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Growth and yield response of African spinach plant grown in different substrates culture of drip hydroponic farming method

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General Note
Article is recommended to print as color version in recycled paper. *Save Trees, Save Nature*.

ABSTRACT
The hydroponic techniques of growing vegetables have increased tremendously in developed countries over years while it is still new in developing countries such as Nigeria and other African countries. The knowledge of this methods and choice of suitable substrates for growing hydroponically are not known to many. More also, the behaviour of the crops when organic growing media are used as support system has not been established in Nigeria. African spinach plants were grown hydroponically using sawdust and rice husk as support system. This research determines the effect of substrates on optimum growth, yield and nutrient composition of African spinach plant so as to form an effective basis for selection of substrates to be used as plant support in soilless farming methods. The experiment was carried out in a completely randomized design with three treatments (sawdust, rice husks and soil) and replicated three times. The agronomic and physiological responses of this crop using different support systems

and/or planting systems were measured, the vegetative growth, yield, biomass weight, water and nutrient, proximate and mineral composition were measured and also, the physicochemical properties of the substrates and the soil. The results showed that rice husk as supporting system for African spinach gave the highest plant height of 29.32 cm, number of leaves of 47.51 and stem girth of 0.3835 cm respectively while soil as supporting system for African spinach gave the lowest plant height of 20.43 cm, lowest number of leaves of 41.93 and stem girth of 0.2859 cm. Higher yields were also recorded from rice husk for African spinach plant while the soil (conventional farming) has the least yield. Rice husk as substrates for African spinach plant recorded significantly higher fresh weight of leave substrate^{-1} of 37.61 kg, fresh weight of stem substrates^{-1} of 226.01 kg, fresh weight of root substrates^{-1} of 47.55 kg, fresh weight of seed substrates^{-1} of 89.6 kg while soil (conventional farming) has the least fresh weight of leave substrate^{-1} of 31.81 kg, fresh weight of stem substrates^{-1} of 187.12 kg, fresh weight of root substrates^{-1} of 42.24 kg, fresh weight of seed substrates^{-1} of 79.8 kg. The physiological appearance of the crop and the yields were significantly ($P<0.05$) affected by the various treatments due to effects of the substrates and the planting methods. The proximate and mineral compositions of the vegetables were higher in that from rice husk and least in soil as support. These were significantly ($P<0.05$) affected by the treatments effects as a result of its physicochemical features. With the outcome of this research, it is advisable that soilless farming should be embraced by farmers in areas where there is limitations of land for agricultural activities.

Key words: Hydroponic, Substrate, Growth, Yield, Quality, African spinach

1. INTRODUCTION

Since time immemorial, man has learnt how to grow plants under natural environmental conditions. Greater percentage of crops, either food or cash crops are grown in open field in Nigeria in which soil is usually its available growing medium. The soil provides anchorage, nutrients, air, water, etc. for plant growth (Aatif *et al*. 2014). It can be defined in many ways to suit different purposes, but to agriculturist, soil is the medium for crop growth, anchorage for plants, it contains nutrients, water and air on which plants depend (Ibiyoye, 2006; Pawlson *et al*. 2013; Arshad Ali *et al*. 2019). However, these soils do pose serious limitations for plant growth often. Some of them are presence of disease causing organisms and nematodes, unsuitable soil reaction, unfavourable soil compaction, poor drainage, degradation due to erosion, etc (Aatif *et al*. 2014; Mahmud Imam Mohammed and Jimoh, 2018). More also, open field agriculture is difficult as it involves large space, lot of labour and large volume of water. In most urban and industrial areas, soil is less available for crop growing, or in some areas, there is scarcity of fertile, cultivable arable lands due to their unfavourable geographical or topographical conditions and climatic conditions (Aatif *et al*. 2014; Ajay Kumar Singh and Pritee Sharma, 2018). Due to the circumstances as described above, soilless farming techniques of growing some high value crops can be introduced. Soilless farming is a method of growing without soil. Soilless farming method is the technique of growing plants in soilless condition with their roots immersed in nutrient solution (Maharana and Koul, 2011). Soilless farming is considered as a modern day practice, but growing plants in containers above ground has been tried at various times throughout the ages. Growers go into soilless farming because of the difficulty and cost of controlling soil born pests and diseases, soil salinity, lack of soil fertility, water shortage etc. Wall paintings found in the temple of Deir el Bahari appear to be the first documented case of container-grown plants (Naville, 1913; Gopinath *et al*. 2017). They transfer mature trees from native countries of origin to the king's palace and then grown as soilless farming, when local soils were not suitable for the particular plant. African spinach botanically called *Amaranthus cruentus L.,* and popularly called *"Amaranth* or pigweed", is an annual herbaceous plant of 1- 6 feet high. The leaves are alternate petioled, 3–6 inches long, dull green, and rough, hairy, ovate or rhombic with wavy margins. The flowers are small, with greenish or red terminal panicles. Taproot is long, fleshy red or pink. It is rather a common species in waste places, cultivated fields and barnyards. African spinach is a cool weather crop that does not grow well in hot weather. It grows optimally under warm conditions (not greater than 24^0C during the day and not lower than 15^0C at night). The young leaves, growth points and whole seedlings of amaranth are harvested and cooked for use as a vegetable (Jansen van Rensburg *et al*. 2007). This research work aims to comparatively evaluate the potential of organic growing media (sawdust and rice husks) and soil on African spinach and to examine its effects on yield quality using drip flow substrate technique hydroponic farming inside the greenhouse and conventional farming respectively.

2. MATERIALS AND METHOD

Study Area

This study was carried out at Agricultural and Environmental Engineering experimental farm site, Federal University of technology, Akure, Ondo State, Nigeria, (7.2995^0N, 5.1471^0E). As a tropical area, Akure has a high temperature throughout the year. The average daily temperature is 26°C with a range between 18°C and 35°C. Mean annual relative humidity of about 80% and relief is about 396 m above sea level (Odubanjo *et al*. 2011).

Field Experimental Procedure

African spinach seed bought from National Horticultural Research Institute, Ibadan were sown on drip hydroponic structure using sawdust and rice husk as plant support under greenhouse conditions and conventional farming with soil to serve as control. Samples of sawdust and rice husks were randomly taken from sawmill and rice mill. Also, soil samples were randomly collected within the depths of 0 - 15 cm using a hand auger from the agricultural engineering experimental farm site where the conventional farming was carried out. Each sample was separately labeled, air-dried, crushed to pass through a 2 mm sieve, and taken to the laboratory for physicochemical analysis by standard methods prior to application of inorganic nutrients/solution and planting. Substrates were put in 3" drilled hole inserted with disposable empty water bottle and filled with sawdust and rice husk in a 4"•4"•72" PVC pipes laid layout in completely randomized design with three replicates. Treatments consist of two different substrates (sawdust and rice husk) in the drip hydroponic soilless structure as shown in figure 1 and soil in conventional farming as control respectively to determine the growth and yield of African spinach plants. The experimental field for the open field farming was cleared, manually tilled prior to planting while the drip hydroponic soilless farming structure is being built. There were five observations of plants on each substrates and soil. The planting space is between 200 mm within row and 300 mm between rows. It was sown directly in the drip hydroponic planting structure and in the soil on the 13th of March, 2017 at the rate of three seeds per hole and water everyday every day. Drip hydroponic substrates culture supplied a standard nutrient solution to the plants. The nutrient solution that was used for this research contained: 0.76 g/l sodium nitrate, 0.24 g/l potassium sulphate, 0.25 g/l mono-calcium phosphate, 0.71 g/l magnesium sulphate, 0.27 g/l potassium nitrate, 0.76 g/l calcium nitrate and 0.03 g/l iron sulphate. The electrical conductivity of solution was maintained from 1.5 and 2.5 dS/m while the pH was maintained in the range of 5.8 and 6.5. The volume of nutrient solution applied varied from 1623 to 1912 ml for five observed plants in an experimental unit per week. The plants were irrigated 2 times a day with the same nutrient solution until the end of experiment. Irrigation frequency was based on solar radiation and stage of plant growth in greenhouse. Average day and night temperatures in the greenhouse were 31ºC and 22ºC respectively. The relative humidity varied between 52% and 75%. Data collection on plant height, number of leaves, stem girth began a week after planting and counting of number of flowers, number of fruits and continues every week at its stages. Total fruit yield of the crops and biomass yield were measured and evaluated.

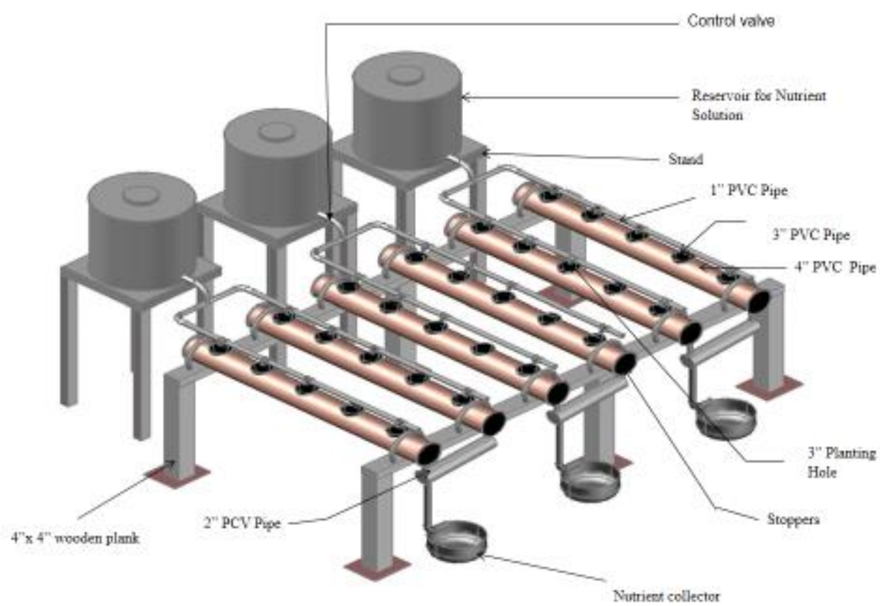

Figure 1 Isometric view of drip hydroponic soilless structure

Proximate and Mineral Analysis of the African Spinach Vegetable

Samples of the African spinach vegetables were plucked from each substrate and the soil. It was cleaned by rinsing it with deionised water. The samples were stored in the refrigerator (4-8^{0}C) for proximate and mineral analysis test in the laboratory. The proximate composition of the vegetable was determined using AOAC, (2000) procedure for the determination of moisture content, ash content, protein, crude fibre, fat and energy while the mineral elements comprising sodium, calcium, potassium, magnesium and iron were determined according to the method of Shahidi*et al*. (1999) and Nahapetian and Bassir, (1975) with some modifications (Akubugwo *et al*. 2007).

Statistical Analyses

Analysis of variance was performed on the data of physiological responses of African spinach plants, its yield, proximate and mineral composition of its fruits. The means of significant treatment effects were separated with the Least Significance Difference test. All the tests of statistical significance were based on a 5% level of probability.

3. RESULTS AND DISCUSSION

Physical Properties of the Substrates and the Soil

Result of the sawdust, rice husk and soil samples used as substrates for plants support system of the plants showed the following values of some physicochemical properties as shown in Table 1. The particle size analysis of the soil at the experimental farm is loamy sand in texture while sawdust and rice husk indicates no sample for particle size classification. A soil's ability to hold and supply nutrients is related to the number of parking spaces for nutrients on substrates/soil particles. Since the result of the coefficient of permeability of the sawdust, rice husk and soil has been established to be low, very low and high respectively, it implies that less water/nutrient solution will move through the sawdust and rice husk which economized its use for the crops while the high permeability level of soil result to more water and nutrient been easily drained and not available to crops in the long run. The soil is low in organic matter as reflected by the low content of organic matter (2.98 g/kg) which is very low compared to sawdust (9.53 g/kg) and rice husk (12.2 g/kg). Typical amount of organic matter in soil varies from <1% in ordinary soil to 90% in both peat soil and between 15 to 20% in mineral soils (Awofolu *et al*. 2005; McCauley *et al*. 2017). Organic matter obtained in both substrates and soil was within this range. The relevance of organic matters to this study is its influence on the mobility and flux of extractable bases and micronutrients. The normal range of organic matter obtained signified that metals in soil and substrates are bio-available since these metals are known to form complex with organic matter that influence their availability (Awofolu *et al*. 2005; Ashraf *et al*. 2012). The moisture content of the sawdust, rice husk and the soil are 12.1%, 18.8% and 8.70% respectively (Table 1). Moisture content is related to organic matter; it helps to improve the structures of the substrates as well as water and nutrient holding capacity, support soil microbes and protects soil and the substrates from erosion and competition. Total nitrogen of soil (0.14 g/kg) compared to sawdust (0.5 g/kg) and rice husk (0.65 g/kg). Nitrogen is an important building block of proteins, nucleic acids and other cellular constituents that are essential for all forms of life. Soil pH is a measure of a soil solution's acidity and alkalinity that affects nutrient solubility and availability in the soil/substrates. The pH of soil is strongly acidic with a mean value of 5.3 while rice husk and sawdust has pH of 6.5 and 6.1 respectively. This is considered suitable and good better performance of vegetables. Soil pH levels near 7 are optimal for overall nutrient availability, crop tolerance, and soil microorganism activity (Tindal, 1983; Pureseglove, 1991; McCauley *et al*. 2017). Soil pH can be modified by using chemical amendments which is considered in chemical composition of the nutrients used for the planting of this crops (McCauley *et al*. 2017). The available Sodium (Na), Potassium (K), Calcium (Ca) and Magnesium (Mg) with mean values of (0.77 mg/100g, 2.12 mg/100g and 0.34 mg/100g), (0.34 mg/100g, 0.55 mg/100g, and 0.06 mg/100g), (5.73 mg/100g, 8.18 mg/100g, and 2.11 mg/100g), (1.63 mg/100g, 3.97 mg/100g and 0.84 mg/100g) for sawdust, rice husk and soil respectively were seemingly low compared to the ratings of FMANR (1996) for the ecological zone (Olaniyi and Ojetayo, 2010). A substrate/soil's ability to hold and supply nutrients is related to its cation and anion exchange capacities; these revealed there is need for amendment in form of fertilizer or nutrient solution application to improve the growth and the yield of the vegetables.

Table1 Result of mean physical and chemical properties of the substrates and the soil

Parameters Measured	Values Obtained		
	Sawdust Samples	Rice husk Samples	Soil Samples
Moisture Content	12.1%	18.8%	8.7%
Water Holding Capacity	54	76	14
Total Porosity	46	24	86
Permeability	Low	Very Low	High
Bulk Density	0.94 g/cm^3	0.92 g/cm^3	1.41 g/cm^3
Clay	NS	NS	9.5%

Silt	NS	NS	3.8%
Sand	NS	NS	86.7%
Ph	6.1	6.5	5.3
EC	470µS/cm	651µS/cm	425µS/cm
Organic Carbon	5.54	7.10	1.73
Organic Matter	9.53 g/kg	12.2 g/kg	2.98 g/kg
Total Nitrogen	0.50	0.65	0.14
Fe	75.3 mg/kg	92.4 mg/kg	188.1 mg/kg
Mn	5.17 mg/kg	6.82 mg/kg	24.4 mg/kg
Zn	18.3 mg/kg	22.9 mg/kg	37.1 mg/kg
Cu	1.10 mg/kg	1.25 mg/kg	5.46 mg/kg
Pb	0.24 mg/kg	0.19 mg/kg	0.82 mg/kg
Na	0.77 mg/100g	2.12 mg/100g	0.34 mg/100g
K	0.34 mg/100g	0.55 mg/100g	0.06 mg/100g
Ca	5.73 mg/100g	8.18 mg/100g	2.11 mg/100g
Mg	1.63 mg/100g	3.97 mg/100g	0.84 mg/100g

Each data is mean of three replicates.

Plant Height, Number of Leaves and Stem Girth of African Spinach as Influenced by the Substrates and the Soil

Testing for the differences among the pair of means, using LSD (0.05), the plant height of African spinach showed no statistically significant differences ($p<0.05$) among the mean plant height on the substrates as shown in Table 2. African spinach planted on the rice husk has the highest mean plant height of 29.32cm while that planted on the soil has the least mean plant height of 20.43cm. This agreed with findings of Rodriguez-Ortega *et al.* (2017) which states that plants grown hydroponically had the greatest vegetative growth, characterized by their plant height, number of leaves and stem biomass. Generally, the plant height increased as the plant aged (Figure 2). In terms of physiological features of the plant, either rice husk or sawdust could be recommended because the plant height from these two substrates produces the highest yield. The differences in plant height could be attributed to irrigation time and difference in physicochemical parameters as rice husk contain high organic matter and others.

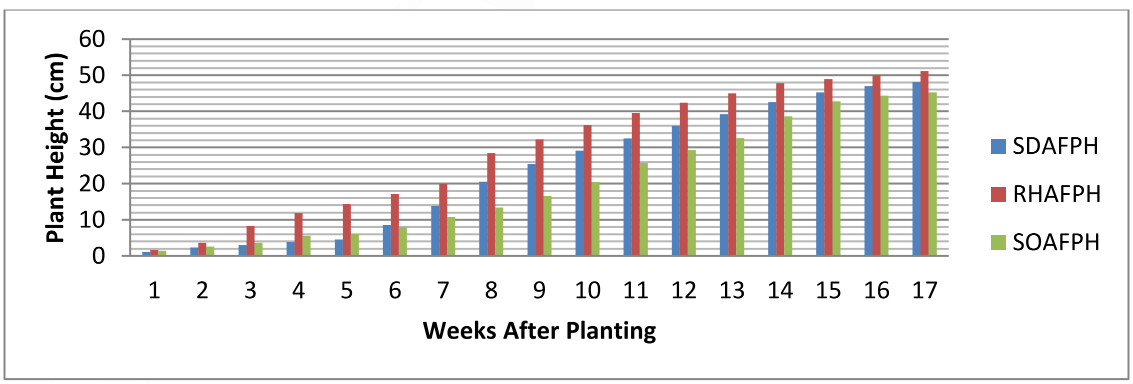

Figure 2 Plant height (cm) of African spinach with different substrates

Testing for the differences among the pair of means, using LSD (0.05), the number of leaves of African spinach showed no statistically significant differences ($p<0.05$) among the mean plant height on the substrates as shown in Table 2. African spinach planted on the rice husk has the highest mean number of leaves of 47.51 while that planted on the soil has the least mean number of leaves of 41.93. This agreed with findings of Rodriguez-Ortega *et al.* (2017) which state that plants grown hydroponically had the greatest vegetative growth, characterized by their plant height, number of leaves and stem biomass. Generally, the number of leaves increased as the plant aged (Figure 3). In term of physiological features of the plant, either rice husk or sawdust could be recommended because the number of leaves from these two substrates produces the highest yield. The differences in number of leaves could be because of irrigation time and difference in physicochemical parameters as rice husk contain high organic matter and others.

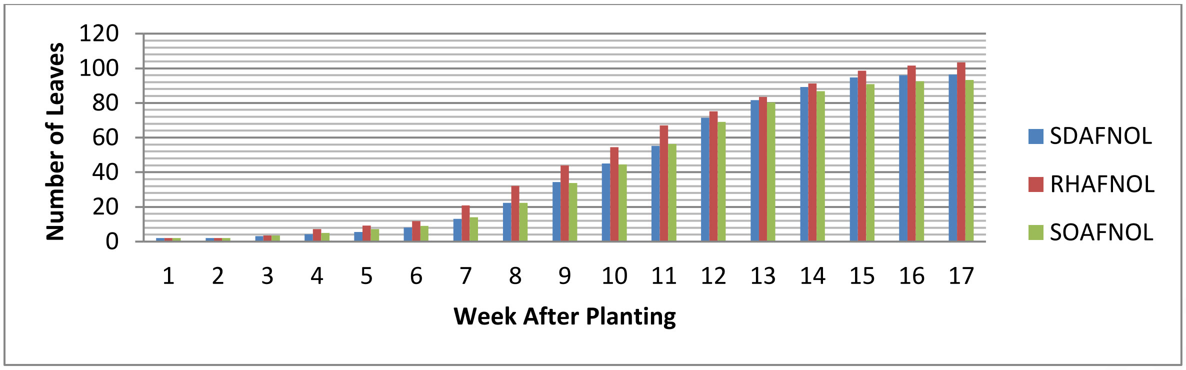

Figure 3 Number of leaves of African spinach with different substrates

Testing for the differences among the pair of means, using LSD (0.05), the plant height of African spinach showed statistically significant differences ($p<0.05$) among the mean stem girth on the substrates as shown in Table 2. African spinach planted on the rice husk has the highest mean stem girth of 0.3835cm while that planted on the soil has the least mean stem girth of 0.2859 cm. This agreed with findings of Rodriguez-Ortega *et al*. (2017) which state that plants grown hydroponically had the greatest vegetative growth, characterized by their plant height, number of leaves and stem biomass. Generally, the stem girth increased as the plant aged (Figure 4). In term of physiological features of the plant, either rice husk or sawdust could be recommended because the stem girth from these two substrates produces the highest yield. The differences in stem girth could be because of irrigation time and difference in physicochemical parameters as rice husk contain high organic matter and others.

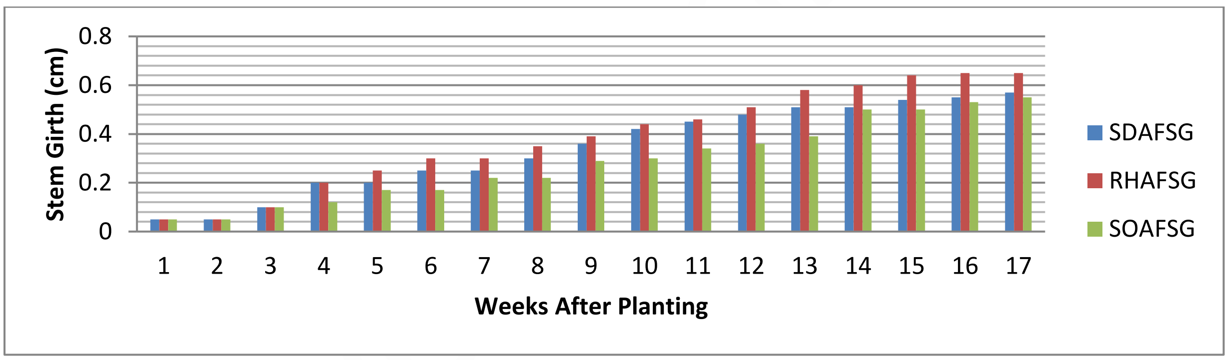

Figure 4 Stem girth of African spinach with different substrates

The growth parameters can be seen to be increasing with age. The African spinach plant growth pattern shows an initial slow growth and then accelerated as observed in figure 2- 4 after the normal slow establishment of the plant. This result agreed with the findings of other researchers (Olaniyi and Fagbayide, 1999; Olaniyi *et al*. 2010) who found that the plant showed growth in height at the beginning rather slowly, increasing to a maximum then slow down again so that the chart obtained by plotting height, number of leaves and stem girth against weeks after planting is an oblique 'S' in shape. Generally, this result agreed with findings of Silber bush and Ben-Asher, (2001) that peat moss produced higher yield and number of fruits than conventional growing system in greenhouse vegetable production.

Table 2 Plant height, number of leaves, stem girth of African spinach plants grown on the substrates and the soil

Substrates	Plant height (cm)	Number of leaves	Stem girth (cm)
Sawdust	23.70a	42.64a	0.3406a
Rice husk	29.32a	47.51a	0.3835a
Soil	20.43a	41.93a	0.2859a

Means that do not share a letter are significantly different at $p < 0.05$ according to Fisher's Least Significance different (LSD).

Yield and Biomass Components of African Spinach as Influenced by the Substrates and the Soil

The fresh weight of leaves, stem and root of African spinach plant as influenced by different substrates in drip substrates soilless farming system is presented in figure 5. Rice husk has the highest value of these component parts of the plant. Although, there was no significant difference in fresh weight of leaves, stem and root in the three substrates as shown in Table 3. This agreed with findings carried out that most experiments comparing different substrates for horticultural crops indicate that the differences were not marked (Voca *et al*. 2007; Borowski and Nurzyński, 2012). At the end of the experiment, regardless of the substrates treatment, the plants grown on rice husk and sawdust had the greatest vegetative growth, characterized by their high leaves, stem and root biomass value.

Table 3 Yield and biomass components of African spinach as influenced by different substrates

Substrates	Fresh weight of leaves/substrates	Fresh weight of stem/substrates	Fresh weight of root/substrates	Fresh weight of seed/substrates
Sawdust	33.052ab	195.29b	43.02a	80.6a
Rice husk	37.61a	226.01a	47.55a	89.6a
Soil	31.81b	187.12b	42.24a	79.8a

Means that do not share a letter are significantly different at p < 0.05 according to Fisher's Least Significance different (LSD).

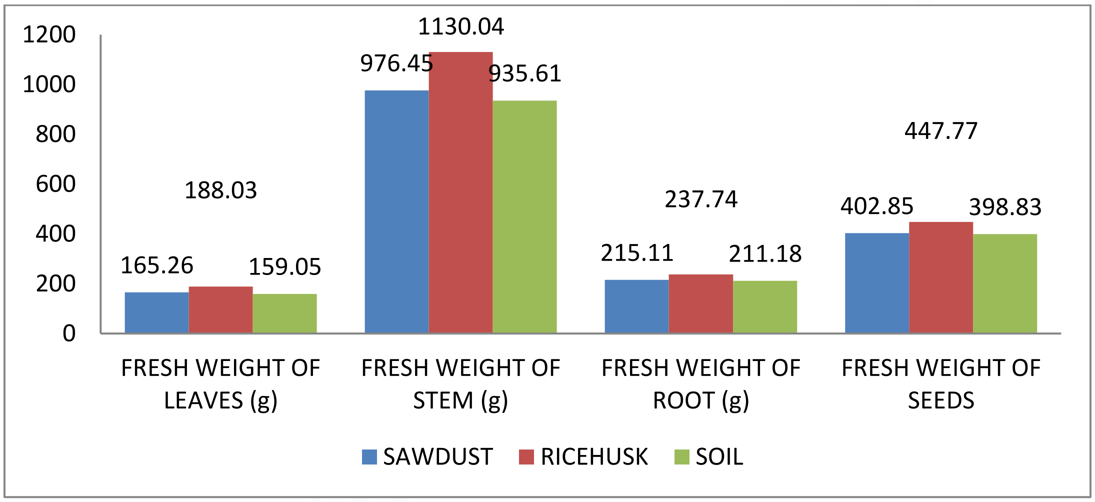

Figure 5 Yield and biomass components of African spinach with different substrates

Proximate Analysis and Mineral Composition of African Spinach with the Substrates and the Soil

The results of the proximate analysis and mineral composition of African spinach vegetable with different substrates are presented in Table 4. The mineral nutrient composition such as sodium, potassium, calcium, magnesium and iron from rice husk and sawdust showed significant difference. There is inconsistency in the nutritional values obtained in the study of African spinach with different substrates. The African spinach on rice husk closely followed by sawdust recorded higher nutritional values more than the soil that served as control. This agreed with findings of Barbosa *et al.* (2015) whom found that plants from a soilless culture had higher percentage of nutritive values compared to plants harvested from soil culture as affirmed by result shown in table 4. The outstanding values of the African spinach as a source of special nutrient needed in the diet are indicated by the nutritive values. Calcium aids the formation of bones, while iron in the diet serves as a source of blood formation to the body of a man (South pacific foods, 1995). All the substrates used are good sources of quality and mineral elements. These nutrient elements were above the World Health Organization (WHO) as shown in Table 4. The variation in the nutritive values of these plant using different substrates as support system might be because of environmental effect in which the crops were grown and chemical composition of the substrates. This agreed with study of Russo (1996) that distribution of minerals needed for human health in the edible portion of plants can be affected by cultural production method. Leafy vegetables had great potential for enrichment of minerals, bioactive compounds and health promoting substances. Commercial cultivation of this crop for a specific dietary requirement can be possible in order to meet the demand of people. The percentage of moisture content, ash content, crude protein, fibre, fat and energy values of African spinach showed significant influenced by the substrates. There is inconsistency in the nutritional values obtained in this study of African spinach with different substrates. The African spinach on rice husk closely followed by sawdust recorded higher values of these parameters more than the other (soil) which served as control. Leafy vegetables are source of macro and micronutrients that play major role in maintaining healthy living (Iheanacho and Udebuani, 2009). Protein helps in the building up of new cells in the body and enhances growth. Fat in the diet serves as a source of energy in the body of a man (South pacific foods, 1995).

Table 4 Proximate analysis and mineral composition of African spinach with different substrates (values per 100 g edible portion, Fresh weight basis)

Parameters	% MC	% Ash	% Protein	% Fibre	% Fat	Energy (KJ/g)	% Mg	% Ca	% Na	% P	Fe (mg/kg)
Sawdust	61.30b	3.43b	33.83c	8.49ab	10.63b	667.95b	4.82c	51.92a	26.20a	86.38a	0.92ab
Rice husk	63.18a	3.52a	35.47a	8.52a	10.83a	668.15a	4.92b	51.83b	24.55a	86.30a	0.93a
Soil	61.29b	3.44b	34.78b	8.48b	10.54c	667.94b	5.14a	51.74c	26.21a	85.40b	0.91b
WHO Values	25 – 50	-	-	-	-	-	0.032	0.02	0.015	0.035	20

Means that do not share a letter are significantly different

Mg: Magnesium; P: Phosphorus; Na: Sodium; Ca: Calcium; Fe: Iron; MC: Moisture content.

4. CONCLUSION

This study was carried out to evaluate some growth and yield indices of two different organic substrates (rice husk and sawdust) inside greenhouse and soil for convectional farming method with African spinach vegetable. Result of the experiment revealed that planting with substrates such as rice husk and sawdust had the highest physiological appearances and growth of the plant. It also suggests that inability to go for conventional farming techniques in area such as desert, riverine area, urban centers, etc., any of the substrates may be used to obtain similar or higher result of yield. Therefore, in our growing condition, the substrates such as rice husk and sawdust in drip hydroponic soilless planting system is the most suitable while soil by conventional farming for cultivation of this vegetable gave least values in most of the parameters measured. The selection of these suitable media is the key that ensures the success of this technique, seeing that the adoption of conventional planting system as control for this experiment did not produce as such in the greenhouse planted through rice husk and sawdust. Proximate and mineral analysis showed that these vegetable contain appreciable amount of proteins, energy, fat, fibre and mineral elements. Thus, it can also be concluded that these crops can be grown hydroponically and contribute significantly to the nutrient requirements of man in area where soil for conventional farming support cannot be found or scarce such as urban centers or riverine area. Also, as growing condition of crops is becoming difficult most especially in urban cities where there is no availability of fertile soil or where the distance to available and fertile soil for crop production is not within reach, people can venture into the production of this vegetable at their home where there is open structure by adopting soilless farming technique and to help improve the yield and quality of the produce even at where the soil is good so that we can ensure food security of our country. In spite of the close proximity of values obtained for the substrates and the soil, optimization of the management of this system could lead to better results, while avoiding contamination of soils, underground water and aquifers due to the release of fertilizers and other chemicals on soil for crop productions.

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