

Seed Yam Production in an Aeroponics System: A Novel Technology

N.G. Maroya, M. Balogun, and R. Asiedu



Seed Yam Production in an Aeroponics System: A Novel Technology

N.G. Maroya, M. Balogun, and R. Asiedu

YIIFSWA Working Paper Series No. 2

© IITA 2014

International Institute of Tropical Agriculture
PMB 5320
Oyo Road
Ibadan, Nigeria
www.iita.org

ISBN 978-978-8444-37-4

Printed in Nigeria by IITA

Correct citation: Maroya, N., M. Balogun, and R. Asiedu. 2014. Seed yam production in an aeroponics system: a novel technology. YIIFSWA Working Paper Series No 2 (Revised). Yam Improvement for Income and Food Security in West Africa, International Institute of Tropical Agriculture, Ibadan, Nigeria. 20 pp.

Cover photo: Yam bulbils.

Contents

Acronyms and abbreviations	iv
Acknowledgements	v
Preface	vii
1. Introduction	1
2. Traditional Seed Yam Production Technologies	1
3. Advances in Seed Yam Production Technology	1
4. What is the Aeroponics System?	2
5. Aeroponics System Structure	3
6. Origin of the Concept of Aeroponics Seed Yam Production Technology at IITA	4
7. Aeroponics Seed Yam Experiment	6
8. Preliminary Findings	7
9. Production of Bulbils	7
10. Challenges	8
11. Conclusion	9
12. References	10

Figures

1. Detailed layout of IITA aeroponics system for seed yam production at Ibadan.	3
2. Drawing of control panel components of automatic timer.	3
3. Top: The aeroponics system with feeding pipes. Bottom: Group photograph of workers who established the aeroponics system.	4
4. Left: Inside view of the box of two-node yam vine cuttings planted. Right: Fully established rooting system 3 weeks after planting.	5
5. Left: Professor Felix Nweke (Michigan State University) in the aeroponics screenhouse checking the tubers. Right: A close shot of the minitubers.	5
6. Top: A bulbil on a <i>D. rotundata</i> plant in aeroponics. Bottom: Bulbils on a <i>D. alata</i> plant in aeroponics.	6

Acronyms and abbreviations

AGRA	Alliance for a Green Revolution in Africa
AS	Aeroponics System
AU	Abuja University
BMGF	Bill & Melinda Gates Foundation
CRI	Crops Research Institute, Ghana
ECOWAS	Economic Community of West African States
IITA	International Institute of Tropical Agriculture, Nigeria
MAFF	Ministry of Agriculture, Forestry and Fishery, Japan
NARS	National Agricultural Research Systems
NASC	National Agricultural Seed Council, Nigeria
NRCRI	National Root Crops Research Institute, Nigeria
VP	Vine propagation
YIIFSWA	Yam Improvement for Income and Food Security in West Africa

Acknowledgements

The authors would like to thank the following people for the most significant contributions towards the establishment and production of the seed yam in the aeroponics system at IITA.

The engineers Bamidele Buraimoh, Peter Kolawole, and Musendeeq Oyedeji and other staff of IITA Farm Management Services for their invaluable technical support to the construction of the aeroponics greenhouse.

Beatrice Aighewi of IITA for her major contributions in aeroponics documentation.

Jemo Martin of IITA for technical advice and support on fertilizers for the nutrient solution.

Gueye Badara of IITA for the transfer of the screenhouse 43 to the aeroponics experiment.

Antonio Lopez-Montes of IITA for providing the first set of vine cuttings from his breeding nurseries.

Lava Kumar of IITA for the supply of virus-free vine cuttings for seed yam production in aeroponics.

Felix Nweke for his invaluable assistance and advice for this working paper on the aeroponics system.

The Bill & Melinda Gates Foundation for their financial contribution for the development of the aeroponics system.

Preface

The YIIFSWA (Yam Improvement for Income and Food Security in West Africa) project is an R4D project of IITA. The project is funded by the Bill & Melinda Gates Foundation and executed in Nigeria and Ghana by IITA in partnership with a consortium of national and international R4D agencies and in collaboration with service provider organizations, the private sector, farmers, and yam traders.

The YIIFSWA project has the following broad objectives:

1. Strengthen small-scale farmer and trader market linkages, particularly in less accessible producing areas, to realize benefits from improved ware yam productivity and market demand.
2. Strengthen capacities and empower smallholder farmers in the yam value chain.
3. Establish sustainable availability of high quality seed yam on a commercially viable and price competitive bases in targeted areas.
4. Reduce postharvest losses and improve product quality.
5. Develop technologies for high ratio propagation of high quality breeder and foundation seed yam.
6. Evaluate and scale out yam production technologies with improved and local popular varieties.
7. Identify more effective prevention and management tools and strategies for pests and diseases.

Each objective is addressed by a team of researchers supported by other researchers working on two cross-cutting components: impact monitoring, evaluation, and learning; and communication and information dissemination.

The YIIFSWA Working Paper Series is published informally by YIIFSWA to disseminate its intermediate outputs. Publications in the series include methodologies for, as well as preliminary results of, the various objective teams of the YIIFSWA project. The series is aimed at scientists and researchers working with national agricultural research systems in West Africa, the international research community, policy makers, donors, and members of international development agencies that are interested in yam. As these papers are not in their final form, comments are welcome. Such comments should be addressed to the respective authors or to the YIIFSWA Project Manager.

Individuals and institutions may obtain copies by writing to:

The Project Manager
Yam Improvement for Income and Food Security in West Africa
International Institute of Tropical Agriculture
PMB 5320, Oyo Road
Ibadan, Nigeria

Introduction

The slow technology for seed yam production is one of three obstacles which stand in the way of cost reduction and expansion in yam production in West Africa; others are the high labor requirement and problems of pests and diseases. Yam is traditionally propagated by tuber, the edible part, with a very low multiplication rate; often one plant produces only one seed yam. The low multiplication rate is made worse by the long growth cycle of the crop and the long dormancy period. The growth period is from 5 to 9 months, depending on variety and tuber size; the dormancy period is between 2 and 3 months after senescence. The worst scenario, which is common in practice, is that one plant which produces one seed yam takes one year to produce another single seed yam. At best, if one tuber produces five seed yam through being cut into pieces, after one year it could generate five seed yam, i.e., before discounting for losses due to pests and diseases. This low rate of multiplication and the use of the tuber, the edible part, for propagation make seed yam extremely expensive (Nweke forthcoming). In this Working Paper the traditional technology for seed yam production and emerging new technologies are first reviewed to provide the background for the discussion of seed yam production using the aeroponics system.

Traditional Seed Yam Production Technologies

Seed yam production methods in Nigeria and Ghana vary as widely as the methods of yam crop production (Nweke forthcoming). The methods can be classified into two broad groups. The separation of seed yam production from ware yam production is the central distinguishing practice of one group which is practiced in Nigeria along the River Niger basin. The production of seed yam as an integral part of ware yam production is more widely practiced throughout the yam belts of Nigeria and Ghana. Within this second broad group, two subgroups of practices are distinguishable: milking and sorting. In the “milking” technique (Okigbo and Ibe 1973; Okoli et al. 1982), tubers are harvested two-thirds of the time into the growing season without destroying the root system, providing early ware yam for consumption. Before senescence the parent plant regenerates small new tubers which are used as seed yam for the following season. This system therefore doubles the propagation ratio relative to the traditional method although multiplication ratios are still very low (1: 6 compared with 1: 200 in some cereals (Mbanaso et al. 2011). Milking practice represents a significant investment by the farmer. First, there is a yield loss from harvesting the main tuber before senescence when maximum yield is attained (Onwueme 1977). Secondly, harvesting labor is increased because of the double harvesting. These additional costs explain the very high cost of seed yam. At harvest, tubers are sorted by size: small ones are used for seed yam, medium ones for table yam, and very large ones for ceremonial purposes. The use of seed yam produced by sorting, especially those seed yam which are small due to the micro-environment or variations from pests and diseases in the field, facilitates the recycling of pests and diseases (Nweke forthcoming).

Advances in Seed Yam Production Technology

In the past 30–40 years, significant progress has been made towards improving the efficiency of the traditional technology of tuber seed yam production by developing methods that can increase the multiplication rate. One of the technologies which aim to improve on a traditional method is known

as the miniset technique. This technology was developed by the National Root Crops Research Institute (NRCRI), Umudike, and the International Institute of Tropical Agriculture (IITA) in the early 1970s to overcome the critical problem of the unavailability of good quality seed yam by improving the rate of multiplication, especially of white yam. The process involves the cutting of “mother” seed tubers from a non-dormant tuber into small setts of 25–50 g, each part containing the periderm and some cortex parenchyma (Okoli and Akoroda 1995). With the technique, the multiplication ratio of white yam moved to 1: 10 from the traditional 1: 3. Numerous adoption studies yield discouraging results of low adoption and in some cases of reverse adoption (Nweke forthcoming). The modified miniset technique (Kalu and Erhabor 1992; Ikeorgu and Igbokwe 2003, Ikeorgu et al. 2007) using minisets weighing 25–80 g has reduced the production cost of seed yam (Okoli et al. 1982; Otoo et al. 1987) but the rate of adoption is low (Kalu and Erhabor 1992).

More recent alternatives to the tuber seed yam method that are at various stages of development by researchers in West Africa include rooting stem cuttings of the yam plant, producing and germinating true seeds of some varieties, and rooting yam sprouts generated by tubers in storage after dormancy. The rooting system of 1–3 node vines 20 cm long (Acha et al. 2004; Kikuno et al. 2007; Agele et al. 2010) produced minitubers of 50–600 g after 8 months, giving a 1: 30 propagation ratio. Other technologies exist with a high propagation ratio but are not being used for yam (Balogun and Gueye 2013). Three of the new technologies are Aeroponics System (AS), Temporary Immersion Bioreactors System (TIBs), and Photoautotrophic Culture (PC) and these were targeted to be implemented for seed yam propagation in the project *Yam Improvement for Income and Food Security in West Africa* (YIIFSWA), funded by the Bill & Melinda Gates Foundation. These technologies are known to be effective in other vegetatively propagated and horticultural crops for a high ratio of propagation and an assurance of high seed quality. However, the efficiency and cost-effectiveness of these technologies for yam propagation are not known. Very recently there was an experiment with the aeroponics technique for seed yam production at IITA-Ibadan.

What is the Aeroponics System?

The International Union of Soil Sciences Working Group on Soilless Culture defines aeroponics “as a system where roots are continuously or discontinuously grown in an environment saturated with fine drops (a mist or aerosol) of nutrient solution” (Nugali et al. 2005). Went (1957) named the air-growing process in spray culture as “aeroponics”. Simply put, aeroponics is a method of growing plants in a soilless environment with very little water (Carter 1942). Basically, it is growing without earth. Techniques for growing plants without soil were first developed in the 1920s by botanists who used primitive aeroponics to study plant root structure (Barker 1922). This absence of soil made study much easier since in aeroponics, the plants’ roots dangle in midair with only the plants’ stems being held in place. Hydroponics, a similar technology (growing roots in a nutrient-rich, water-based medium instead of soil), emerged later in the 1970s and overtook the development of aeroponics. The aeroponics system has been used successfully in the production of several horticultural and ornamental crops (Biddinger et al. 1998). Aeroponics system has been applied successfully in Korea for potato seed tuber production (Kang et al. 1996; Kim et al. 1999). At the International Potato Center (CIP) in Peru, yields of over 100 tubers/plant were obtained (Otazu 2010). The technology is being tested in several African countries for the production of potato minitubers (Lung’aho et al. 2010).

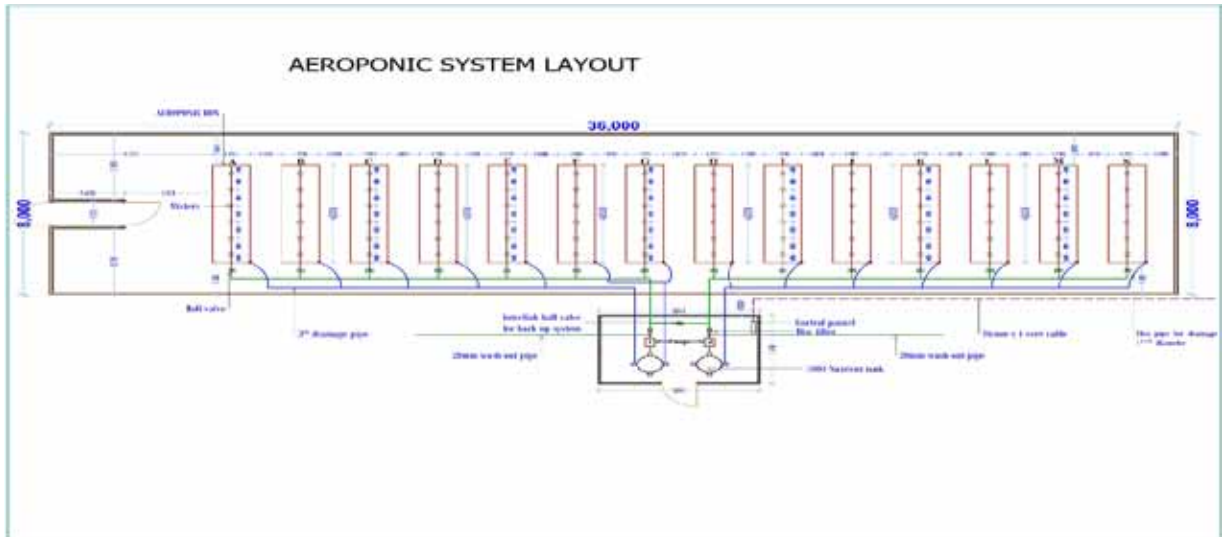


Figure 1. Detailed layout of IITA aeroponics system for seed yam production at Ibadan.

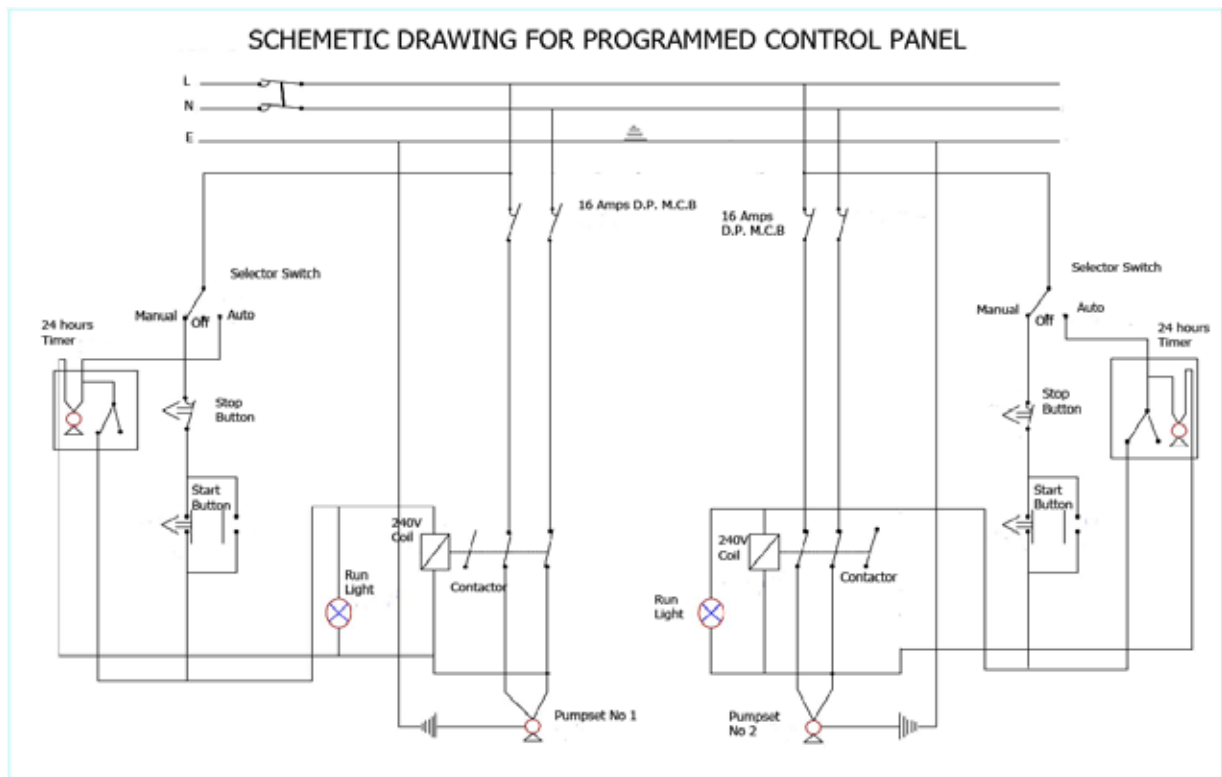


Figure 2. Drawing of control panel components of automatic timer.

Aeroponics System Structure

For a functional aeroponics system a greenhouse has to be constructed containing isolated boxes. The greenhouse roof needs to be covered by a shading net to lower the solar heat inside. Boxes can be distributed lengthwise or widthwise, depending on the greenhouse size, but the best pattern has windows at each side, thus making management and harvesting simpler. The boxes are enclosed areas known as root chambers. The purpose of this area is twofold: it protects the roots from light and holds the nutrient/water solution that feeds them.

In addition to the greenhouse, a powerhouse is constructed with underground tanks for the nutrient solution. A pump pushes the nutrient solution through a piping system and out of a series of nozzles inside the boxes that atomize the solution and spray a fine fog directly onto the roots. The way nutrients and water are delivered also demonstrates the efficiency of aeroponics. The nutrient solution used on plants requires only a little water. In the enclosed system, whatever doesn't get absorbed by the roots falls back down and returns to the nutrient tank by gravity and gets cycled through again. For this purpose the boxes should have a slope towards the return piping system to the tanks. The feeding pump is set to an automatic timer through an electric control panel and delivers this high-powered nutrient solution at regular intervals. In enclosed systems, water use is even further diminished. 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 because they are delivered via the mist.



Figure 3. Top: The aeroponics system with feeding pipes. Bottom: Group photograph of workers who established the aeroponics system.

Origin of the Concept of Aeroponics Seed Yam Production Technology at IITA

At the YIIFSWA First Annual Progress Review and Planning Workshop held in Accra, Ghana, in September 2012, seed yam production technology was the central subject of discussion. A casual suggestion was made to the effect that there would be no harm in making an attempt to produce seed yam using aeroponics, a technique that was used to produce potato seeds in Kenya. The idea was not discussed further in the meeting but the YIIFSWA team took it seriously. In January 2013 a consultant engineer from Kenya, where this technique is used by private potato seed producers, was hired by IITA to help to establish the first aeroponics system for seed yam production.

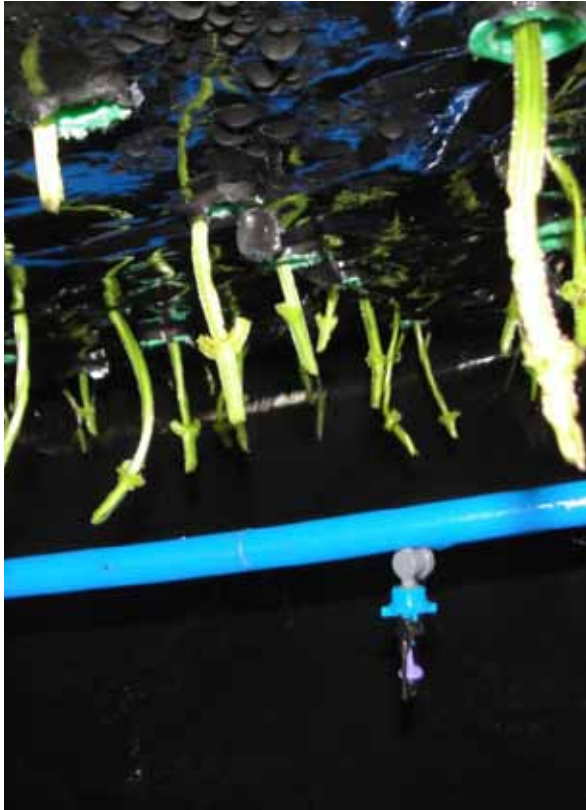


Figure 4. Left: Inside view of the box of two-node yam vine cuttings planted. Right: Fully established rooting system 3 weeks after planting.



Figure 5. Left: Professor Felix Nweke (Michigan State University) in the aeroponics screenhouse checking the tubers. Right: A close shot of the minitubers.

The consultant together with the in-house engineers of IITA's Farm Management Services (FMS) transformed an existing screenhouse, 36 m × 8 m, to build the aeroponics system composed of 14 boxes for seed yam production. Figure 1 shows the layout of the boxes, 4.8 m in length and 1.2 m wide, with 1 m space between two adjacent boxes. The tops of the boxes are covered with Styrofoam, 25 mm thick, cut into pieces (tables) of 1.2 m × 1.2 m, corresponding to 4 tables/box perforated at 20 cm × 20 cm, giving 36 planting holes/table (400 cm²/plant). One of the boxes was perforated at a density of 10 cm × 10 cm to test the higher density of 132 holes/table (100 cm²/plant).

Aeroponics Seed Yam Experiment

The experiment of seed yam production using aeroponics technique started with the following:

- Preparation of pre-rooted plants. When the experiment started in December 2012 the only source of vines was the breeding seedlings, 5 months old (raised from true seeds) that had been transplanted in July 2012. One-node vines were cut from the seedlings and planted in black plastic pots for pre-rooting. Three different substrates were used, i.e., river sand, carbonized rice husks, and a mixture of 50% of both river sand and carbonized rice husks).
- The one-node vines were planted in pots 6–19 December 2012 for pre-rooting and transplanted to the newly constructed aeroponics system 26–28 February 2013. Only five and half boxes were covered with the pre-rooted one-node vines.

As the half-planted box 6 was fully atomized with the nutrient solution, the empty space was filled by planting two-node vines cut directly. The two-node vines directly planted were cut from another seedling, transplanted in August 2012. The next day the vine cuttings directly planted on the aeroponics system exhibited vigorous growth. To confirm the result of direct yam vine planting on



Figure 6. Top: A bulbil on a *D. rotundata* plant in aeroponics. Bottom: Bulbils on a *D. alata* plant in aeroponics.

the aeroponics system, we planted two-node vine cuttings (5-month-old plants) collected from the same August 2012 seedling on 1 March 2013 on box 7. The fertilizers used were Ammonium nitrate, Potassium nitrate, Calcium sulphate, Magnesium sulphate, Boric acid, and EDTA (iron).

Preliminary Findings

The initial results of both pre-rooted vines and directly planted vines were impressive as plants and vines suspended in air continued growing normally with the development of new roots and shoots. Within 10 days, more than 50% of the vines produced roots and in week 3 after planting, 85–100% of the direct vine cuttings produced roots on the aeroponics system. After 4 months of growth in aeroponics, both the pre-rooted plantlets and the vine cuttings produced viable minitubers which were harvested in June 2013.

This experiment is the first reported on successful yam propagation on the aeroponics system. Also all existing reports on aeroponics for potato or horticulture crops used only transplanted rooted plantlets but never non-rooted direct vine planting (Otazu 2010). The IITA aeroponics yam experiment is the first successful experience of the use of direct vine cuttings in an aeroponics system.

Based on the results of the yam vines, new sets of improved yam genotypes (TDa 291; TDa 98/01176; TDr 89/02475; TDr 02665; TDr 95/18544; TDr 95/19177 and TDr 98/19158) were potted in the glasshouse to generate vines using minisetts of 50 g from the head, middle, and tail parts of tubers. Vines of all these genotypes grew well in aeroponics but the best was TDr 95/18544 in terms of percentage survival and growth performance. Other varieties tested in the aeroponics system are landraces (Maccakusa; Kadarko, Ogoja, Alumako, Alushi, and Obioturugu). The vines of these landraces were supplied by the virology laboratory of IITA as plants tested virus-free. There were variations among the landraces in the performance of their vine cuttings. The best variety for the survival of landraces in aeroponics is Ogoja, followed by Obioturugu and Maccakusa.

Production of Bulbils

The weights of the minitubers harvested from the first experiment ranged from 0.2 to 2.7 g. To increase the size of the minitubers, the second experiment was conducted with, new fertilizers: Ammonium nitrate, Potassium nitrate, Calcium sulphate, Magnesium sulphate, Potassium sulphate, and Triple-superphosphate micron (micronutrients). After 45 days from vine cutting and planting in the aeroponics system many varieties of both *D. rotundata* (white yam) and *D. alata* (water yam) produced bulbils, sometimes on plants without a rooting system. All the bulbils produced by *D. rotundata* were growing with new shoots and roots and increasing in size; the situation was similar for most of the bulbils from *D. alata*.

Some bulbils, harvested mainly from *D. rotundata* and planted in plastic bags, sprouted and grew normally.

Challenges

The biggest challenge is the use of an existing screenhouse that was not planned for aeroponics. The height and shape of the screenhouse are not appropriate for this system as these create heat stress for the plants despite the shade on the roof. Also there is no lavatory with tap water and a wash hand basin in the pre-chamber for proper hand-sanitation. This may cause infection of the plants with diseases. Although it was known that unnecessary entrance to the screenhouse should be avoided and all visitors should be kept outside, the experiment attracted many visitors and aroused much curiosity with a great influx of people, predisposing the plants to pest infestation and disease infection. Ideally, the aeroponics system environment should be kept free from pests and diseases so that the plants will be healthier and grow more quickly than plants grown in a soil medium. None of the sanitation measures listed below (put in place for potato seed production in an aeroponics system) was used during our experiment for the production of seed yam:

- The operator should not be in a crop field before entering the screenhouse.
- If no plants are to be touched, hands should be washed with soap and water. If plants are to be handled, disinfectant and soap should be used. Disposable gloves may be used when many plants are to be handled. Disinfectant should be used after handling each plant.
- The operator should always use a clean coat, which should always remain in the pre-chamber. This procedure diminishes the chances of carrying clothing into the greenhouse that may be impregnated with insects.

The makeshift arrangements for seed yam production does not provide an ideal environment due to the lack of control on temperature and pest and disease infestation. Yam plants generated in the aeroponics system were frequently infested (19–29%) by *Colletotrichum* sp. (both leaves and stems), *Sphaerosporium* sp. (stems) (typically saprophytic), and *Fusarium* sp. (stems). Steps are being taken towards reducing the heat inside the screenhouse through the use of industrial fans and enhanced shading. To take appropriate measures against fungal pathogens, plants to be used in the aeroponics system have to be tested and certified free of diseases and pests.

Another challenge is the necessity to identify appropriate fertilizers in terms of types and rate adapted to seed yam production in an aeroponics system and their availability. In fact, the fertilizers actually currently being used were procured in four countries: Bénin, Ghana, Kenya, and Nigeria.

Conclusion

Despite the fact that yam propagation in the aeroponics system is in an embryonic stage, less than one year old, some of the results obtained so far are very encouraging. It is now known that seed yam can be produced by this method. Both pre-rooted and fresh vine cuttings can be used for seed yam production using this technique. For success in the aeroponics system, an appropriate greenhouse should be constructed and the sanitation rules set up for potato seed production must be respected. Micro-tubers, bulbils, and mini-tubers can be rapidly propagated using the aeroponics technique.

References

- Acha, I.A., H. Shiwachi, R. Asiedu, and M.O. Akoroda. 2004. Effect of auxins on root development in yam (*Dioscorea rotundata*) vine. *Tropical Science* 44: 80–84.
- Agele, S.O., T.G. Ayankanmi, and H. Kikuno. 2010. Effects of synthetic hormone substitutes and genotypes on rooting and mini tuber production of vines cuttings obtained from white yam (*Dioscorea rotundata*, Poir). *African Journal of Biotechnology* 9(30): 4714–4724.
- Balogun M.O. and B. Gueye. 2013. Status and prospects of biotechnology applications to conservation, propagation and genetic improvement of yam. Pages 92–112 in *Bulbous Plants: Biotechnology*, edited by Kishan Gopal Ramawat and Jean-Michel Merillon. CRC Press, USA.
- Barker, B.T.P. 1922. Studies on root development. Long Ashton Research Station Annual Report 1921: 9–57.
- Biddinger, E.J., C.M. Liu, R.J. Joly, and K.G. Raghothama. 1998. Physiological and molecular responses of aeroponically grown tomato plants to phosphorous deficiency. *Journal of the American Society for Horticultural Science* 123: 330–333.
- Carter, W.A. 1942. A method of growing plants in water vapor to facilitate examination of roots. *Phytopathology* 732: 623–625.
- Ikeorgu, J.E.G. and M.C. Igbokwe. 2003. Seed yam production with minitubers. *Nigeria Agriculture Journal* 34: 63–67.
- Ikeorgu, J.G., H. Oselebe, J. Oluwatayo. K. Ugwuoke, U. Ukpabi, and R. Asiedu. 2007. Farmer participatory evaluation of four hybrid, water yam clones in the yam belt of Nigeria. Pages 226–230 in *Securing Livelihoods through Yams*, edited by B. Nkamleu, D. Annang, and N.M. Bacco. Proceedings of a technical workshop on progress in yam research for development in West and Central Africa held in Accra, Ghana, 11–13 September 2007.
- Lung'aho, C., M. Nyongesa, M.W. Mbiyu, N.M. Ng'ang'a, D.N. Kipkoech, P. Pwaiswai, and J. Karinga. 2010. Potato (*Solanum tuberosum*) minituber production using aeroponics: another arrow in the quiver?. In *Proceedings of the 12th Biennial Conference of the Kenya Agricultural Research Institute*.
- Kalu, B.A. and P.O. Erhabor. 1992. Production and economic evaluation of white Guinea yam (*Dioscorea rotundata*) minisetts under ridge and bed production systems in a tropical Guinea savanna location, Nigeria. *Tropical Agriculture* 69: 78–82.
- Kang, J.G., S.Y. Kim, Y.H. Om, and J.K. Kim. 1996. Growth and tuberization of potato (*Solanum tuberosum* L.) cultivars in aeroponic, deep flow technique and nutrient film technique culture films. *Journal of Korean Society of Horticultural Science* 37: 24–27.
- Kikuno, H., R. Matsumoto, H. Shiwachi, H. Youhara, R. and Asiedu. 2007. Comparative effects of explants sources and age of plant on rooting, shooting and tuber formation of Vine cutting of yams. *Japanese Journal of Tropical Agriculture* 51(Extra issue 2): 71–72.
- Kim, H.S., E.M. Lee, M.A. Lee, I.S. Woo, C.S. Moon, Y.B. Lee, and S.Y. Kim. 1999. Production of high quality potato plantlets by autotrophic culture for aeroponic systems. *Journal of Korean Society of Horticultural Science* 123: 330–333.
- Mbanaso, E.N.A., C.N. Egesi, E. Okogbenin, A.O. Ubalua, and C.K. Nkere. 2011. Plant biotechnology for genetic improvement of root and tuber crops. Pages 45–64 in *Root and Tuber Crops Research for Food Security and Empowerment*, edited by C.O. Amadi, K.C. Ekwe, G.O. Chukwu, A.O. Olojede, and C.N. Egesi. National Root Crops Research Institute, Umudike, Nigeria.
- Nugali Yadde, M.M., H.D.M. de Silva, R. Perera, D. Ariyaratna, and U.R. Sangakkara. 2005. An aeroponic system for the production of pre-basic seed potato. *Annals of the Sri Lanka Department Agriculture* 7: 199–288.
- Okigbo, B.N. and D.G.E. Ibe. 1973. New method of yam propagation. Paper prepared for the Third Symposium of the International Society for Tropical Root Crops, IITA, Ibadan, Nigeria. 2–9 December.
- Okoli, O.O. and M.O. Akoroda. 1995. Providing seed tubers for the production of food yams. *African Journal of Root and Tuber Crops* 1(1): 1–6.

- Okoli, O.O., M.C. Igbokwe, L.S.O. Ene, and J.U. Nwokoye. 1982. Rapid multiplication of yam by the miniset technique. Research Bulletin 2. National Root Crops Research Institute (NRCRI), Unudike, Nigeria, 12 pp.
- Onwueme I.C. 1977. Field comparison of West African planting and harvesting practices in yam (*Dioscorea rotundata*): pre-sprouting, dry season planting, and double harvesting. The Journal of Agricultural Science 88(2): 311–318.
- Otazú, V. 2010. Manual on quality seed potato production using aeroponics. International Potato Center (CIP), Lima, Peru. 44 pp.
- Otoo, J.A., D.S.O. Osiru, S.Y.C. Ng, and S.K. Hahn. 1987. Improved technology for seed yam production. Second edition. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. 56 pp.
- Went, F.W. 1957. The experiment control of plant growth. Ronald Press, New York.

