TRAINING FOR AEROPONICS TECHNICIANS/OPERATORS IN MAXIMIZING EARLY GENERATION SEED (EGS-MINITUBER) POTATO PRODUCTION IN RWANDA

TRAINING REPORT AND RECOMMENDATIONS

13-23 JUNE, 2023
RAB, MUSANZE, RWANDA

Prepared by

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1 JUSTIFICATION FOR THE AEROPONICS TRAINING

Aeroponics is a highly specialized skill/knowledge set, with few having knowledge/experience in the technology. Aeroponic facilities which were introduced by CIP in Rwanda and other EA countries in 2010/11 to increase production of early generation seed (EGS) are currently performing below the potential, and with many risk factors. For example, the aeroponics facility constructed in 2022 by Seed Potato Fund (SPF) in the Musanze region, Rwanda is very new (only in the second production cycle) and they are already facing several technical challenges. The other aeroponics facilities in the county are facing similar challenges or have stopped operating. Both low productivity at the aeroponics facilities and nonfunctional aeroponics facilities translates to a loss of income for Early Generation Seed (EGS) seed producers and a loss of opportunity for potato farmers in accessing certified seed potatoes.

Through the two-year (2023-2024) USAID-funded project, Partnership for Seed Technology Transfer in Africa (PASTTA 2), CIP prioritized activities towards increased production of EGS. Maximizing EGS-mini tuber potato production in aeroponics facilities was identified as a key demand-driven intervention under the project. Both the public and private institutions engaged in EGS production had requested support from CIP for tackling the technical challenges limiting EGS productivity in the aeroponics units. For example, the Manager, SPF-IKIGEGA, a large-scale private seed multiplier requested technical backstopping in solving challenges constraining minituber production in their newly constructed mega aeroponics facility.

Table 1. What Do We Know About Aeroponics?

WHAT WE KNOW IN AEROPONICS ?

- ✓ Pre-basic seed can be increased drastically
- ✓ Potato cultivars respond differently
- ✓ It is sensitive weather conditions
- ✓ Vegetative growth stage is lengthened
- ✓ Sequential harvests are needed
- ✓ Aeroponically produced minitubers yields the same as minitubers from conventional methods
- ✓ Some soilborne bacteria have been shown to increase minituber production significantly
- ✓ Initial Investment can be recovered rapidly
- ✓ Higher income can be obtained/production cost can be reduced

Some of the key challenges identified included: incorrect nutrient formulation, low number of minitubers/plant which in turn resulted in low minituber production /cycle and consequently low starter material for the following seed classes (basic seed through to certified seed), premature dying of plants and other risk factors leading non functionality of some of the aeroponics units.

To provide the much-needed technical backstopping, CIP engaged Dr. Victor Otazu, a former CIP Scientist and a globally recognized aeroponic specialist. Victor introduced aeroponic technology in Rwanda when he was working at CIP in 2010/11. He supervised the construction and operationalization of the first facility at Rwanda Agriculture and Animal Resources Development Board, (RAB Musanze), and trained the initial cohort of lab technicians most of who have left the stations. After the construction in 2011, Victor continued to provide technical support before he retired from CIP in 2015. Currently, Victor is actively providing a helping hand in seed potato technologies in many countries including Peru, his home county, and China. Additionally, the project partners, RAB and SPF in Rwanda specifically requested if they can get technical expertise from Victor Otazu who introduced the technology and has worked with them in the past.

2 LEVEL OF ADOPTION OF AEROPONICS TECHNOLOGY 12 YEARS LATER

Dr. Victor Otazu had not visited Rwanda since he constructed the first aeroponics in RAB Musanze in 2011. Victor was therefore impressed to see larger aeroponics structures with structural improvements compared to the initial aeroponic module that was constructed about 12 years ago at RAB Musanze with support from CIP under the 3G USAID-funded program. The original aeroponics structure has since been converted into a diffused light store (DLS), and two improved structures constructed at RAB, Musanze. The adoption of aeroponics technology has expanded with several private organizations having constructed the facility for seed potato production.

Table 2 provides a list of some of the private institutions that are currently operating aeroponics and/or previously operated aeroponics but are currently not operational. It is worthwhile to mention Seed Potato Fund (SPF-IKIGEGA) which owns a mega aeroponic unit newly constructed in 2022.

Table 2. Private and Public Institutions Owning Aeroponics Facilities for EGS Seed Potato Production in Rwanda

Name of Institution	Type of institution	Year of construction establishment	Capacity	# of production cycle/season/yr	Current status (June 2023)
RAB, Musanze	Public	2013-2015	2 units @ with 50 boxes of 7 m holding 180 plants/box, Total 9,000 plants	2 seasons/yr	Operational
Seed Potato Fund (SPF-Ikigega	Private	2022 by private joint venture enterprise	72 boxes of 5 x 1.2 x 1m 15,000 plants.	2 seasons/yr	Operational
Appolinare Karegeya (Nyange)	Private	2015 by individual seed producer	10 boxes of 7.20 x 1.2 x 1m 2400 plants		Not working
Mudende Seed Production Ltd	Private	2018 with the support of USAID.	20 boxes of 5m each		Not working

3 TRAINING PROGRAM, 12th – 23rd JUNE 2023

The practical training sessions were facilitated by Dr. Victor Otazu from 12th to 23rd June 2023. The training program (Annex 3) on aeroponic production of seed potatoes was carried out at Rwanda Agriculture and Animal Resources Development Board (RAB), Musanze, and at the mega aeroponics facility of the Seed Potato Fund (SPF-IKIGEGA). A total of 11 staff working at the aeroponics facilities attended the on-site training sessions, Table 3. Out of the 11 trainees, six were staff from RAB Musanze and five from private institutions that own aeroponics facilities.

Table 3. List of Aeroponics Technicians Trained in Aeroponics Technology Management, 12-23 June 2023, At Rwanda Agriculture and Animal Resources Development Board, Musanze, Rwanda

Nº	Name	Venue	Organization
1	MUNYANKERA Elias	MUSANZE	RAB
2	KAREGEYA Appolinaire	MUSANZE	Private seed producer
3	HAGUMIMANA Leonidas	RUBAVU	Mudende seed company
4	AHISHAKIYE Domitilie	MUSANZE	RAB
5	UWAYISABA William	MUSANZE	Private seed producer
6	NKAMIRABATUJE Analyse	MUSANZE	RAB
7	NDACYAYISENGA Theophile	MUSANZE	RAB
8	NSABIMANA Evariste	MUSANZE	SPF Ikigega
9	MUJAWAMARIYA Berthilde	MUSANZE	RAB
10	HABUMUREMYI Andre	MUSANZE	RAB
11	BAYINGANA Innocent	RUBAVU	Mudende seed company

Dr. Victor Otazu started the training by conducting an initial evaluation of aeroponics facilities located at RAB Musanze, SPF-Ikigega, Kinigi, and Rubavu. The evaluation reviewed all the processes involved in aeroponics, with special emphasis on nutrient preparation, greenhouse management, and hygiene and sanitation practices, Annex 2.

This was followed by practical training sessions on how to make a risk analysis in an aeroponics facility. Risk analysis of each aeroponic unit was then performed, Table 4, and new protocols were produced with the participation of all trainees. All the practical sessions were conducted at the SPF facility. As a complimentary seed production system, Victor introduced sandponics technology emphasizing its benefits compared to the conventional method of seed potato propagation system mainly used at RAB Musanze.

Figure 1. Aeroponics technicians attending different sessions during the 10-day training facilitated by Dr Victor Otazu at RAB Musanze. The training was conducted between 12- 23 June 2023. Photo Credit: Victor Otazu

Figure 2. *Aeroponics technicians attending different sessions during the 10-day training facilitated by Dr Victor Otazu at RAB Musanze. The training was conducted between 12- 23 June 2023. Photo Credit: Victor Otazu*

Table 4. Risk Analysis for four Aeroponic Facilities in Rwanda. The Analysis was Conducted on 25 June 2023

Location	Risk Factor	Impact	Prob. of Occurrence	Risk level
Mudende-Priv.	Adequate electricity**	5	5	25
	Adequate climate	2	2	4
	Water quality	2	4	8
	Supporting equipment	3	5	15
	Staff training	3	4	12
	Logistics and administration	3	2	6
	Total Risk value			**70**
RAB Musanze	Adequate electricity	1	1	1
	Adequate climate	3	3	9
	Water quality	2	2	4
	Supporting equipment	3	5	15
	Staff training	2	2	4
	Logistics and administration	3	2	6
	Total Risk value			**39**
Nyange-Private	Adequate electricity	5	3	15
	Adequate climate	2	3	6
	Water quality	2	3	6
	Supporting equipment	3	5	15
	Staff training	3	3	9
	Logistics and administration	2	2	4
	Total risk value			**55**
SPF _ Private	Adequate electricity	1	1	1
	Adequate climate	1	2	2
	Water quality	2	2	4
	Supporting equipment	3	4	12
	Staff training	2	2	4
	Logistics and administration	1	1	1
	Total risk value			24

*Interpretation:

24-33: Aeroponics can be done with no major risks
34-50: Aeroponics can be performed with caution
>50 : Most probably aeroponics will fail. Consider an alternative technology
**Pumps used are too big for the size of aeroponics. Electricity bills are too high.

4 TOPIC'S COVERED DURING THE TRAINING

The topics covered during the 10-day practical-oriented training session were informed by the findings from the evaluation and risk analysis exercise as detailed in Tables 4 and Annex 1.

For both aeroponics and sandponics practical sessions, the topics of focus included but are not limited to nutrient preparation, assembling of the essential equipment/devices, pest and diseases management, avoiding greening of stolons, and routine monitoring and evaluation. At the end of the training sessions, general maintenance procedures after each production cycle were reviewed with all participants.

1) Recommended Nutrient Preparations

An important aspect of the training had to do with nutrient preparation. None of the participants knew the recommended expression of nutrients in ppm (parts per million). Also, they were not aware of the existence of a new manual that CIP produced with the participation of 3 Latin-American institutions (hard copies in Spanish, English version only online). The manual is useful and contains more key information on aeroponics.

Manual on seed quality potato using aeroponic: https://cipotato.org/wp-content/uploads/2014/08/005447.pdf

Manual for seed potato production using aeroponics. Ten years of experience in Colombia, Ecuador and Peru: https://cgspace.cgiar.org/handle/10568/98459

The protocol on nutrient preparation explains how African institutions adopted the current formulation based on Calcium nitrate, because at that time there was no alternative (no ammonium nitrate was available in Africa by then). Consequently, institutions are not using optimized formulations in order to improve aeroponic production.

Generally, there is no generic optimum formulation, because there has been no specific research done to optimize aeroponics minituber production. Consequently, regions adopt their own unique formulation. For instance, Latin-American institutions use 200 ppm of calcium which translates to 700 g of Calcium nitrate/1000 litres of water against 236 g of Calcium nitrate /1000 litres of water that aeroponics technicians were using in Rwanda. Thus, there is need to adopt a new protocol to improve the current formulation used in the Rwandan aeroponics units.

From the practical training session, the trainer found out that the Calcium nitrate that was being used at the SPF facility and which was in the original sack did not look like calcium nitrate fertilizers. The color and texture of the fertilizer were different and its solubility was different. The trainer suspects it could be a phosphate fertilizer. However, the color and solubility of the same fertilizer at RAB Musanze was normal, and different from the same fertilizer at SPF.

2) Proper Assembling of the Essential Equipment/Devices

Essential aeroponic components in some of the aeroponics units were not properly assembled. For example, at the Mudende location, two 3HP pumps had been installed. The size of each pump is too large for a small size facility and it uses a lot of electric power resulting in high electricity bills and increasing production costs.

Besides, the drainage pipe that collects the recirculating nutrient solution is at the same level of the lowest part of each box leading to poor recirculation. Only the facility at SPF had a drainage filter. The filter is important to retain pieces of root tissue and dropped minitubers entering to the nutrient tank.

3) Pest and Diseases Management

The trainer observed an alarming incidence of powdery mildew in the operational units and particularly at SPF. At the SPF unit, the trainer noticed that the technicians did not recognize the disease problem and so no control measures were put in place. Consequently, potato plants were dying prematurely, about 4 months after transplanting. Under good management, plants in aeroponics will produce minitubers for 5-6 months after transplanting. This, therefore, calls for routine scouting and control of fungal disease and good management of the aeroponic facility.

Caution: It is important to note that an adverse reaction of nutrients with cement from concrete walls/floors can also be the reason for the premature death of the plants in the aeroponics units. The plastic lining is recommended for use in the aeroponics unit. For example, RAB Musanze which uses plastic lining did not have this problem of powdery mildew infestation.

Control Check at SPF: After controlling powdery mildew, SPF should be keen during the next production cycle, to see if early death of the plants will occur. If they have a normal production cycle, with an efficient powdery mildew control, then powdery mildew was the cause of the premature death of plants.

4) Avoiding Greening of Stolons

At both SPF and at RAB Musanze, the trainer observed some incidence of the greening of stolons. Stolons, when exposed to some light, instead of forming tubers, will start to turn green and will behave as stems. To avoid this situation, the trainer emphasized the importance of having proper light blocking in all the boxes as described in the manuals.

5) Routine Monitoring and Evaluation

In all the four aeroponics facilities, there was a lack of a proper monitoring program to check nutrient quality, greenhouse weather information, and insect and disease incidence.

Yellow Traps: Though all four facilities had placed yellow traps in their units, there is no record of a weekly or monthly recording of insect incidence. Some traps were already crowded with aphids, an indication of poor-quality control measures in greenhouses. The trainer emphasized the importance of insect surveillance through regular recording of insect infestation and regular replacement of yellow traps.

Rwanda Inspectorate, Competition, and Consumer Protection Authority (RICA), performs the quality test of all greenhouses, analyzing the leaf material of plants in order to detect virus diseases. Pre-basic seeds must be disease-free.

pH and EC Meter: Electric conductivity (EC) meter measures the total salts in the nutrient, and the pH meter measures the range of acidity or alkalinity of the nutrient solution. Both pieces of equipment are essential during nutrient solution preparation and for monitoring the nutrient status during the production cycle of aeroponics. In the absence of the two devices, technicians would not know when the nutrient solution needs to be changed.

Unfortunately, these equipment's are not available in Rwanda and so they are currently imported from Nairobi, Kenya.

Caution: Although the distributing agents are expected to sell calibrated pH and EC, often this is not done. Therefore, the user/buyer must confirm that the devices are properly calibrated. The trainer found out that some of the devices used by the facilities were not properly calibrated. For example, when he opened a brandnew EC meter and a pH meter at RAB, Musanze, the laboratory pH meter was not working properly either because calibration had not been done or it was malfunctioning. Similarly, a backup pH meter at RAB did not work either. To make it worst the RAB did not have a standard solution to calibrate the EC meter.

Max and Minimum Thermometer: All the four facilities did not have a functional max and min Thermometer in their aeroponic unit which means there is no record of daily temperatures. Surprisingly, all but one location has shading nets, but they are not using them to control temperature fluctuations. Shading nets ae used when temperatures approach 30 ^{o}C.

5 RECOMMENDATIONS

1) Adopt an Environmentally Friendly and Efficient Seed Production System

The trainer observed the ongoing construction of large new infrastructure for conventional seed potato multiplication at RAB Musanze. Both the new and old conventional units require the use of soil substrate which involves expensive sterilization procedures. Soil sterilization, when done with a steam boiler is an expensive operation. When it is done using firewood as is the case at RAB Musanze, it leads to environmental pollution and the destruction of forests.

To align EGS seed potato production activities with the Government, National Environment and Climate Change Policy which aims at a clean, and an healthy environment resilient to climate variability and change, Victor recommended the adoption of sandponics technology.

Sandponics seed production system is cheaper and easier to operate but importantly, it is environmentally friendly compared to a soil-based conventional method, Figure 3. Sandponics is an excellent complementary technology to aeroponics in the sense that it can be used to further multiply very small minitubers obtained from aeroponics units that otherwise would go to waste. It can also be used as an alternative technology to decrease the risk of production.

Figure 3. *Potato plants growing in the sandponics seed production system. Photo Credit: Victor Otazu.*

Table 5. Comparison between Heat Sterilization Method used in Conventional Seed Production System and Sand Disinfection used in Sandponics Seed Production System

LIMITATIONS OF HEAT STERILIZATION	SAND DISINFECTION
○ Most pathogens only die at 70 ºC for ½ hr. ○ Steam boilers are expensive and must use fuel and electricity. ○ Use of firewood is cheaper, but it is not environment friendly. ○ If not properly monitored, excessive temperatures can release toxic Mn from the substrates. ○ Solarization does not eliminate all pathogen population.	○ SODIUM HIPOCHLORITE (SH) IS A COMMON DISINFECTANT (bleach). ○ SH gets deactivated by sun, heat and vaporization and does not harm the environment. ○ A mixture of 1:19 of bleach and water is applied to the sand for 10 min. ○ Then, sand is rinsed with clean water and drained. ○ Sand must be kept in plastic bags to avoid contamination.

2) Use only Genuine Fertilizers

The use of the correct fertilizer type is crucial in aeroponics. During the practical sessions at the SPF unit, the trainer detected one instance in which the color and dissolving property of a sample of "calcium nitrate" fertilizer at SPF did not correspond to the original calcium nitrate fertilizers. While this type of fertilizer may only cause minor damage if applied in the field, it would cause major damage when used in aeroponics.

Since all aeroponic operators import fertilizers from Nairobi, Kenya, CIP-Nairobi should help in identifying the genuine source of aeroponics fertilizers and if possible, take a sample of the questioned "calcium nitrate" fertilizer and make sure that the distributor is aware of this poor quality of the fertilizer they supplied to SPF. Besides, the plastic containers are not properly labeled which can create a problem when calculating ppm.

3) Functional Equipment/Devices

All aeroponics technicians/operators must have the proper equipment/devices and use them according to new protocols: Correctly calibrated pH Meter, EC Meter and Maxi/Min Thermometer, standard solution to calibrate the EC meter, insect traps, and shading nets.

RAB Musanze needs to improve its laboratory facilities in order to provide adequate space to support all essential equipment used in aeroponics.

4) Regular Water Analysis

Regular water analysis must be performed at all locations. Chemical and microbiological analyses are important to determine water quality.

6) Routine Risks Analysis

Whilst a risk analysis was conducted at the start of the 10-day training (June 2023), the findings for each of the four aeroponic facilities provided in Table 3 are only an indication of the actual situation. After making improvements in the structures or management, a new risk analysis must be performed by each institution, and compare the new findings in Table 3. Each operator must make an effort in order to be in the green sector.

7) New Aeroponics Protocols

The new version of the aeroponics manual produced by CIP is only available on line. Only the Spanish version is available as hard copies. It would be useful to download the English version and distribute hard copies to greenhouse managers. There is important information in the new manual.

New protocols developed by Dr Victor Otazu after the training are provided as Annex 2.1.2.2 and 2.3

6 CLOSING CEREMONY AND AWARDING OF CERTIFICATES TO THE TRAINED TECHNICIANS

During the last day of the training, a wrap-up interactive session was organized for the trainer to present key findings and recommendations to enable the trained technicians /operators to maximize EGS minituber production in aeroponics. The meeting provided a question-and-answer session for trainees to seek clarifications from the trainer.

Mr. RUKUNDO Aimable, Station Manager of RAB Musanze thanked CIP for the support and Dr Victor Otazu for facilitating the much-needed practical training. He committed to ensuring all the trained technicians /operators put into practice the skills and knowledge acquired during training. He promised to convert some of the conventional structures to the environmentally friendly sandponics seed systems.

"*The training in aeroponics was long overdue because our technicians have been making mistakes, especially in mixing the fertilizers used in their respective units. On the other hand, the training on Sandponic has come at the right time when the protection of our environment is the responsibility of each one of us. With Sandponics technology, sand will replace soil used in conventional methods thereby saving on cuttings of trees for firewood*" said Theophile NDACYAYISENGA, in- Charge, Potato Program at RAB, Musanze.

Dr Dinah Borus, Project Leader for the PASTTA2 program congratulated all the 11 trainees for successfully completing the 10- day training. She thanked Theophile NDACYAYISENGA, for coordinating Victor's visit and all the training logistics.

She appreciated Victor for accepting to come back to Rwanda, 12 years later to bring new ideas and tricks of the trade in aeroponics. She recons Victor's commitment to transforming the global seed potato sector through introduction of rapid seed multiplication technologies including aeroponics and sandponics. Dinah informed the meeting that Victor will be traveling to RAB, Rubona to support the establishment of sandponics facility for sweetpotato vine multiplication.

"*Maximizing EGS for potato is one the priority interventions that CIP through PASTTA2 program is supporting to enhance production and access of certified seed potato for potato farmers in Rwanda and maximizing minituber production from aeroponics facilities is an entry point*". Dinah concluded.

On behalf of the trainees and institutions that own aeroponics facilities, Mr. Appolinaire KAREGEYA, the first private individual farmer who adopted aeroponic technology, (Nyange unit, constructed in 2015), thanked RAB and CIP for supporting the much-needed training. He specifically thanked Victor for sharing his knowledge and skills with aeroponics owner in Rwanda and for his commitment to see that each unit if functional. Appolinaire is the Chairperson of the SPF aeroponics facility.

"*We have learned new ideas and tricks of the trade in aeroponics and we commit to putting into practice what we have learned, our passion is see that every potato farmer has access to certified seed potatoes and even have supply for cross border trade*" said Appolinaire.

At the end of the meeting, all 11, trained aeroponics technicians/operators were awarded a certificate of completion (Figure 4). Among the trainees, Evariste NSABIMANA received special recognition for his skills and competence in the construction and management of aeroponics and sandponics seed potato production systems.

7 PERSONAL REFLECTION FROM THE TRAINER

Finally, I would like to mention that I was the one who started aeroponics at CIP-Huancayo in Peru, Lima, and I am happy to see all the improved facilities in Rwanda. My intention is not to criticize persons or institutions in Rwanda, but I want to see successful technology at all locations in order to improve seed potato production. That is why when a private operator asked a question at the closing ceremony on 23rd June 2023, on who will give technical support to the private sector after I leave, I suggested that RAB should do it, and when they cannot handle a particular situation, they can contact me through my e-mail: viota68@gmail.com

"*My stay in Rwanda was a personally enriching experience. I am grateful to CIP for enabling me to reconnect with the aeroponics team in Rwanda to share my global experience and introduce new ideas to the aeroponics facilities in Rwanda*". Victor Otazu concluded.

Figure 4. Top: A wrap-up interactive session during the closing ceremony at RAB, Musanze, 23rd June 2023. Bottom. Group photo of all the trained aeroponics technicians after receiving a certificate of completion. Photo Credit: Victor Otazu

8 Annexes

8.1 Annex 1. Evaluation Report on Aeroponic Facilities in Rwanda as at 20th June 2023

SPF Ikigega

This impressive facility was built in 2022 by a private joint venture enterprise. An adequately designed greenhouse contains 72 boxes of 5x1.2x1 m. with a capacity to plant 15,000 plants. They produce 2 seasons/year. Calcium nitrate-based nutrient solution is used in the two 5000 litre tanks, each with a 2 HP pump, which is adequate for the size of operation. Besides, they have solar panels as a backup, when there is no electricity. The production manager (Evariste Nsabimana) was trained during my first visit to Rwanda when we constructed the first aeroponic module at the RAB Musanze station. Apart from him, all of the actual staff is new. The aeroponic boxes were built with concrete and Styrofoam tops. The side windows are covered with a layer of black plastic and a movable metallic cover. Apparently, the unit is working well, with a production per plant of 45-72 minitubers, depending on the cv used, with an average of 54 minitubers/plant. Actually, they have 10 varieties growing and are already producing minitubers.

The manager was concerned about the presence of minituber malformation in some cases, fearing that may be due to some disease. This situation is due to physiologic disorders and when planted in the field, they will produce normal tubers. The other aspect had to do with the early browning of the root system. According to the manager, this may be due to the fertilizers used. During the practical training, we must get more information on this site, but some indicators tell me that the management of the unit has to be improved. They do not have a thermometer (**Max. Min), an EC meter, or a pH meter**. These instruments are important during the conduction of aeroponics.

Presently in aeroponics, the measurements of nutrients are expressed in ppm. They are not used to this terminology. The maintenance of the irrigation system after each production cycle was another concern. This aspect will be covered during the practical session. Finally, it was apparent that some cultivars produce many small (>6g) minitubers, which do not perform well when planted in the field. Since SPF has another facility that they plan to use to produce in-vitro plantlets, this facility can easily be converted to a sandponic unit as a complementary facility to aeroponics. Small (<6g) minitubers produced from the aeroponics unit can be planted under a sandponics system where they have been shown to perform well. SPF is interested in sandponics technology which is expected to reduce its production risk.

Appolinaire Karegeya (Nyange)

William Uwayisaba manages this private facility. The greenhouse is adequately designed and contains 10 boxes of 7.20x 1.2x 1m. Each box contains 240 plants, making a total of 2400 plants. The facility was built in 2015. Due to difficulties to get Styrofoam, the materials used for box construction are wood and plywood. The nutrient solution used is based on calcium nitrate. All fertilizers are imported from Kenya. This is costly and calibration of nutrients is also a problem according to the manager. They have a backup generator for power cuts. They plant only 1 season/year and the cvs used are Kinigi and Kirundu. The production is rather poor. They only get 10-20 minitubers/plant. They do not have a thermometer; EC meter or pH meter and the management seems to be poor.

With some training, the production may be improved. However, this facility is a candidate to fail after the risk analysis exercise. I have to interview the owner and the manager to get more information and see the possibility to convert one-half of the facility into sandponics.

Mudende Seed Production Ltd.

This unit is almost abandoned. Boxes are used for drying maize kernels. It was built in 2018 with plywood material; and with the support of USAID. The greenhouse has an adequate design (20x10 m) and houses 20 boxes of 5 m each. It has no shading net. They have an electric generator for power cuts. During the first cycle of production, they obtained good yields, up to 60 minitubers/plant. No technician was at the site. A telephone interview with the owner indicated that he is no longer interested in aeroponics because of high electricity bills. After a close inspection, I noticed that the drainage pipe was too high. The drainage has to be below the drainage opening of boxes so that the nutrient solution goes back to the tanks by gravity. In this case, it is evident that a large quantity of nutrient solution remained in the boxes, causing problems in the operation. Besides, after an inspection of the powerhouse I noticed that the pumps were of 3 HP, which is too big for a small operation. As a result, they use a lot of unnecessary electricity. I would like to have a personal interview with the owner to see if he is interested to convert this unit into sandponics.

RAB Musanze

The initial module constructed over 10 years ago no longer exists, but converted into DLS. It has been replaced by 2 large improved aeroponic facilities. Each greenhouse has 50 x 17 m with a high roof of over 4 m, which is adequate for aeroponics. Each facility houses 50 boxes of 7m each, with a capacity to plant 180 plants/box, making a total of 9,000 plants. The boxes are made of wood and plywood. The powerhouse has 2 x 5000 lt tanks, each with a 2 HP pump, which seems to be adequate for the size. Each tank pumps nutrients to 25 boxes alternatively.

There were four areas of concern:

First, the facility lacks a filter in the drainage pipes. The filter is useful to retain root pieces and other organic elements that may cause problems in the operation.

Secondly, only 1 greenhouse is operating all year, with a 2–3-week break for maintenance. On average, they get 25 minitubers/plant. Many cvs yield poorly except two 2 cvs with good performance. In the one production cycle, the unit recorded total crop failure due to an unidentified disease. Probably that is the reason why they are building more infrastructure for conventional operation.

Thirdly, they sterilize their substrate with firewood, which is a problem for the environment.

Lastly, they have to frequently change most of the plywood material of the boxes because of rotting over time.

They Centre Management agreed to convert one of the new facilities for conventional production into sandponics. In this new facility, they can further multiply very small minitubers (less than 6 g) produced in aeroponics, instead of going to waste. In addition, cvs that perform poorly in aeroponics, can be multiplied in sandponics. Therefore, this facility would become a complementary technology to aeroponics, reducing also the production risk.

Evaluation conducted by Dr. Victor Otazu
Musanze, Jun. 20th 2023

8.2 Annex 2.1. Protocol for Nutrient Preparation to be used in an Aeroponic System for Quality Seed Potato Multiplication

Introduction

Initially, when aeroponics started in at CIP-Huancayo in Peru, Lima, the Agrarian La Molina University based in Peru came up with the nutrient formulation. The same formulation was used in other trials with the nutrient film technique (NFT). This formulation contained ammonium nitrate, potassium nitrate, calcium triple superphosphate, magnesium sulfate, and micronutrients.

In Kenya, when the "3G"[1] project supported the introduction of aeroponics technology in 2009, it was not possible to locally obtain ammonium nitrate. Trying to replace the nutrient solution was difficult. However, a Mauritius scientist who was conducting trials with aeroponics seed production systems and who came to Kenya to learn more about aeroponics procedures came up with an alternative. He was using a calcium nitrate based-nutrient solution, and this was adopted in Kenya. The same formulation is still currently used in most African locations.

However, according to Andrade-Piedra, et al. 2019, there are many institutions involved in the aeroponic production of early generation seed potatoes and they are using different formulations for the nutrient solutions. Additionally, it is not possible to recommend a generic rate because each fertilizer in a given location may have different formulation and concentration. Consequently, concentration of nutrients is now expressed in parts per million (ppm). I ppm = 1 part of nutrient in 1 million parts of water.

In order to standardize procedures, it is necessary to re-calculate the amounts of nutrients to make standard nutrient solutions for aeroponics. CIP-Lima and other Latin-American institutions are using the following amounts of nutrients in ppm (Andrade Piedra, et al, 2019), Table 6. These amounts of nutrients are based on growth observations of potato plants and other crops like tomatoes. Overall, there is no blanket formulation to optimize minituber production.

Table 6. Amount of Nutrients used in Aeroponics units by CIP-Lima and other Latin-American Institutions

Macro and Micro Nutrients	Parts per Million (ppm)
N	190 initial and 160 final
P2O5	80 initial and 100 final
K2O	200 initial and 240 final
CaO	200
MgO	75
S	80
Fe	1
Mn	0.4
Mo	0.04
B	0.13
Cu	0.04
Zn	0.07

From the calculations performed in Rwanda, it is evident that low amounts of nutrients are presently applied. For example, if one needs to apply 100 ppm of P, he/she will need to put 844 g/1000 l of monopotassium phosphate but currently, the aeroponics technicians in Rwanda are only applying 136 g/1000 l. For 200 ppm of

CaO, one needs to apply 700 g/1000 l, of calcium nitrate compared to 236 g/1000 l currently used by aeroponic technicians in Rwanda, Figure 4.

Therefore, there is a need to double the current amounts of monopotassium phosphate and calcium nitrate. The other formulation remains the same as currently used by the technicians in Rwanda. Adjustment can be done based on further observations of plant growth and tuber formation performance of potato plants under aeroponics production systems. It is worthwhile to note that no deficiency or toxicity symptoms were observed with the current formulations in any of the three functional aeroponics units that were evaluated.

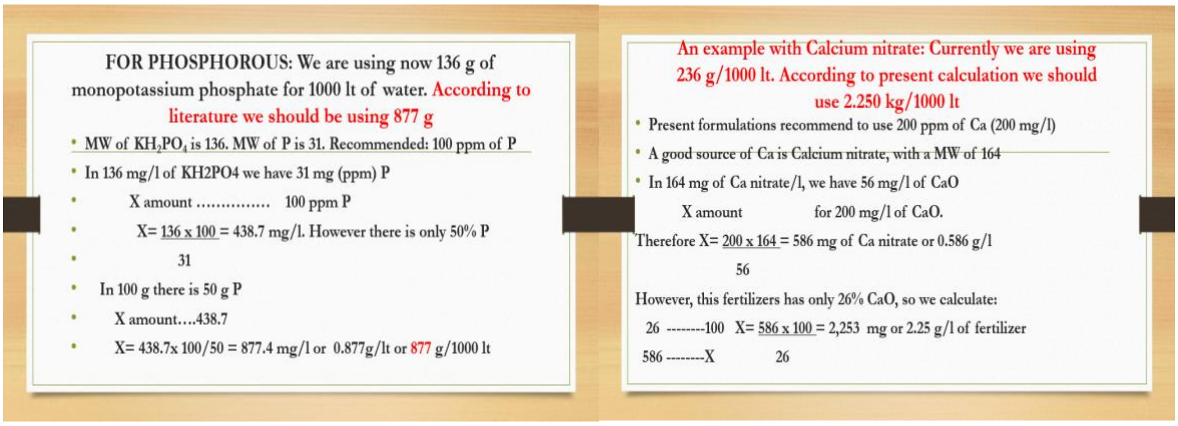

Figure 5. Correct calculations of phosphorus and Nitrogen for Nutrient solutions: Credit photo: Victor Otazu

Essentials Nutrients for Potato Development

Nutrients are contained in Regular Fertilizer and Potato plants need nutrients for proper crop growth and development including

- ✓ MACRONUTRIENTS: Present in plant tissue - 4% of the dry weight of the plant.
  - They are: N, P, K, Ca, Mg, and S.
- ✓ MICRONUTRIENTS: Present in plant tissue in small amounts (200 ppm)
  - They are: Fe, Mn, Cu, Zn, B, Cl, Mo

Table 7. Types of Fertilizers used in Seed Potato Aeroponics Productution Systems in Rwanda (June 2023)

FERTILIZER	FORMULAR	CONCENTRATION (%)
Calcium nitrate:	$CaCO_3$	15.5% N, 26% CaO
Monopotassium phosphate	KH_2PO_4	P:52%, K:34%
Potassium nitrate:	KNO_3	N:13%, K:46%
Magnesium sulfate:	$MgSO4.7H_2O$	Mg:9.6%, S:12.9%
Microsol B, Fe EDTA		

Procedure for Preparation of a 20lt of Nutrient Solution for a 1000 l Tank

1. In a 10-litre bucket, place 272 g of monopotassium phosphate, adding 10 litres of water. Wait for ½ hr. Warm water helps to dissolve the fertilizer quickly.
2. With the help of a piece of net, crush the fertilizer until it totally dissolved.
3. In another 10-litre bucket, place 472 g of calcium nitrate in a 5 litres of water. It should dissolve readily.
4. In another 10-litre bucket, add 504 g of potassium nitrate adding 5 l of water.
5. Mix well and add 492 g of magnesium sulfate in the 3rd bucket.
6. Add 23.4 g of Fe EDTA and 12 g of Microsol B in the 3rd bucket.
7. Mix well and add all 3 containers to the 1000 l tank. First monopotassium phosphate, second calcium nitrate and finally the last mixture.
8. Adjust for 2000 or 5000 l capacity tank.
9. Measure pH and EC of final solution and make necessary adjustments. EC readings should not exceed 2.0, and pH should not exceed 7.2.

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[1] https://cgspace.cgiar.org/bitstream/handle/10568/57047/77302.pdf?sequence=1&isAllowed=y

8.3 Annex 2.2. Protocol for Management of a Greenhouse used for Aeroponic Seed Potato Production

Introduction

Besides nutrient preparation, and hygiene and sanitation management practices and procedures, the aeroponics' greenhouse managers are expected to diligently perform other essential practices including temperature control, pest and disease control, and regular monitoring of pH and EC for the nutrient solutions. In different locations, these practices and procedures are not uniformly observed, nor are they correctly applied. Therefore, it is necessary to establish a protocol in order to have uniform practices and procedures for aeroponics technicians/managers to optimize minituber production.

Correct Nutrient Formulation and Preparation

Refer to protocol 2.1.

Temperature Control

Potato plants are stressed by high temperatures (higher than 30 ^{o}C). Thus, it is important to monitor the temperatures in the greenhouse on a daily basis. Shading nets should be used to lower temperature when temperatures approach 30 ^{o}C.

Monitoring equipment

- ✓ Max and Min thermometer

Pest and Disease Control

The major pest and disease problems encouraged in greenhouses include the prevalence of aphids, the infestation of late blight, and powdery mildew. Yellow traps are useful in controlling insects, but most importantly, they are more useful to monitor aphid populations in the greenhouse in order to determine if pesticide application is necessary.

Safe use of pesticides should always be observed and pesticides should never be applied to the rooting system.

A dark brown color of the root system is normally attributed to excess humidity and poor oxygenation. An application of 5000 ppm hydrogen peroxide (H_2O_2) to the tank will help to control browning. However, a lower concentration should be used at the start.

Essential Materials

- ✓ Yellow traps
- ✓ Fungicides; Recommended fungicides for late blight control and powdery mildew - Metalaxyl-MZ, S-containing fungicides, Benomyl or any available
- ✓ Insecticides: recommended pesticides found in local market for aphid control.
- ✓ Hydrogen peroxide (for testing)

Regular Monitoring of pH and EC of Nutrient Solutions

The Electric Conductivity (EC) meter measures the total salts in the nutrient, and the pH meter measures the range of acidity or alkalinity of the nutrient solution. Both pieces of equipment are essential during nutrient solution preparation and for monitoring the nutrient status during the production cycle of aeroponics. In the absence of the two devices, technicians would not know when the nutrient solutions need to be changed.

Monitoring equipment

- ✓ EC meter, pH meter

Mandatory Management Procedures in the Aeroponics Unit

1. At the beginning of each production cycle, i.e., Immediately after the transplanting process, place **yellow traps** in the greenhouse.
2. One yellow trap must be located at the door, and the others in each box. Use a minimum of 3 traps per 7m long box.
3. **Yellow traps** must be inspected every week, and the number of aphids trapped is recorded in the notebook/record sheet. If excessive numbers of aphids are recorded within a short time, period, then the manager must check if there are some openings/holes/leakages and/or if there are careless personnel. Take the immediate necessary control measures to normalize the situation.
4. **Rule of thumb:** If many aphids are detected in the traps, there must be more in the plants. Therefore, an insecticide must be applied. Use the recommended/registered pesticides found in the local market.
5. After one month of transplanting, **check for disease symptoms**. If some plants show symptoms of powdery mildew, a preventive fungicide must be applied immediately. If the greenhouse is too hot, these fungicides may cause phytotoxicity. Use Benlate or other similar curative fungicides available in the local market.
6. If **late blight symptoms** are evident, remove affected leaves. If symptoms are showing in many plants, proceed with the application of Metalaxyl-MZ fungicide.
7. Place a **Max-Min thermometer** in each greenhouse, and make daily recordings in a notebook/record sheet. Always erase thermometer readings after recording.
8. Always **record readings** at a certain hour, for instance daily at 10am.
9. The thermometer will read the actual temperature and minimum temperature of a given day between 3-5 am and the maximum temperature of the previous day between 1-4pm.
10. Use the Temperature record to determine when to **place the shading net**.
11. Clean disk filters at least once a week.
12. Clean drainage filters at least once a month.
13. Using a mixture of soap and bleach, clean the anti-aphid net every year. Rinse with water using a power sprayer. Dust always accumulates on the sides. This procedure improves the light inside the greenhouse.

8.4 Annex 2.3. Protocol for Aeroponic Greenhouse Maintenance After a Production Cycle

Introduction

One production cycle of an aeroponics greenhouse takes 5 to 6 months of continuous operation of the irrigation systems and powerhouse. During this period, the floor of boxes accumulates pieces of root remains, tiny minitubers, and other debris. Pipes and nozzles will have salt accumulation that needs to be removed. Fungi and bacteria may also be present.

Therefore, it is important to perform a maintenance procedure before the next production cycle starts. Also, it is critical to check if any repairs are needed to be made to the plastic covers or plywood. Boxes made of concrete will need a different maintenance system compared to the ones made with plywood structures. Small pores on the concrete walls and floors may accumulate dirt and microbes more than plastic, which is easier to disinfect.

Maintenance and Cleaning Materials

- ✓ One bottle of liquid soap/detergent
- ✓ 2 – 3 gallons of bleach (Jik)
- ✓ 4 l of vinegar
- ✓ A big brush
- ✓ 5 units of sponge
- ✓ Protective gloves

Mandatory Maintenance/Cleaning Procedures after Every Production Cycle

1. Clean and sweep the greenhouse.
2. Remove the tops of the boxes and clean them with soap using a sponge. Disinfect the tops with bleach (1% chlorine). Always wear protective gloves.
3. Bleach comes in different concentrations. For bleach with 5% Na hypochlorite, use 200 ml of bleach and 800 ml water (1% solution) or 100 ml of bleach and 900 ml water for 0.5% solution. Adjust accordingly for commercial products with different concentrations.
4. Clean the floors of all the boxes. Be cautious not to damage it as it will lead to seepage.
5. Clean the plastic covers with soap using a sponge and disinfect the covers with a 1% chlorine solution. For concrete covers, use the same procedure with a heavy-duty brush.
6. Remove nozzles and place them in a bucket with vinegar overnight. Vinegar (acetic acid) removes accumulated salts inside the nozzles.
7. Check nozzles if they need additional cleaning.
8. Clean empty tanks (inside) with soap using a sponge and disinfect the tanks with a 1% chlorine solution.
9. Clean the disks and drainage filters.
10. Fill ½ of a tank with water and add bleach to make a 0.5% chlorine solution.
11. Pump out this solution until the tanks are empty.
12. Remove caps at the end of pipes and flush with water.
13. Check for any repairs in the infrastructure.
14. Dry all boxes, replace nozzles, and place the tops on all boxes.

8.5 Annex 3. Training Program for Aeroponics and Sandponics Technicians in Maximizing Early Generation Seed (EGS-Minituber) Production in Rwanda

Date: 12-23 June 2023
Trainer: Dr Victor Otazu
Participants: 11 Public and Private Aeroponics Technicians/operators

Date	Time	Activity
Monday 12/06/2023	14.00 -17.00	- Arrival in Kigali - Travel to Musanze
Tuesday 13/06/2023	8.00 - 12.00 12- 17.00	- Visit RAB facilities/Musanze station Visit Private facilities (Sandponics related activities) - Visit sand sources to select the best - Interact with local plumber - Review locally available materials - Visit GH for sandponics. Make a decision on type of production. Visit Private facilities (aeroponics related activities) - Kinigi site: Farmer Aeroponic - Busogo site : SPF Aeroponic system - Mudende site: Farmer Aeroponic
Wednesday 14 /06/2023	8.00 -13.00 14.00- 17.00	- Introduction to Aeroponic system - Installation of irrigation system - Measurement of nutrient solution vs size of aeroponic system - Hygiene of irrigation system - Potato physiology responses to Nutrient solution
Thursday 15/06/2023	8.00 -13.00 14.00- 17.00	- Appropriate Fertilizers used in Aeroponic their composition and dosage - **Protocol for:** In-vitro plantlets preparation for planting in Aeroponic (Acclimatization and Hardening practical's) - **Protocol for**: Preparation of Nutrient Solution (theory and practical) - Nutrient feeding regime based on crop age in Aeroponic and Measurement of EC, pH, and T° and their impact on potato minitubers. - Measurement of light intensity, Temp and its impact in the Aeroponic system and their impact - **Risk analysis in aeroponics**
Friday 16/06/2023	8.00 -13.00 14.00- 17.00	- **Practicals - Make a risk analysis for Rwanda** - Evaluation report on current practices/ methods and identifying areas limiting the potential of the EGS/minituber production at the aeroponics facilities
Monday 19/06/2023	8.00 -13.00 14.00- 17.00	- **Practicals -** In-vitro plantlets preparation for planting in Aeroponic (Acclimatization and Hardening) - Practical: Preparation of Aeroponic Nutrient Solution
Tuesday 20/06/2023	8.00 -13.00 14.00- 17.00	- Pests and disease management in Aeroponic - Harvesting in Aeroponic and post-harvest handling

Date	Time	Activity
Wednesday 21/06/2023	8.00 -13.00 14.00- 17.00	- Introduction to Sandponic system on potato minitubers production - **Sandponics for seed potato production. Power point presentation** - Screenhouse preparation of sandponics - Preparation of nutrition solutions
Thursday 22/06/2023	8.00 -13.00 14.00- 17.00	- **Practicals -** Preparation of Sandponics Nutrient Solution - **Practicals -** Preparation of Sandponics nursery bed - **Practicals -** Planting invitro-plantlets in Sandponics nursery bed
Friday 23/06/2023	8.30- 17 .00	- Wrap up meeting - Key findings and recommendations - Closing ceremony

9 REFERENCES

1. Andrade-Piedra, J., P. Kromann; and V. Otazu (eds). 2019. Manual for seed potato production using aeroponics: Ten years of experience in Colombia, Ecuador and Peru. Quito, Ecuador. CIP, INIAP and CORPOICA. 265p. https://hdl.handle.net/10568/98459
2. Otazu, V. 2010. Manual on quality seed potato production using aeroponics. International Potato Center (CIP). Lima, Peru 44p

Cover photo: Minitubers produced in an aeroponics facility in Huancayo CIP station, Peru.
Photo Credit: Victor Otazu

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