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Growing Seed Yams in the Air: the Agronomic Performance of Two Aeroponics Systems Developed in Ghana

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Abstract

Aeroponics has been perceived as a technology crammed innovation, far out of reach of the ordinary farmer. Apart from its continuous dependency on electrical power, the technology comes with very sophisticated inputs such as solenoid valves, timers, misters, CO_2 tanks, and air and water pumps. The main objective of this study was to evaluate the option of using gravity-fed and pressurised aeroponics system for propagating seed yams from vine cuttings. The study was setup at the CSIR–Crops Research Institute in collaboration with the Agricultural Engineering Department of the Kwame Nkrumah University of Science and Technology. The basic advantage of the gravity-fed system is its non-dependency on electrical power, pumps or timers and its ability for continuous production. The two systems were set-up using conventional materials and equipment available on the local market. The treatments were arranged in a split-split-plot design with the two aeroponic units as the main plot, four nutrient concentration levels (C1 - , C2 - , C3 - and C4 -) as the sub plots and vine cuttings from three *Dioscorea rotundata* varieties (*Dente, Pona and Mankrong Pona*) as sub-sub plots respectively. Results showed there were significant differences (P<0.05) in minituber weight and days to emergence of planted miniubers. The agronomic response of the two systems in producing mini-tubers was suggestive of the fact that both systems could be used to effectively produce mini-tubers.

Keywords: nutrient concentrations, vine cuttings, propagation, gravity-fed, power-dependent aeroponics, soil-less cultivation

1. Introduction

Plants require light, water, nutrients, oxygen and carbon dioxide for photosynthesis to grow and thrive. Soil can be a supplier of nutrients, but is not necessarily in and of itself nutrients - hence the effectiveness of hydroponic and aeroponics. However, water in itself is becoming more and more scarcer as a commodity and as global population increases, the concern over water and soil quality also continues to grow. New technologies for growing foods that are not overly dependent on soils and water are becoming not only a distinct advantage, but a necessity. The aeroponics and hydroponics technologies have been demonstrated in several ways to be significantly more water- and energy-efficient means for food production. It is therefore in this regard that the technology is being adapted for use in this research to propagate seed yam.

Aeroponically generated seed yams can improve the seed multiplication ratio of yams and thus make available more seed yams on the market. It can also reduce disease incidence of seed yams which results in yield losses. Aeroponics, if successfully used in the propagation of seed yams, can significantly increase the incomes of farmers, improve access to quality seed yams all year round (by making it more accessible and affordable to commercial growers and small scale farmers) and reduce the production costs of yams. This would improve farmers' livelihood and also enhance food security in the country.

In aeroponics, plants are grown in an air or mist environment without engaging soils or any soil aggregate or soil medium (Arunkumar & Manikand, 2011). Aeroponics gives room for easy access to plant roots since it is not planted in any aggregate media (Pagliarulo & Hayden, 2002). The growth chamber and fertigation system employed in aeroponics give room for complete regulation of the root zone setting, including temperature, humidity, pH, nutrient concentration, mist application frequency and duration. Plants grown using aeroponics often show signs of accelerated growth and early maturity (Mirza, Younus, Hoyano, & Currie, 1998). These abilities have made the technology a popular research tool for studying root growth and nutrient uptake (Barak, Smith, Krueger & Peterson, 1998).

Since its introduction into the science arena, aeroponics has offered researchers a non-invasive means to examine plant roots during development (Mbiyu *et al*., 2013). It also allows researchers a large number and wide range of experimental parameters to use in their work (Stoner, 1983). The ability to precisely control the root zone moisture levels and the amount of water delivered makes aeroponics ideally suited for the study of water stress and irrigation/fertigation related research. The aeroponic technology has also been successfully used for crops that are vegatatively propagated, the most recent being the successful application of the technology in the propagation of yams (Oteng-Darko, Otoo, Kyei-Baffour & Agyare, Unpublished; Maroya, Balogun, & Asiedu, 2014). In further advancement, Oteng-Darko, Kyei-Baffour, Otoo and Agyare (Unpublished) developed the gravity-fed aeroponic option alongside the pressurised system for seed yam production. This paper presents the findings and enhancements made to the technology and the successes achieved in its application for seed yam generation.

2. Method

Two aeroponic systems were designed and set up as has been described by Oteng-Darko, Kyei-Baffour, Otoo and Agyare (Unpublished) at the CSIR-Crops Research Institute, Kumasi, Ghana. Two agronomic evaluations were done subsequently to determine the system's ability to produce seed yams. The agronomic evaluation involved two phases: evaluating the two aeroponic systems for its ability to produce mini-tubers and evaluating the mini-tubers produced for their ability to be used in propagating seed yams. In the first agronomic evaluation, one and two node cuttings of three yam varieties were planted on the aeroponic units and fertigated with four different nutrient concentrations. The experimental design was a split-split plot design whereby the aeroponic units were the main plot, nutrient concentrations the sub plots and yam varieties, the sub-sub plot.

In the second agronomic evaluation, three experiments were carried out, all set up in a split-split plot design with the main plot subjected to mini-tubers harvested from the two aeroponic units, the sub plots to mini-tubers from the various nutrient concentrations (C1, C2, C3 and C4) and the sub-sub plots subjected to mini-tubers from the three yam varieties used. The first experiment was subjected to a treatment in which dormant mini-tubers were planted in pots at a screenhouse, one day after harvesting. The second experiment, non-dormant mini-tubers were planted directly in the field. In the third experiment, non-dormant mini-tubers were nursed using sawdust in a screenhouse and transplanted two weeks after emergence.

Data was collected on days to rooting, days to tuber initiation, days to emergence (mini-tubers), yield and yield components. Data collected was analysed using Genstats 9.0 and Mstat 5.4 statistical package. Mean separation was done using the Fishers unprotected least significant difference. Results were judged significant at $p < 0.05$.

3. Results

Planting with one node cuttings showed significant differences ($p<0.05$) between Aeroponic units and variety; and nutrient concentration and variety (Figures 1 and 2). Significant differences ($p<0.05$) also existed between the two aeroponics systems and the various nutrient concentrations.

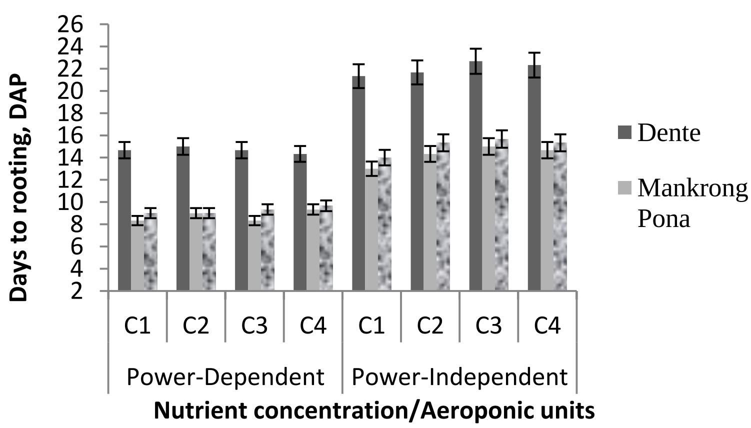

Figure 1. Number of roots for one-node cuttings

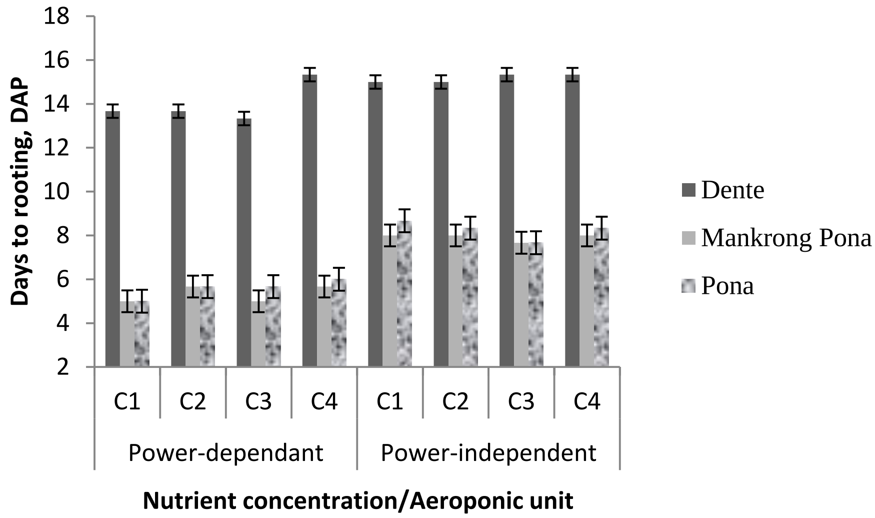

Figure 2. Number of roots for two-node cuttings

Significant difference ($p<0.05$) existed between the main treatments (pressurised – PD and gravity-fed – PI aeroponics systems) for both the one and two node cuttings. Varieties also showed highly significant differences at $p<0.01$ (Figure 3) in their response to the number of roots at root initiation for both the one and two-node cuttings. The number of roots observed was also significant for the one-node cuttings under the two-way-aeroponics unit x variety- interaction.

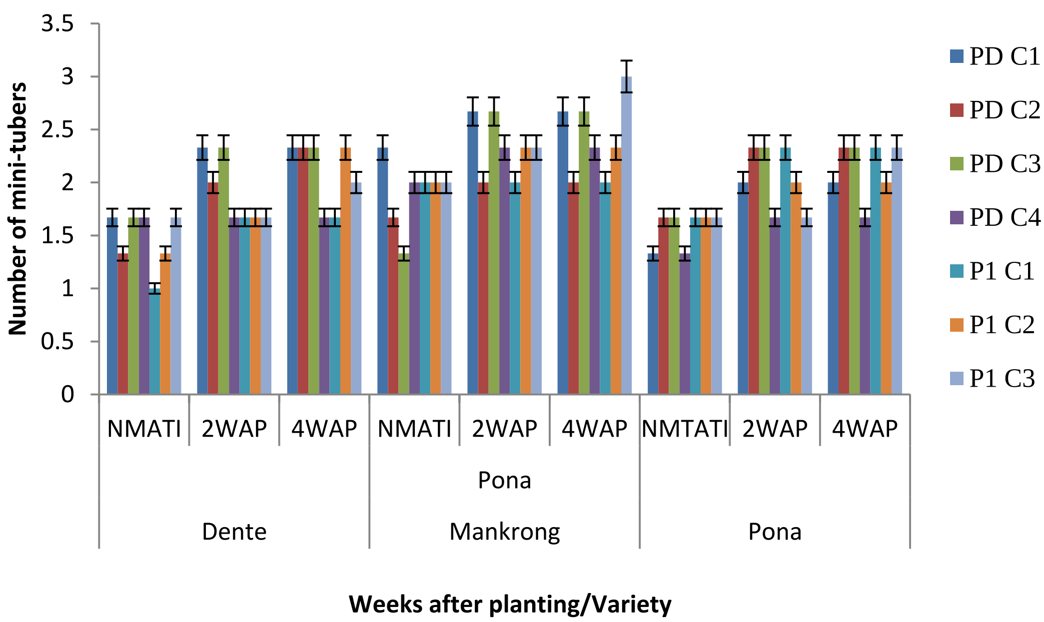

Figure 3. Number of mini-tubers of varieties under both power dependent and gravity-fed system

No significant differences were seen in the number of mini-tubers for any of the treatment interaction at two weeks after planting (Figure 3) for the one node planting. However, with the two-node cuttings, significant differences were seen in the main treatment (aeroponic units), sub plot (nutrient concentration) and sub-sub plot (variety). Significant differences also existed between the two way interactions between aeroponic units x variety and nutrient concentration x variety for the two node cutting but not the one node cuttings. At four and six weeks after planting, significant differences ($p<0.05$) were seen in the nutrient concentration treatments (Figure 3) for both the one and two node cuttings

The grand mean for the total number of mini-tubers harvested per plant (from both the first and second harvest) was 2.38. The aeroponics systems had means of 2.89 and 1.89 for the power dependent and power independent systems respectively (Figure 4). There were no significant differences in the three-way interaction between aeroponics system, nutrient concentration and variety. Significant differences were seen in the various nutrient concentrations used. There was a highly significant difference ($p < 0.01$) between the varieties.

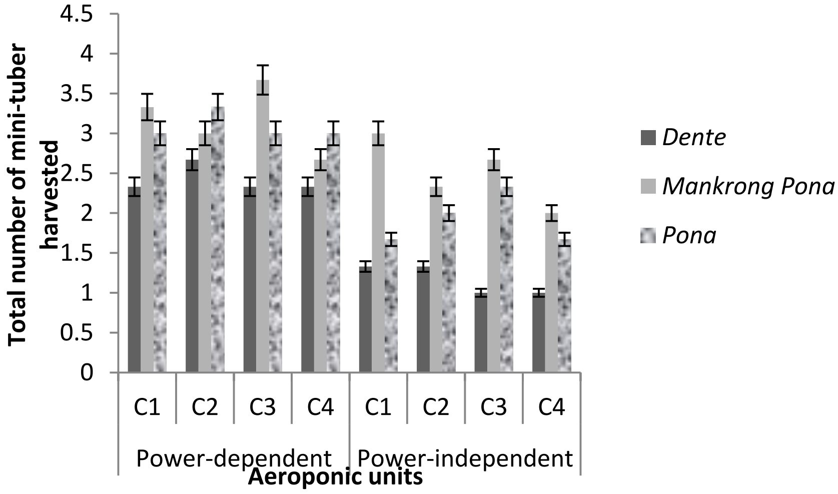

Figure 4. Number of mini-tubers harvested per plant

In planting with non-dormant seeds in the field, the mean emergence for both the power dependent and gravity-fed aeroponics systems was 5.36 days after planting, showing no significant differences between any of the interaction under this treatment (Figure 5).

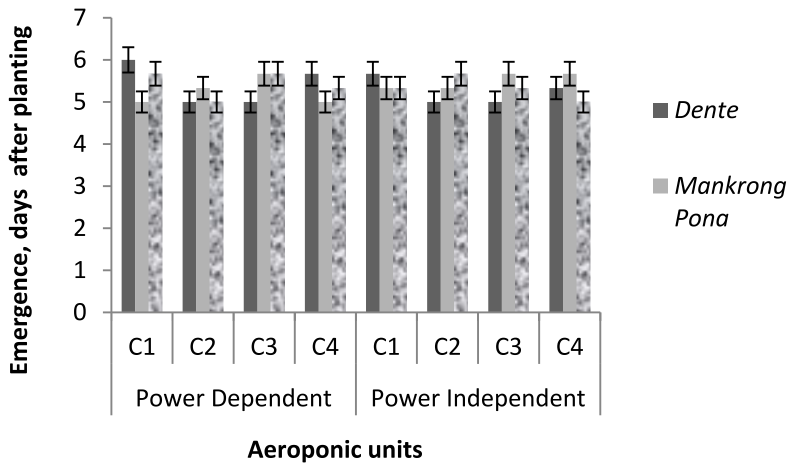

Figure 5. Emergence of nursed seeds in the screenhouse

Mean emergence for directly planted dormant mini-tubers derived from the power-dependent and power-independent aeroponics systems were 60.56 and 59.86 days after planting (Figure 6). The mean emergence for C1, C2, C3 and C4 were 60.17, 58.00, 60.39 and 62.28 DAP respectively. Varietal means were 81.25, 56.08 and 43.29 for *Dente*, *Mankrong Pona* and *Pona* respectively.

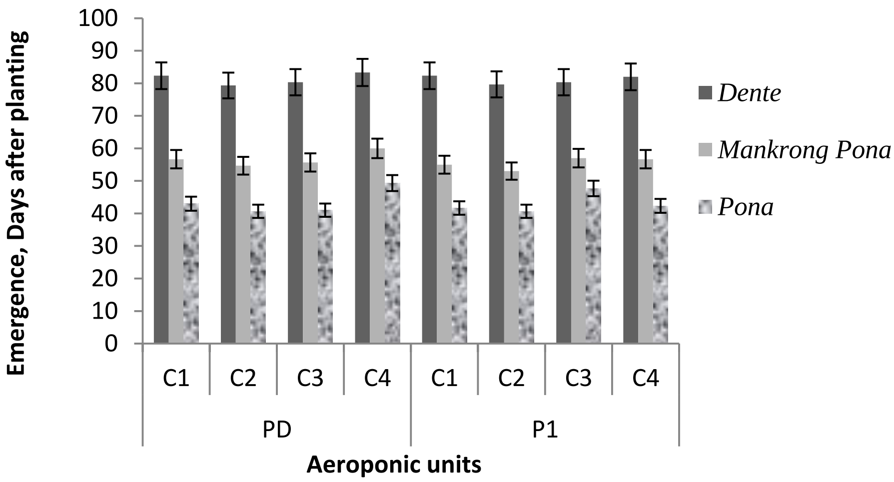

Figure 6. Emergence of directly planted dormant mini-tubers

The grand mean for emergence of planted non-dormant mini-tubers was 5.36 days after planting (Figure 7). Mean emergence for both the power-dependent and power-independent aeroponics systems was 5.36 days after planting. There were no significant differences between any interactions under this treatment.

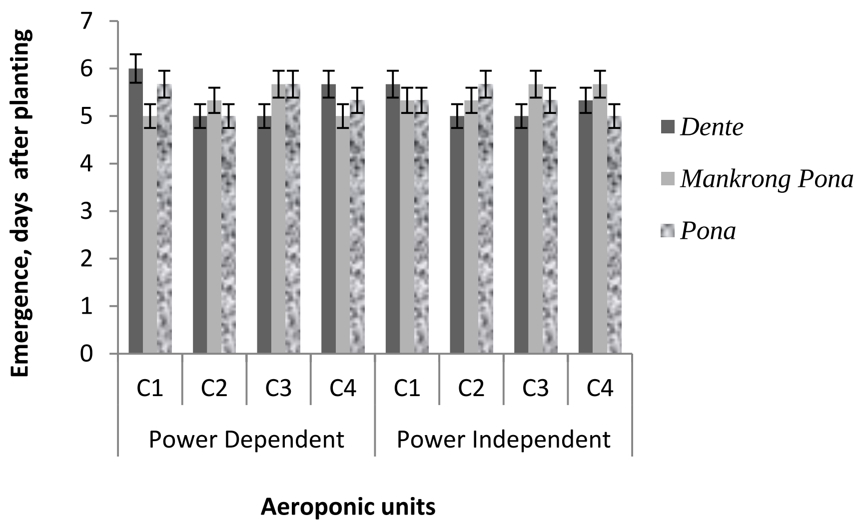

Figure 7. Emergence of directly planted non-dormant mini-tubers

Significant differences were seen in the mini-tuber weight of the various varieties produced using the various nutrient concentrations (Figure 8).

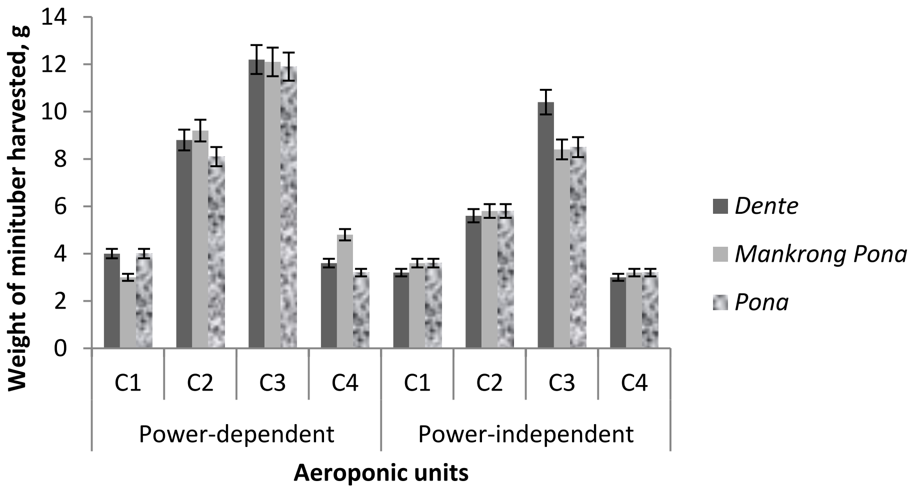

Figure 8. Weight of harvested mini-tubers

The mean number of seed yam tubers produced was significant ($p<0.01$) for all varieties propagated using C3 (Figure 9). Even though the nutrient effects were not so significant in any of the previous discussions, it stands to be argued that the nutrient concentration used in propagating the mini-tubers, whether by the power-dependent or power-independent aeroponic systems has significant impact on the final yield of the second generation seed.

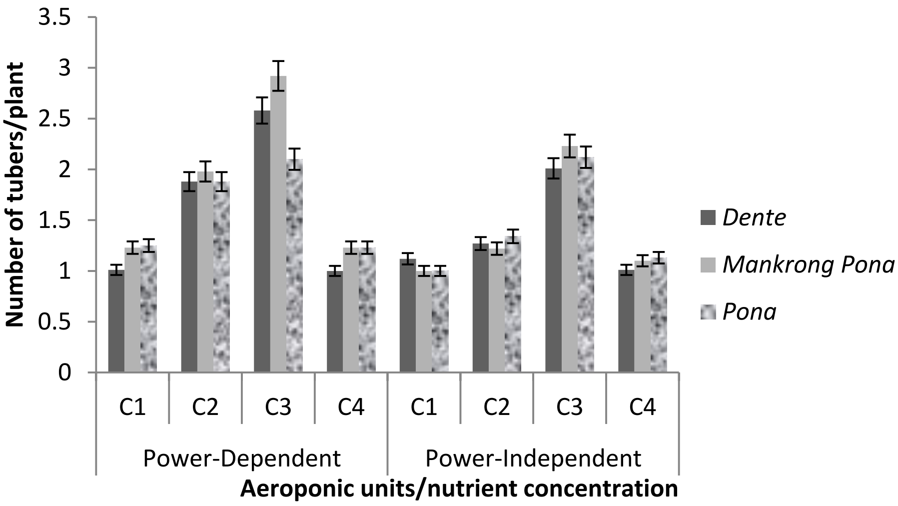

Figure 9. Chart showing number of seed tubers per plant

Using the two-node cuttings, a mean of 130 vines were cut per explant for transplanting onto the aeroponic units. The maximum mean number of mini-tubers harvested for dente was attained using nutrient concentration C2 whereas the maximum number of mini-tubers for pona and mankrong pona were attained using nutrient concentration C3.

Propagation using the power-dependent aeroponic system gave a mean multiplication ratio of 404 mini-tubers per explant (Table 1). Using the power-dependent system, *Mankrong Pona* had the highest multiplication of 477 mini-tubers/explant followed by *Pona* and *Dente* with 390 and 347 mini-tubers/explant respectively.

Propagation using the power-independent aeroponic system again showed Mankrong Pona having the highest multiplication ratio of 347 mini-tubers/explant followed by Pona and Dente with 302 and 173 mini-tubers/explant respectively (Table 1). The mean multiplication ratio of the power-independent system was

274 mini-tubers per explants.

Table 1. Mean mini-tuber yields and multiplication ratio of the yam varieties under the two aeroponics systems

Aeroponic unit	Vine cuttings per plant	Mean yield per cutting			Multiplication ratio/explant			
		Dente	*Mankrong Pona*	*Pona*	*Dente*	*Mankrong Pona*	*Pona*	*Mean*
Power-Dependent	130	2.67	3.67	3.00	347.10	477.10	390.00	404.70
Power-Independent	130	1.33	2.67	2.33	172.90	347.10	302.90	274.30

Significant differences were seen in the multiplication ratio of vines planted on the two aeroponic systems used (Figure 10). Mean seed yam multiplication ratio of the power-dependent aeroponic system for all the varieties was 1035 mini-tubers/explant. *Mankrong Pona* had the highest multiplication ratio of 1393 seed yams/explant followed by *Dente* and *Pona* with 895 and 819 seed yams/explant respectively.

The highest multiplication ratio using the power-independent aeroponic system was 774 seed yams /explant for Mankrong Pona. Pona and Dente had 642 and 347 seed yams/explant respectively. The mean seed yam propagation ratio using the power-independent system was 587 seed yams/explant (Figure 10).

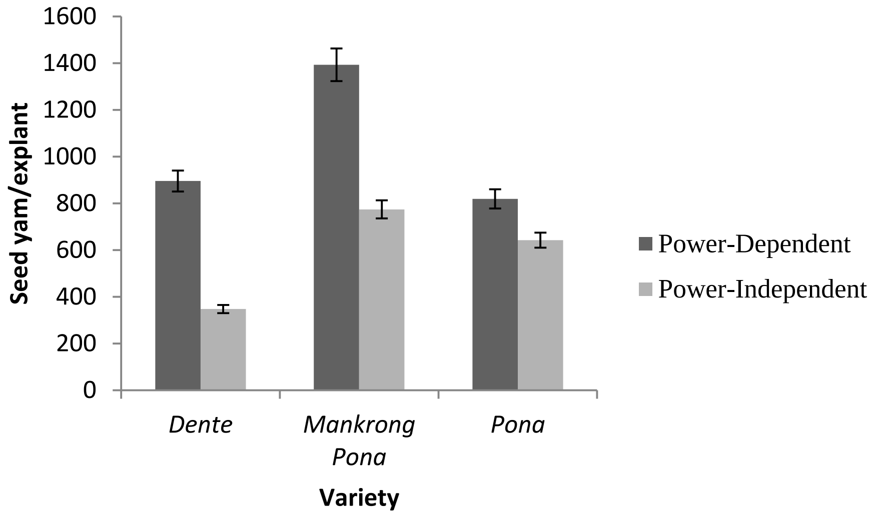

Figure 10. Number of seed yam generated per explant

4. Discussion

In yams, mini-tuber production is affected by genotype, as has been seen by Powell, Brown and Caligari (1989) for potato. This research confirms the assertion that genotypes differ widely in their capacity to produce mini-tubers, some being more prolific than others (Venkatasalam *et al.*, 2011; Sharma, Venkatasalam & Kumar, 2013). The prolific nature of these genotypes established a positive correlation between days to rooting and days to mini-tuber initiation (Figure 11).

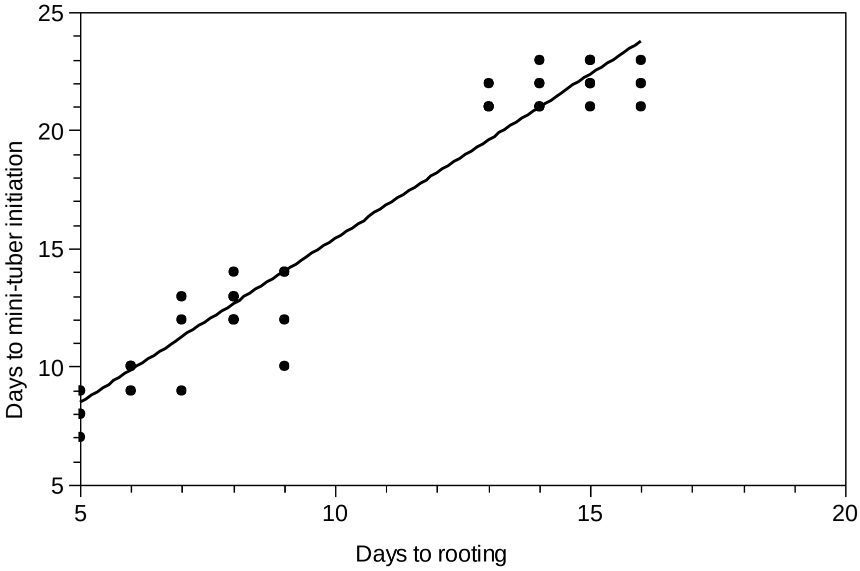

Figure 11. Correlation between days to rooting and days to mini-tuber initiation

Even though no correlation was observed for days to root initiation and number of roots at root initiation, the same was not the case for days to mini-tuber initiation and number of mini-tubers at mini-tuber initiation. A negative correlation (R^2 = 0.196) was observed between the number of days to mini-tuber formation and the number of mini-tubers at tuber initiation establishing that early tuberisation does not have any effect on the number of mini-tubers as shown in Figure 12. This can also be attributed to the genotypic differences between the yam varieties used.

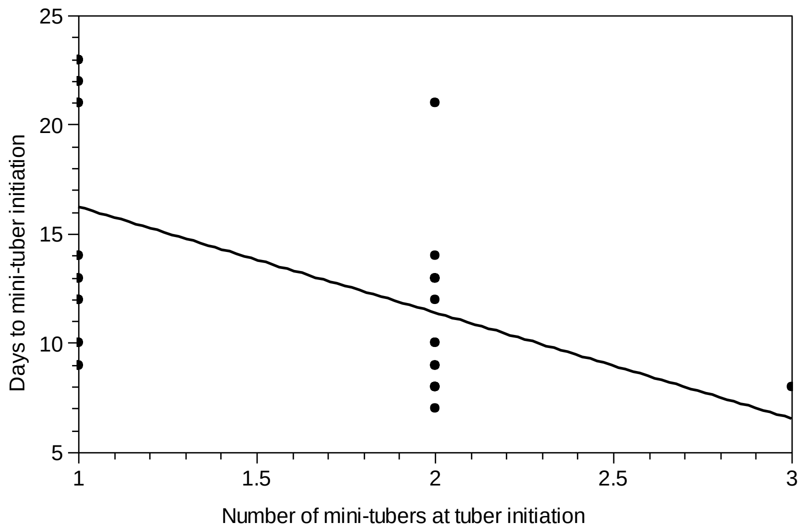

Figure 12. Correlation between days to mini-tuber initiation and number of mini-tubers at tuber initiation

As has been reported by Soffer and Burger (1988), aeroponics optimizes root aeration resulting in more yields than classical hydroponics. A positive correlation (R^2 = 0.1274), though not very strong was observed between number of roots and number of mini-tubers. From Figure 13 varieties with the most prolific rooting system also yielded more mini-tubers, thus confirming the report by Soffer and Burger (1988).

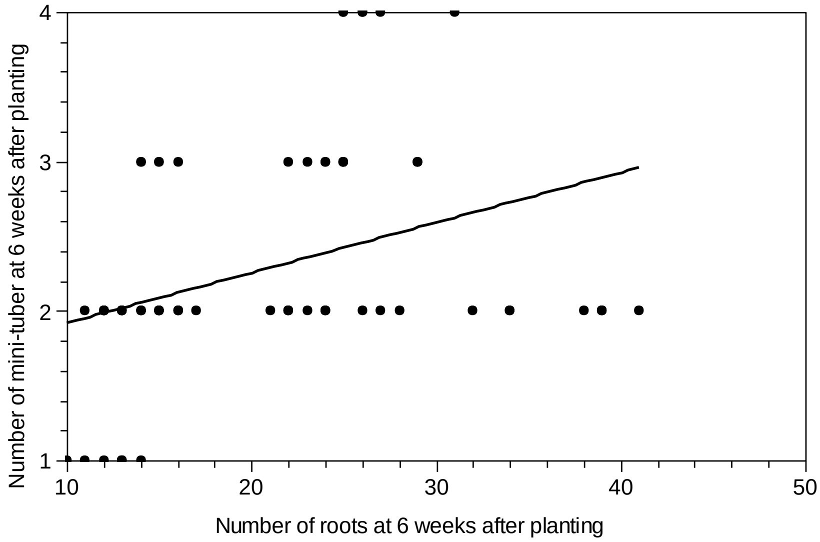

Figure 13. Correlation between number of roots and number of mini-tubers at six weeks after planting

There was also a positive correlation ($R^2 = 0.344$) between days to rooting and days to new leaf (Figure 14). Early rooted varieties also had early new leaves. Although the early rooting may have played some role in vine cuttings expressing new leaf/leaves, one remains free to speculate that the quantitative genotypic reflect the physiological differences in the cultivars used. Thus, the correlations between the number of days to root initiation and new leaf/leaves formation may depend on the physiological conditions of the cultivars used and not necessarily on the nutrient concentration used.

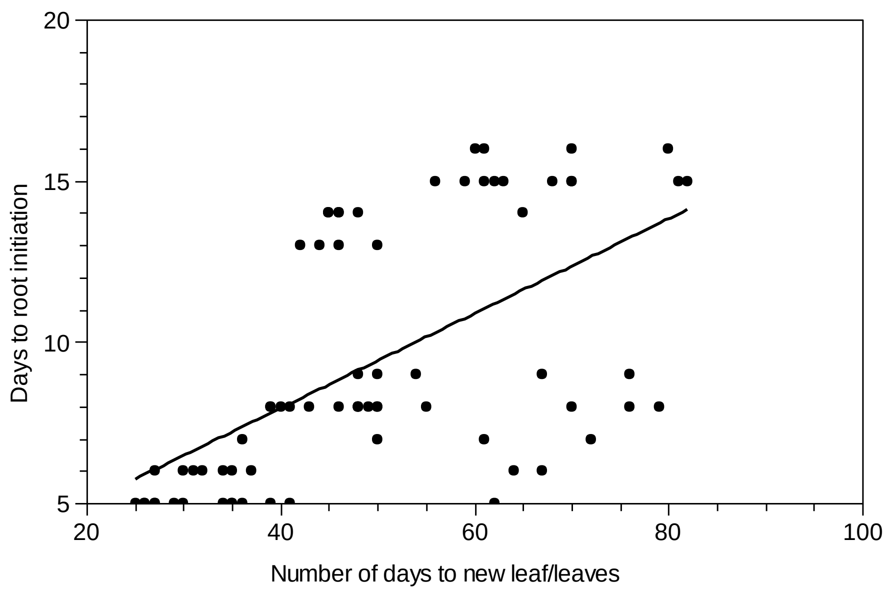

Figure 14. Correlation between days to root initiation and number of days to new leaf

The negative correlation ($R^2 = 0.28$) between days to mini-tuber initiation and number of mini-tubers at six weeks after planting (Figure 15), though weak, is suggestive of the fact that initiating early tuberisation does not affect final yield or number of mini-tubers that would be produced per plant. This is because many factors have been reported to affect tuber formation (Kempen, 2012: Menzel, 1980: Sattelmacher & Marschner, 1978). According to Kempen (2012), even the bacteria living in the root zone are reported to have an influence; however, nitrogen levels, temperature and light have the greatest effect. Reports show that short days and cool night temperatures also promote tuberization whereas long days, high night temperatures, and high nitrogen fertilisation inhibit or delay the process (Menzel, 1980, Sattelmacher & Marschner, 1978). This research did not go further to corroborate these findings.

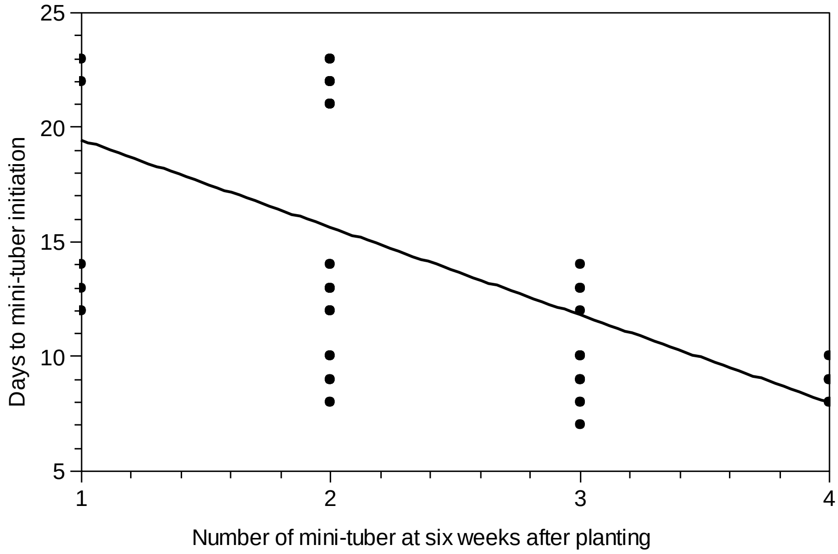

Figure 15. Correlation between days to mini-tuber initiation and number of mini-tubers at six weeks after planting

The planting density, number and timing of harvests are key factors in optimizing mini-tuber production. The planting density used resulted in optimized resource use efficiency. Maroya, Balogun & Asiedu (2014) reported using a planting density of 400 and 100 cm^2/plant which resulted in mini-tuber every three to five months whereas this research used a planting density of 36 cm^2/plant and reports mini-tuber yields from 4 months onwards and subsequently every two weeks.

In evaluating mini-tuber harvested, plants propagated from mini-tubers nursed in the screenhouse had rudimentary leaves before transfer to the experimental field 21 days after emergence. According to Haverkort, Van De Waart & Marinus (1991) and Lommen (1999), glasshouse raised transplants from very early cultivars sometimes show a poor performance after transplanting into the field. This has been attributed to the fact that immediately after transplanting, a major part of the daily dry matter production is invested in tuber growth (Lommen, 1999). This high degree of partitioning to tubers leads to a limited growth of the haulm and thereby limits the biomass production and final tuber yield (Lommen, 1999).

Nutrient concentration did not have any significance on the number of mini-tubers harvested. However, significant differences were seen in harvested mini-tuber weights and eventual number and weight of seed yams harvested using the various varieties produced under the different nutrient concentrations. It thus stands to be argued that the nutrient concentration used in propagating the mini-tubers, whether by the power-dependent or power-independent aeroponic systems has significant impact on the final yield of the second generation seed.

The two aeroponics systems were developed to enhance and optimize the rapid multiplication of seed yams. The potential benefits herein discussed such as rapid rooting and tuberisation and high multiplication ratios gives these systems the potential to improve seed yam production in the country.

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