/1/2” Granite	5 tons
55	Digging for the underground tank	
56	Excavation, block work and plastering labour	
57	Cement	15 bags
58	$1^{1/2”}$ Galv. Pipe	11 Nos
59	3/4” Galv. Pipe	8 Nos
60	Aluminium Sheet	7 Nos of .55x4m
61	Aluminium hooks with washer, nut, and veit	80 Nos
62	Electrode G12	1 Pkt
63	1.5mm Sheet	3 Nos
64	Wire Mesh	3 Nos
65	Thinner	2 gallon
66	Paint (green)	2 gallon
67	Paint(Red Oxide)	2 Nos
68	Digital Timer	2 Nos
69	Contactor	2 Nos
70	Circuit Breaker	6 Nos
71	Push button	4 Nos
72	Switch	1 Nos
73	Panel Box	1 Nos
74	Gear Box Switch 32A	1 Nos
75	10 mm Armoured Cable (length to be determine according to the location)	/meters
76	Double 4ft. Florescent Fittings complete	2 Nos
77	20mm Distance Saddle	10 Nos
78	13A Socket (double)	2 Nos
79	10A Gang switch metal complete	1Nos

Appendix 2 contd.

S/Nos	Description	Quantity
80	6mm X 4core Flexible cable	2 meter
81	1.5 mm X 3core Flexible cable	20 m
82	2.5 mm X Single core Black	15 m
83	2.5 mm X Single core Red	15 m
84	2.5 mm XSingle core Green	15 m
85	20mm Galv. coupler	20 Nos
86	20mm PVC pipe	6 Nos
87	16 mm Cable gland	2 Nos
88	20 mm Male and female bush PVC	10 Nos
89	20 mm PVC coupler	10 Nos
90	20 mm PVC clamp	10 Nos
91	20 mm Galv. male bush	15 Nos
92	20 mm Galv. tee box	3 Nos
93	20 mm Galv. angle box	3 Nos
94	20 mm Galv. through box	3 Nos
95	Dixon shelve of 4 ft length each for side brassing	400 Nos
96	Dixon shelves stand at 6 ft height	100 Nos
97	Dixon shelves angle bracket	6 Pkt
98	M13 bolts and nuts	1 Pkt
99	5 cm Styrofoam	60 Nos
100	Epoxy bond	2 Nos
101	Cable tie	200 pcs
102	Labour staff	
103	Transport of materials and staff	
104	Supervision	
105	Per diem	
106	Contingency	
	TOTAL	