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ECONOMIC ANALYSIS OF SEED YAM PRODUCTION IN AEROPONICS SYSTEM. IMPLICATIONS ON EMPLOYMENT AND FOOD SECURITY IN GHANA

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Abstract. The supply of seed yams for intensive yam production is hindered by many constraints, including diseases and pest infestations as well as the unavailability of quality planting material. The combination of tissue culture and aeroponics system is perceived to be the way towards clean and adequate supply of seed yam for enhanced yam production. However, the system is considered as expensive for any individual to implement. In order to encourage private sector to participate in this venture, the economic analysis determining the feasibility and viability of using aeroponics in seed yam production was performed. Using data from established tissue culture and aeroponics system in Ghana, the fixed cost and variable cost parameters as well as production costs were obtained. Results revealed that total cost of building aeroponics structure amounted to GH₵ 94,178.00 (USD 17,938.70). Annual cost of aeroponics structure was GH₵ 9,417.82 (USD 1,793.87). Annual total cost of production totalled GH₵ 204,391.75 (USD 38,931.61). Annual net revenue was GH₵ 75,888.00 (USD 14,454.86). Payback period was 15 months and benefit cost ratio was 1.4. Aeroponics system for seed yam production is therefore profitable since short period would be needed to recoup investment. For food security and creation of workplaces, government could partner with the private sector in the establishment of aeroponics systems to increase yam production and export.

Keywords: benefit-cost ratio, net revenue, payback period, private sector, tissue culture

INTRODUCTION

Yam production in Ghana, though very important, is burdened with many constraints including diseases and pest infestations as well as the unavailability of quality planting material. Yam, forming an edible tuber, is traditionally propagated vegetatively. This practice is associated with low multiplication ratio (less than 1:10 compared to 1:300 for some cereals), long dormant phase of the tuber prior to sprouting, and planting materials that are infested with pathogens (Odu et al., 1999; Oppong et al., 2007). The above-mentioned problems connected with the acquisition of planting materials culminate into high cost of planting material and, if further compromised, they can lead to high production losses. There is therefore the urgent need to ensure the regular availability of clean planting seed yam as well as a properly defined yam seed system, which will ensure high crop productivity.

In traditional yam cultivation, there is no separation of seed and ware yam production (Aighewi et al., 2015). Farmers either 'milk' parent plant or sort ware yam for cultivation. 'Milking' is carried out in the course of yam production, where tubers are harvested two to three months before senescence without destroying the root system, providing early ware yam for consumption. The parent plant regenerates small new tubers which

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are used as seed yam commonly referred to as "sett" for the following season cultivation. In this method, propagation ratio of 1:6 is achievable (Okoli and Akorada, 1985). However, yield loses are possible in this method as yams cannot reach full maturity before harvesting. In the sorting of ware yam, during harvesting, 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 small sized yams as seed yams selected by sorting increases recycling of pests and diseases since small sized yams might be as a result of pests and disease problems in the field (Maroya et al., 2014). In Ghana, the traditional methods of seed yam production are predominant.

Over the years, several rapid multiplication techniques for seed yam production have emerged worldwide. They include mini-sett technology, vine multiplication technique, tissue culture multiplication and aeroponics seed production. Mini-sett technique is the production of seed yams from 'mother seed' yams of 500–1000 g that have broken dormancy and are cut into pieces (mini-setts) weighing (25–50) g (IITA, 1985; Kissiedu et al., 1994). The freshly cut mini-setts are treated in wood ash or fungicide and insecticide, for 1–2 days before planting. Vine multiplication method also involves 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 (Maroya et al., 2014). 1–3 node vines, 20 cm long, could produce minitubers of 50–600 g after 8 months, giving a 1: 30 propagation ratio (Kikuno et al., 2007; Agele et al., 2010). Tissue culture multiplication method involves small plant parts grown in test tubes to regenerate complete plant (plantlets) in a controlled laboratory environment. Through this technique, disease-free planting materials are rapidly produced (Yam and Arditti, 2009).

AEROPONICS SYSTEM FOR CROPS PRODUCTION

'Aeroponics system' is a method of growing plants with nutrient water in a soil-less environment. It is defined by the International Society for Soilless Culture as "a system where roots are grown continuously or discontinuously in an environment saturated with fine drops (a mist or aerosol) of nutrient solution". Crops are grown in a medium that only contains the nutrients, water, light, oxygen and carbon dioxide, without the use of soil (Nugali et al., 2005). The use of aeroponics in the successful production of several horticultural and ornamental crops is reported by Biddinger et al. (1998). In Korea, the system has been successfully used to produce potato seed (Kim et al., 1999). Otazu (2010) reported of yields of over 100 tubers per plant in potato production in Peru.

Aeroponics system for crop production is very advantageous as disease-free materials are produced in the process. More importantly, Mbiyu et al. (2012) enumerate benefits of aeroponics production as ecologically friendly and safe, free of soils and soil-borne organisms or diseases and contaminants, accelerated plant growth and development cycles resulting in early maturity and harvest, elimination of water and nutrient competition which gives room to higher planting densities and thus increased yields, efficient use of water and nutrients due to reutilising properties of the nutrient solutions used as well as elimination of soil fertility and degradation issues in crop production. Aeroponics production of seed yams in Ghana is seen as the solution to problems related to planting material acquisition.

The technology is new in Africa research agenda and has only been practiced by research institutions. Under the "Yam Improvement for Incomes and Food Security in West Africa (YIIFSWA) project", aeroponics system has been applied to seed yam production (Maroya et al., 2014). In the yam aeroponics system, in vitro generated "clean" virus indexed yam plantlets are hardened in the screenhouse and seedlings are established in aeroponics system. Data on studies performed so far indicated that aeroponics technology should be considered as an effective yam propagation method. Genotypes of both *D. rotundata* and *D. alata* were successfully propagated in it using both pre-rooted and fresh vine cuttings. Results of these studies revealed that yam minitubers harvested from aeroponics varied from 0.2g to 110g depending on the genotype, the age of harvest and the composition of the nutrient solution. Various sizes of minitubers and yam bulbils can be generated using aeroponics (Maroya et al., 2014). Currently, seedlings are being generated from profuse vines produced in aeroponics system. Here, single nodes are harvested from lateral branches of the 4–5 months old plants in aeroponics system. They are rooted on appropriate medium and 6 weeks old seedlings generated are then planted on the field for seed yam production. Preliminary data has it that 70% of the seedlings generated seed yam tubers of weight approximating 3 kg.

The system has been perceived as an expensive one for any individual to undertake (Sace and Natividad Jr, 2015). However, it is thought to be a very lucrative business venture for production of high-quality seeds for both local consumption and export. To encourage private sector participation in this venture in Ghana, economic analysis to determine the feasibility and viability of aeroponics system is necessary. The objectives of this study were to investigate the cost of establishment of aeroponics structure in Ghana and to assess the potential benefits of seed yam production using aeroponics.

MATERIALS AND METHODS

The study of seed yam production in aeroponics system at the Biotechnology Laboratory of the CSIR – Crops Research Institute, Ghana, commenced in July 2016. The system was constructed by local artisans from the institute in an insect – proof screen house. There are 10 boxes in the aeroponics system, 4.0 m long and 1.0 m wide, with a distance of 1.0 m between each box. The tops of the boxes are covered by 25 mm thick Styrofoam cut into 4 pieces (tables), 1.0 × 1.0 m long, which makes up 4 tables in a box. Perforations were made at a distance of 13.0 × 13.0 cm, giving 49 planting holes per table. The sides and base of the boxes were constructed with 50 mm thick Styrofoam and lined with thick black plastic, covering the insides of the boxes.

Both primary and secondary data were collected for this study. Primary data were collected from aeroponics system at the CSIR-CRI. Data log sheets were developed and provided to staff being in charge of the system. To obtain information, face to face interviews with staff were performed and, subsequently, data sheets were completed. In the log sheet, all stages of cultivation using aeroponics and their related costs were captured. Data obtained include the list of aeroponics components, the cost of each component (piece of land, container to keep the nutrient solution (a reservoir), submersible pump, pipes to distribute water from the reservoir pump to the mister heads in the growing chamber, enclosed growing chamber for the root zone, mister/sprinkler heads, water and light tight container for the growing chamber where the plants root systems will be, pipes to return the excess nutrient solution back to the reservoir), inputs (e.g. ammonium nitrate, calcium nitrate, magnesium sulphate etc.) and inputs costs, consumables (e.g. pesticides, fungicides, robes, nose masks etc) and costs of consumables. Economic formulas were then applied to calculate the share of costs of production and the benefit-cost ratio. Data were analysed using Excel software.

ECONOMIC ANALYSIS

In order to perform economic evaluation, all revenues and expenses should be specified. Consequently, all revenues and costs related to aeroponics cultivation of seed yams were identified. Total revenue (TR), net revenue (NR), total variable costs (TVC), total fixed costs (TFC), benefit cost ratio (BCR), and payback periods (PP) were obtained following Gittinger (1982) and Mateus-Rodriguez et al. (2013).

Total fixed cost (TFC)[1]

Fixed costs are costs that always remain unchanged with an increase or decrease in the quantity of products produced. Fixed costs were estimated by adding the costs of all fixed items. The fixed items identified were land, screen house, plumbing and plumbing equipment (submersible pump, pipes, mister/sprinkler heads), boxes and tables, electrical works, nursery construction and others (field coats, buckets, sprayers).

Fixed costs were estimated from the following equation:

$$D = \frac{P - S}{L} \quad (1)$$

Where:

- D is the amount of annual depreciation in linear method
- P is purchase price of equipment used
- S is salvage value of equipment used
- L is lifetime of the equipment used

Total variable cost (TVC)

Variable costs are costs that change proportionally to the production output. In other words, when the production output is zero, such costs will also be zero. TVC is expressed as:

$$TVC = F(Y) \quad (2)$$

Where Y is the output.

[1] All cost items were obtained from marketplace and so value added tax and withholding tax were included in all the prices quoted.

Total revenue (TR) and net revenue

To obtain the value of total revenue, first of all we calculated the price (P)[2] per yam vine cutting in aeroponics. This was calculated as total production cost (TPC) over total quantity produced (Q) per annum using the formula P=TPC/Q. For the calculation of the total revenue (TR) we used the total quantity produced (Q) and the unit price (P) using the formula:

$$TR = Q \cdot P \qquad (3)$$

The net revenue was calculated as:

$$NR = TR - TPC \qquad (4)$$

Benefit-cost ratio (BCR)

Benefit-cost ratio (BCR) is the ratio obtained through dividing the gross income by the total cost. BCR is mathematically expressed as:

$$\mathrm{BCR} = GI / TC \qquad (5)$$

Where:

BCR is the benefit cost ratio, *GI* is the gross income, *TC* is the total cost.

The decision rule is that the BCR of one indicates a breakeven point, the BCR greater than one indicates a profitable venture and the BCR less than one indicates a non-profitable venture. Aeroponics system for yam production is profitable if the BCR is greater than one and non-profitable if the BCR is less than one.

Payback period

Payback period (PP) is achieved by dividing the investment cost (IC) by the annual net revenue (NR). PP expressed the number of years or months to recover the investment using the formula below:

$$PP = IC / NR \qquad (6)$$

Where:

IC is initial investment cost and NR is net revenue

Assumption(s)

1. Assumes 135m-square aeroponics structure
2. Assumes no aeroponics system repair costs
3. Assumes all production output is sold

[2] Dominant system among few in Ghana for yam vine production and so price leadership was assumed.

RESULTS AND DISCUSSION

Capital investment

First, fixed costs were calculated and their results presented in Table 1. In order to construct aeroponics structure, land must be acquired. Land purchase alone constituted about 34 % to the annual fixed cost. Land asset was not depreciated. A screen house was necessary, which constituted about 26% of the total fixed cost. This was followed by the electrical works and floor works that constituted 10% and 8% respectively of the total fixed cost. Nursery is very important for the acclimatisation and rooting of the vine cuttings in aeroponics system. Nursery cost constituted 7% of the total fixed cost. The total fixed cost of establishing aeroponics structure was GH₵ 94,178.15 (USD 17,938.69). Annual fixed cost was GH₵ 13,917.81 (USD 2,651.01). The capital investment on the whole looked very expensive but considering long term, the fixed costs were low.

Operating cost

Variable costs were also calculated and Table 2 shows the results of various variable cost items. Variable cost items consisted of consumables (pesticides, fungicides, ropes, foams, duct tapes, labels, push pins) and other inputs (staff wages, seed from the tissue culture, electricity fees, nutrients for the solution, labels, irrigation). The result showed that the total annual variable cost of production was GH₵ 190,473.93 (USD 362,80.57). The highest contributors to the total variable costs were seeds (plantlets from tissue culture) and staff wages amounting to 41% and 54% respectively. Tissue culture plantlets in aeroponics involve very high cost due to the long processes and procedures the plants go through in the tissue culture system before cleaned materials emerge. The cost of plantlets could be reduced if private sector participation increased due to economy of scale. The staff wages were also high because of the formal setting of aeroponics system and the quality of staff. The private sector may not necessarily pay those high wages and that may further reduce the variable cost.

The total production cost per season including total fixed cost and total variable cost was GH₵ 204,391,753 (USD 38,931.76). The variable cost constituted about 93% and fixed cost constituted 7% respectively. Mateus-Rodriguez et al. (2013) found in their work on Technical and Economic Analysis of Aeroponics and other Systems for Potato Mini-Tuber Production in

Table 1. Fixed cost for implementing Aeroponics system

Parameter	Unit Value (GH₵)	Total value (GH₵)	Cost per year (GH₵)	Percentage share
Land purchase (acre)	5,000.00	5,000.00	5,000.00	35.93
Screen house	35,600.00	35,600.00	3,560.00	25.58
Floor works	11,380.00	11,380.00	1,138.00	8.18
Welding and fabrication	7,500.00	7,500.00	750.00	5.39
Plumbing works	5,460.50	5,460.50	546.05	3.92
Boxes construction	4,236.65	4,236.65	423.66	3.04
Electrical works	14,168.00	14,168.00	1,416.80	10.18
Field coat and spray suit	408.00	408.00	40.80	0.29
Nursery construction	10,425.00	10,425.00	1,042.50	7.49
Total		94,178.15	13,917.82	100

Note: USD 1 = GH₵ 5.25

Table 2. Variable cost for implementing production in aeroponics system

Item	Quantity	Unit value (GH₵)	Total value per year (GH₵)	Percentage share
1	2	3	4	5
Consumables				
Seed from the tissue culture (plantlet)	1,960	40.00	78,400.00	41,160
Calcium nitrate (gm)	3,870	0.035	135.45	0.071
Ammonium nitrate (gm)	5,454	0.003	16.36	0.009
Magnesium sulphate (gm)	1,966	0.003	5.89	0.003
Triple super phosphate (gm)	1,300	0.004	5.20	0.003
Potassium nitrate (gm)	1,188	0.031	36.83	0.019
Potassium sulphate (gm)	1,200	0.004	4.80	0.003
Idrol Veg (gm)	800	0.046	36.80	0.019
Pesticides (Dursban)	20	8.00	160.00	0.084
Fungicide (Mancozeb)	2	10.00	20.00	0.011
Nylon ropes	12	20.00	240.00	0.126
Foam (1 cm)	5	7.00	35.00	0.018
Brown Packaging envelope	1,960	0.20	392.00	0.206
Duct tape	6.00	50.00	300.00	0.158
Labels	50	1.00	50.00	0.026
Push pins	20.00	3.50	70.00	0.037
Special nose masks	8	3.20	25.6	0.013

Table 2. cont.

1	2	3	4	5
Subtotal consumables	–	–	79,933.94	41,966
Staff wages				
Total labour cost incurred by researchers/month	4	6,625.00	265,00.00	13,913
Total labour cost incurred by the daily or causal labours/month	10	1,200.00	12,000.00	6,300
Total Labour cost incurred by technicians/month	20	3,250.00	65,000	34,125
Subtotal wages			103,500.00	54,338
Utilities				
Electricity charges /month	12	420.00	5,040.00	2,646
Irrigation/week	10	200.00	2,000.00	1,050
Subtotal utilities			7,040.00	3,696
Total variable cost per year			190,473.94	100.000

Latin America that the variable cost constituted 60% of aeroponics system. Their finding is similar to the findings of this study.

Revenue estimation

Vine cuttings are the outputs in aeroponics system. Harvesting of cuttings is performed two times in a year. Table 3 summarises the revenue estimates. Each harvesting produced 107,800 single node cuttings. Within 12 months, an estimated number of 215,600 single node cuttings were harvested. An estimated price per cutting was GH₵ 1.3 (break-even price plus 25% markup). Total annual gross revenue was GH₵ 280,280.00 and total net revenue was GH₵ 75,888.00. The benefit cost ratio amounted to 1.4, which was greater than 1, implying positive returns to investment. The results show that seed yam production in aeroponics system is profitable.

The results also showed that it will take only twenty-four months to get back all the investment made to the yam aeroponics system. It should be noted that an investor may like to consider having a smaller structure and putting in fewer boxes as well as just one reservoir for the single vine production. The profit margin may also be higher when macro tubers and bulbils are factored into the planting materials generated from the system. Results from many studies from different countries (Banerjee, 2014; Maroya et al., 2014; Sace and Natividad Jr, 2015) on various crops have shown that crop production in aeroponics system is profitable, which is in line with the results of this study.

Table 3. Cash flow projections

Production volumes	Column title
Plantlets as seeds in the boxes	1,960
Multiplication rate of plantlets per year	110
Annual production of vines per year	215,600
Cash inflows	
Production volume of yam vines per year (count)	215,600.00
Proposed price per yam vine (GH₵)	1.30
Subtotal inflows per year (GH₵)	280,280.00
Cash outflows	
Total fixed cost as construction (GH₵)	94,178.00
Total fixed cost per year (GH₵)	13,918.00
Total variable cost per year (GH₵)	190,474.00
Total cost of producing yam vines per year (GH₵)	204,392.00
Subtotal outflows per year (GH₵)	204,392.00
Cost and benefit evaluation	
Total production cost per year (GH₵)	204,392.00
Gross revenue (GH₵)	280,280.00
Net revenue (GH₵)	75,888.00
Benefit cost ratio (BCR)	1.37
Payback period (Years)	1.24

CONCLUSION AND IMPLICATIONS

The economic analysis of the seed yam production in aeroponics system in Ghana has been conducted. The purpose of the study was to perform economic analysis of aeroponics system for seed yam production in order to encourage private sector to participate in it. The results revealed that yearly production of 215,600 vine cuttings was achievable in aeroponics system. One plantlet from tissue culture can produce 110 vine cuttings in a period of twelve months. The results showed that the benefit cost ratio (BCR) was greater than 1 and that it would take less than 2 years to recoup investment. It was also established that aeroponics structure cost of GH₵ 94,196.15 (USD 179,3.87) could be covered in less than 2 years. The total operating cost per year was GH₵ 190,474.00 and the total gross revenue per year amounted to GH₵ 280,280.00 (USD 53,386.67) indicating a net revenue of GH₵ 75,888.00 (USD 14,454.86) per year.

Aeroponics system to produce seed yams is therefore profitable and commercial farmers must be encouraged to invest in it. There is no doubt that aeroponics system for seed yam production is sustainable and would guarantee sustainable supply and production for both the local and export market. The problem with the initial capital can be dealt with by public-private partnership whereby government could provide infrastructure and private sector would ensure other inputs. The need to adopt modern agriculture is no more a matter of choice, but necessity.

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