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Extrapolating technology from research plots to commercial scale and challenges involved: Case study of plantain macro-propagation technique

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Commercialization of research technologies and innovations by research institutes is being intensified due to declining government funding for research and dwindling donor inflows. Lack of quality planting materials continues to be a major challenge in the production of plantains. CSIR-Crops Research Institute signed a three-year contract with a private company to supply quality plantain plantlets using the macro-propagation technology. This paper analyses challenges and the lessons learnt in the commercialization by a public research institution, with the macro-propagation for plantain seedlings production as a case study. In 2014, the total seedlings supplied to the private company was 37, 285 with a target of 90,000 while a total of 48,012 seedlings out of a target of 180,000 were produced and supplied in 2015. Lessons learnt to improve production included: (i) Effective supervision of the selection process and uprooting of suckers for paring by technical personnel to reduce diseased, pest infested materials and water suckers; (ii) Sourcing of suckers close to production sites for commercial production of plantlets in order to reduce cost of transportation and also uprooting workable quantities at a time; (iii) The uprooted suckers should be pared on time and buried to avoid deterioration which reduces the multiplication ratio of the pared suckers in the chamber; (iv) Sterilization of sawdust and black soil; (v) Building the capacity of hired labour to acquire the skills and contract them to produce the plantlets at cheaper rates. In addition, research institutions should enter into public-private-partnerships to avoid researchers having divided attention in performing their duties.

Key words: Seedlings, manipulation, macro-propagation, paring, plantlets.

Commercialization of research technologies and innovations by Research Institutes is being intensified due to dwindling donor inflows as well as declining government funding for research and uncertainty in how much funds an institution can attract (Kumi, 2019). In response to Ghana's government request for the thirteen Institutes under the Council for Scientific and Industrial Research (CSIR) to internally generate 30% of their administrative budget, the Council has undertaken reforms to commercialize and upscale developed technologies. This has led to the Council upgrading the Business Development Unit to a full Commercialization Division. Gains from commercialization could be used to support research activities. Effective and efficient

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commercialization of research technologies could be through human capacity development in the form of manpower training, sponsored and contract researches, providing agricultural services, intellectual property rights (licensing, patency, and plant breeder's right), venture capital, and public-private-partnerships among others (Ukwuoma et al., 2013).

The Institute used macro-propagation techniques to efficiently produce quality plantain seedlings on a small scale ranging from 1,000-5,000 seedlings. In 2014, the Institute came out with the production and supply of quality plantain planting materials as one of its flagship projects. Plantain, a perennial crop, matures between 12 and 18 months depending on the variety. It is an important staple food and source of income for smallholder farmers in the Tropics and Sub-Tropics. It is also grown in 52 countries with world production of 37 million metric tons, with Ghana contributing 3.5 million metric tons (FAOSTAT, 2012). In Ghana, plantains are cultivated in six major regions under rain fed. Plantains are often grown as backyard crops or intercropped with food crops, such as yams, cassava, vegetables; and tree crops, such as cocoa, rubber, coffee, and timber species to serve as shade crop for the young seedlings.

Plantains are propagated and cultivated mainly by the use of suckers. Major pests include the banana weevil (*Cosmopolites sordidus*) and a complex of plant parasitic nematodes (*Radopholus similis, Pratylenchus* spp*., Helicotylenchus multicinctus*, and *Meloidogyne* spp.) (Thiemele et al., 2015; Njukwe et al., 2009).

To overcome these constraints, several techniques have been developed for rapid multiplication of plantain planting materials, which include micro-propagation, the *multiplication sur souches décortiquées* (MSD) or macro-propagation (Thiemele et al., 2015; Vuylsteke, 1998). Although planting materials produced using tissue culture techniques can provide large numbers of healthy plantlets, it is usually expensive, though some farmers may be able to afford such plantlets (Ntamwira et al., 2017; Kasyoka et al., 2010). Macro-propagation is a cost effective technology developed by the International Institute of Tropical Agriculture (IITA) and being promoted by Crops Research Institute as an alternative method for producing and rapidly multiplying healthy plantain planting materials. Macro-propagation techniques involve methods that employ whole suckers or relatively large pieces of corm tissue to produce planting materials in a propagator (Tenkouano et al., 2006). Commercialization of the use of macro-propagation techniques has been shown to be profitable. Njukwe et al. (2009) estimated the total cost of constructing and operating a propagator comprising of four chambers with a total capacity of 800 corms at US$ 2,301. By this estimate the 800 corms can produce 8,000 seedlings (1:10). However, the cost and profit margin largely depends on the location, cultivar and methods used and can range from US$ 286 to 1,303 (Ntamwira et al., 2017). Lack of access to disease-free and affordable planting materials often result to high demand for plantain planting materials (Ntamwira et al., 2017). The potential to fill the gap for profit on a large scale was exploited by the commercialization division. The Institute entered into a three-year agreement with a private company that is a rubber plantation and processing company located in the Western Region of Ghana. The company needed the seedlings for three reasons. Firstly, to provide shade for the rubber seedlings, after transplanting. Secondly, to provide food crop for the out growers since most of the arable lands are being occupied by rubber plantations thereby raising concerns about food security in the rubber growing areas. Thirdly, to provide a source of income for the farmers by selling the harvested plantains whilest waiting for the 6 years before the rubber trees could reach tap-able sizes to generate income for the farmers. This paper analyses the challenges faced in the production of the planting materials and lessons learnt in overcoming these challenges in future productions.

MATERIALS AND METHODS

The Institute had two options to approach the production of the seedlings. Firstly, the Institute's tissue culture laboratory was considered. However, the tissue culture, which uses micro-propagation method, takes comparatively longer period to produce seedlings in the situation where proliferating cultures are not available and cultures have to be initiated from field materials. And, due to the urgency at which the private company needed seedlings for their farmers to plant in 2014, the tissue culture method could not be used to meet the timeline. Tissue culture production was therefore, targeted for the 2015 supply. The second option was the use of macro-propagation that takes about 12-18 weeks. The Institute selected this method. Macro-propagation generally consists of generating seedlings from clean planting materials by removing the apical meristems and this involves the following steps: construction of propagators; filling of propagators with smooth sawdust; selection of suckers; preparation of ex-plants and planting; propagator management; potting mixture preparation; rooting; and acclimatization (Njukwe et al., 2009). In 2014, the Institute constructed 48 propagators to produce 60,000 seedlings at Fumesua (Head office) and 37 propagators to raise 30,000 seedlings at Aiyinasi (out-tation of CSIR-CRI located in the Western region of Ghana). Fumesua was chosen because of availability of skilled human resources and close monitoring by Management. Three staff members from Aiyinasi were brought to Fumesua to be trained after which they went back to Aiyinasi to start the production of the 30,000 seedlings. Some of the 60,000 seedlings produced at Fumesua were to be transported to Aiyinasi for hardening before supplying to the company. Suckers were out sourced from Nkoranza in the Brong Ahafo Region as raw materials for manipulation.

After the 2014 production, management decided to move the production from Fumesua to Aiyinasi due to high transportation costs of seedlings and mortality rates recorded owing to poor road network to the private company. In 2015, the tissue culture method could not produce the required quantities of plantlets due to intermittent power supply, which seriously affected production. The macro-propagation method was used with all the production done at Aiyinasi which was closer to the private company. Sawdust was used in 2014 and 2015 as substrate in the humidity chamber

Table 1. Summary of suckers out-sourced for the macro-propagation in 2014 and 2015.

Date	Number of suckers supplied	Number of ex-plants nursed		Number of suckers rejected/ discarded	
		Number	Percentage	Number	Percentage
17/03/2014	3,000	2,908	96.93	92	3.07
04/04/2014	2,000	1,957	97.85	43	2.15
28/04/2014	3,000	2,700	90.00	300	10.00
13/02/2015	5,000	3,374	67.48	1,626	32.52
03/03/2015	4,000	2,800	70.00	1,200	30.00
17/03/2015	3,150	3,117	98.95	33	1.05
05/05/2015	4,000	3,950	98.75	50	1.25
26/06/15	2,994	2,844	94.99	150	5.01
Total	**27,144**	**23,650**	**87.13**	**3,494**	**12.87**

Figure 1. Picture of rejected out-sourced suckers due to defects.

without sterilization. The poly bags were filled using black soil from decomposed refuse dump site without sterilization.

RESULTS

The study revealed that, the following are very important if macro-propagation is to be used in commercial production of plantain planting materials namely, labour availability, selection of suckers, sucker removal, time of uprooting suckers, paring/treatment of suckers, substrate source and type, nursery practices, plantlet survival rates after harvesting from the humidity chamber, transportation, and production costs.

Sucker selection for macro-propagation

In both years, suckers were out-sourced from farmers' fields as raw materials for the manipulation. Table 1 gives the quantities of suckers out-sourced, rejected and successfully manipulated. In 2014 and 2015, quantities of suckers out-sourced were 8,000 and 19,144 respectively. The quantities rejected due to defects were 3,494 suckers representing 12.87%. In 2015, about 19,144 suckers were needed for manipulation to produce 180,000 seedlings. A total of 15,994 suckers were outsourced and brought to the Aiyinasi Station, 12,824 were pared with 3,170 rejected (Figure 1) representing 80.18 and 19.82% of suckers, respectively.

Time of paring to nursing of explants

The uprooted suckers should be manipulated in time and buried in the sawdust to avoid deterioration, which reduces the multiplication ratio of the explants in the chamber. In situations where suckers will have to be

Figure 2. Picture of suckers that did not survive at the nursery in Aiyinasi.

transported for long distances to manipulation site, there should be enough labour to handle the manipulation before burying and also secondary manipulation in the chambers. Preferably, explants should be buried within 48 hours to achieve high sprouting percentage. In 2014, a sub-objective was to use the opportunity to train more staff and this resulted in shortfalls in achieving set targets. Manipulation was affected as the trainees either did not remove the apical, or cut too deep into the flesh creating wounds for disease infections thus, reducing multiplication ratio.

Poor sprouting and low survival rate in chamber and at nursery

In 2014, at Fumesua 5,431 seedlings did not survive at the nursery whereas at Aiyinasi, 205 of them died (Figure 2). In 2015, a total of 20,500 died at Aiyinasi (Table 1).

DISCUSSION

Selection of suckers for macro-propagation

This is very critical since it forms the foundation upon which the success of other steps usually depends. The sword or maiden suckers detached from the growing plants can be used. It is important that such materials are pests and diseases free as diseased material can result in 100% yield loss (Blomme et al., 2014). On the average one clean corm is able to produce 8-15 new suckers after manipulation (Njukwe et al., 2013). These new suckers can also be manipulated to produce another generation of suckers called secondary generation before being transplanted into the poly bags for rooting. This was not achieved in the commercial production. On the average, one corm was able to produce five to eight plantlets. Use of unclean materials such as old, diseased and infested suckers reduces the sprouting ability of paired suckers in the chamber (Dzomeku et al., 2014). Close to 3,605 (Table 1) corms were rejected as a result of weevil infestation, old and diseased corms. Careful selection of active growing suckers as well as pests and disease free source of material is therefore advised. In situations where farmers are to supply corms, a skilled person should be involved to supervise in the selection and uprooting of suckers.

Time of uprooting suckers

This refers to the period between detachments of raw suckers from growing plants in the field to paring/treatment of suckers. This is very critical as deterioration of suckers start as soon as maiden or sword suckers are uprooted. It is therefore very important that the number of suckers uprooted be worked on within a short time (preferably 3-4 days) and buried in the propagator. In this study, corms were out sourced from individual farmers' fields. These farmers took about one week to get enough quantities to fill a truck. This was due to the large quantities of corms needed for commercial production and the long distance (150 km) involved in carting the corms to the propagation site. There was the tendency to cart more suckers to reduce cost of transportation. In one trip 2,000 - 5,000 suckers (Table 1) were transported to the manipulation site. The challenge

Table 2. Quantities and conditions of suckers transported from Kumasi to Aiyinasi for hardening.

Quantity carted	Quantity arrived safely (%)	Quantity injured (%)	Quantity died (%)	Type of vehicle used
6,835	74.10	21.95	3.95	Big truck
6,989	85.86	9.77	4.36	Big truck
9,900	99.60	-	0.40	Big truck
3,000	100	-	-	Small truck
2,655	100	-	-	Small truck

is that more hands will be needed to do the paring and propagation of the corms and when this is not met, the corms loose viability due to dehydration resulting in poor sprouting (Njukwe et al., 2013). For commercial production, it is advised that in a medium to long-term production, a plantain plantation should be established close to the production site where workable quantities can be uprooted and manipulated. This will reduce cost of transportation and maintain viability of corms for higher sprouting. It is also important to construct the propagator before uprooting and get more skilled labour to do the paring.

Substrate source and type for chamber and poly-bags

In all the productions, sawdust was used in the humidity chamber whereas top or black soils from decomposed refuse dump site were used to fill the poly bags without sterilization. Though these can be used (Ntamwira et al., 2017; Njukwe et al., 2009), they could contribute to infections in the humidity chamber and the nursery in the absence of sterilization. Contaminated corms could result in low sprouting and premature deterioration of corms. Treatment of the substrate could be done by steam-sterilization for 12 h in a drum (Njukwe et al., 2009). Considering the volume of substrate needed to achieve the set target, using the drum method could add on to the production cost as more labour and fuel for heating will be needed. No matter how careful one can be it is still advisable to sterilize the substrate used in both the chamber and the poly-bags. This will reduce diseases and pest infestations and increase the sprouting and survival rates in the chamber and nursery, respectively.

Poor sprouting and low survival rate in chamber and at nursery

In 2014, the project trained some personnel for subsequent production. It was realized that some of the apical meristems were not well destroyed. This resulted in sprouting from the main apical end as opposed to buds thus reducing the number of plantlets. The substrate should be kept moist to provide a conducive environment for sprouting to occur. Watering of the humidity chambers is very critical as dryness could lead to poor and reduced sprouting. Too much watering however, coupled with creation of wounds also resulted in some of the corms getting rotten in the chamber. There is therefore the need to site the nursery close to water sources and get well-dedicated labour to do the watering in the chamber and at the nursery.

In macro-propagation, nursery practices should continue after harvesting of plantlets from the chamber for hardening until seedlings are taken to the field for planting. Nursery practices include watering, weed control, fertilization, and rogueing to remove diseased seedlings among others. Failure to ensure good nursery practices could result to high mortality levels at the nursery.

Transportation and handling

Transportation usually involves two stages namely, transportation of raw suckers for manipulation and transportation of seedlings for distribution to farmers for planting. In 2014, suckers for manipulation were outsourced from Nkoranza in the Brong Ahafo region, which is about 150 km away from the manipulation site. In order to reduce cost of transportation the truck used was able to transport maximum of 5,000 corms. This put a lot of pressure on the labour force involved in the paring coupled with the learning process involved. After production, the seedlings were transported to Aiyinasi located about 300 km away from the nursery for hardening and supply to the private company. Again, cost of transportation that was borne by the Institute was very high. Wooden platforms were constructed and placed in the conveying trucks to park the seedlings. The long distance coupled with the very bad road network resulted in high mortality and injured seedlings (Table 2). Most of the wooden platforms caved in on the way due to the weight as 2,655 to 9,860 seedlings were transported at a time. A total number of 29,379 seedlings were harvested in Fumesua and transported to Aiyinasi for hardening and onward supply to the company in 2014. Out of this number 26,581; 2,183, and 615 representing 90.48, 7.43 and 2.09% seedlings arrived safely, injured and died, respectively upon arrival at Aiyinasi. After hardening the

Table 3. Comparison between production of plantain suckers at the research level and upscaling the production at commercial level.

Activity	Research	Commercial	Lessons Learnt
Labour	7 persons can work on 800 raw suckers to raise 8,000 seedlings by 4 months. Cost of production $ 2,800	In 2014, 15 technical staff raised 29,379 seedlings at a cost of $12,558 whereas in 2015, 57,608 seedlings were raised with 8 staff at a cost of $21,829.83	Payment of allowances to staff increased production cost. Commercialization of technologies is capital intensive which in most cases research institutions cannot provide the funding. Sub-contracting others to produce the seedlings will reduce production cost. Alternatively the technology can be licensed to private companies.
Selection of suckers	Suckers could be obtained from one source making it easier for a technician to be involved in the selection	Suckers are out-sourced from farmers without supervision by technician due to large quantities involved and payment of allowances to staff to supervise resulting in inclusion of defective suckers.	Trained person should supervise the selection of the suckers at farmers' fields. Establishment of plantation close to production site will make it possible to uproot workable quantities for paring.
Treatment of substrate/ Growth media	One drum can be used to treat enough media with less labour required	More labour will be needed to treat the large volume of soil and sawdust used. The treatment was over looked due to the cost and methodology involved.	All media needed should be treated to prevent diseases and pests infestations which could increase mortality.
Transportation of plantlets to farms.	Small quantities requiring small space which can conveniently be transported in a pickup vehicle	Large quantities are transported at a time which requires the use of bigger trucks. More space is required to transport just a small quantity. This increases cost of transportation.	Need to research into transportation of potted plantlets to reduce mortality and cost associated with transportation.

26,581 seedlings that arrived safely were further reduced to 22,253 leaving a total loss of seedlings transported from Fumesua to Aiyinasi to 24.26%. It was found that the bigger truck caused more damage and death of seedlings as compared to the smaller truck (Table 2). However, it was more expensive in terms of running cost and time to use the smaller truck than the bigger truck. Therefore, for commercial production siting of nurseries closer to end users is necessary to avoid losses incurred during transportation especially where the road network is not good. This will also reduce the use of bigger trucks, which tend to cause more damage to seedlings. To reduce the high mortality and cost associated with the carting, Management in 2015, decided to relocate the production to Aiyinasi Station, which is much closer to the end users. However, the suckers for manipulation were outsourced in the Ashanti region and transported over a 300 km journey.

High production cost associated with labour

The use of permanent Institute staff was more expensive than the use of casual labourers for similar activities due to payment of allowances. In 2014, three staff from Aiyinasi and four from Kwadaso (Out-station in Ashanti region) came to Fumesua for 14 days and four months respectively, to learn the skills. In 2015, five staff from Fumesua went to Aiyinasi to augment the skilled staff there (due to the target of 180,000 seedlings) for 3 weeks. Hiring of skilled labourers should be considered, as payment of the Institute's staff allowances is more expensive than hired labour. Experience with the use of hired labourers has shown that outputs in most cases are higher than permanent staff. These casuals work for more hours compared to permanent staff. However, getting casual labourers who have the skill to do the plantain sucker manipulation was not possible as the technology is not popular compared to budding and grafting of citrus, mango, and other vegetative propagated planting materials. Out-sourcing may be cheaper than the use of permanent staff. It is advised that some interested casual labourers should be identified and trained at a fee to become out-growers.

Table 3 gives the comparison between the production of plantain seedlings at the research level and upscaling the production at the commercial level. The areas discussed are labour, selection of suckers, media used and transportation of plantlets to farms.

CONCLUSION AND RECOMMENDATIONS

With a target of 60,000 in 2014 at Fumesua 33,260 plantlets were harvested from the chamber out of which 5,431 died, whereas at Aiyinasi, a total of 16,505 plantlets were harvested from the chamber with 205 deaths. The total supplied to the private company was 37, 285 representing 41.43% out of a target of 90,000 seedlings.

In 2015, a total of 48,252 out of a target of 180,000 seedlings representing 26.81% were produced and supplied to the private company. The demand for plantain planting materials by both corporate and private individuals kept increasing with the requests ranging between 325-300,000 seedlings per farmer. Therefore, the use of macro-propagation techniques though it requires less capital investment, its commercialization by a public research institution needs to be well structured. There must be a conscious effort to improve or perfect the stages of production taking into account the large number of seedlings involved. Time for each activity should be carefully planned and followed as delays or omissions could lead to failure of the commercialization.

Technically skilled persons should be involved in the selection of raw suckers for manipulation, as most farmers tend to include pest infested and diseased suckers during outsourcing. Preferably, in a medium to long-term production, there should be an established plantation closer to the nursery site to reduce the cost of transportation and at the same time making sure workable quantities are harvested and pared at a time. Substrates and black soil for the poly bags should be sterilized before usage to reduce transmission of pests and diseases, especially nematodes and plantain weevils. Macro-propagation is labour intensive and therefore only dedicated and skilled people must be engaged.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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