Biochar for Climate Change Adaptation: Effect on Heavy Metal Composition of *Telfairia occidentalis* Leaves

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Contents

Abstract

Gas flaring is a key contributor of greenhouse gases that causes global warming and climate change. Adaptation measures for tackling impacts of climate change

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have gained much research interest. This chapter assessed vegetable farmers' perception of gas flaring and the effect of biochar remediation on the heavy metal composition of cultivated *Telfairia occidentalis.* A gas-flared area, Ohaji/Egbema L.G.A of Imo State, and a non-gas-flared area, Umudike, Ikwuano L.G.A, were selected for this research. Structured questionnaire was used to elicit information from 120 respondents. Soils were collected from the study sites and transported to the greenhouse. Five different rates, 0 t ha^{-1}, 7.1 t ha^{-1}, 13.9 t ha^{-1}, 20.9 t ha^{-1}, and 28.0 t ha^{-1}, of palm bunch biochar were applied to the soils in plastic buckets. After 2 weeks of mineralization, two viable seeds of *Telfairia occidentalis* were planted in each bucket and watered every other day for 8 weeks. The result revealed that 63% of vegetable farmers where female, while 37% were male in the gas-flared area. A total of 97% of the farmers had knowledge of gas flaring. A total decrease of 55% percent income, 90% yield, and 67% market quality of vegetable farmers was attributed to gas-flared activities. The plant height of cultivated vegetables increased every 2 weeks with greater increase in the test plant. Heavy metal concentration (Pb, and Cr) decreased with increasing biochar rate and was significantly lower for 28.0 t ha^{-1}. Biochar can enhance soil fertility and help immobilize heavy metals. The effect of biochar application on the heavy metal composition is dependent on the rate of application. Biochar use could be a cheap adaptation measure in the face of a changing climate.

Keywords

Biochar · Climate change adaptation · Gas flaring · Heavy metal · *Telfairia occidentalis*

Introduction

Natural gas is a component of petroleum that is released during crude oil exploitation (Mohammed et al. 2016). This natural gas is usually vented or flared (burnt off) (Mohammed et al. 2016). Venting has to do with a direct release of natural gas into the atmosphere without burning, while gas flaring is the indiscriminate burning of natural gas during crude oil exploitation. This practice is common in most countries of the world especially in developing countries like Nigeria where oil companies fail to acquire the needed infrastructure for trapping, storage, and use of natural gas. Gas venting and flaring are responsible for enormous waste of nonrenewable resource, pollution, and an annual release of greenhouse gases which contributes immensely to global warming and climate change (Ajugwo 2013). In 2017, World Bank Global Gas Flaring Reduction Partnership reported that more than 140 billion cubic meters (bcm) of natural gas was flared. This huge volume of gas can serve as a reliable source of energy for the African continent yearly, but on the contrary, it has remained an unprecedented source of pollution (Emam 2016; Ismail and Umukoro 2012). As commercial deposits of crude oil was discovered in Nigeria, the nation drifted from agriculture to oil exploitation as its national income base. Oil industry became the nation's gold mine as it accounts for over 80% of her earnings (Ohimain 2013a, b). The oil companies in the Niger Delta region of Nigeria provided more than 80% of funds used for allocating national budget (Ede and Edokpa 2015). Nigeria is ranked one of the ten countries of the world with abundant natural gas reserve (Orlando 2006). It has been ranked the second highest in terms of gas flaring activities and the highest in Africa having a whooping gas reserve of over 180 tcm (trillion cubic meter) that has earned it the seventh largest gas reserve worldwide (Oyedepo 2014; Shaaban and Petintin 2014). World Bank reported that Nigeria flared over 7 (seven) billion cubic meters (bcm) of gas in 2018. Nigeria produces over 2,000 billion standard cubic feet of gas yearly (Nriagu et al. 2008). This volume fluctuates regularly because of incessant unrest from militants, activities of miscreants, vandalization, leakages, and so on. Oil exploitation companies in Nigeria are unable to channel natural gas into gainful use since they consider it cost intensive to procure the facilities needed for gas capture. Gas flaring is therefore employed as a safe means to evacuate any associated natural gas during petroleum exploitation, despite its serious deleterious far reaching environmental effects. Threat of flaring gases is common in oil rigs, crude oil refineries, and plants. In advanced countries like the USA, only 1% of the associated natural gas is flared, while in Nigeria more than 60% natural gas is flared every day. This large volume of flared gas has the potential to generate substantial revenue to the government of Nigeria if properly harnessed for cooking or industrial uses (Agboola et al. 2011). The flared gas could also be used to generate (power) electricity which could end the challenge of inadequate power supply especially now that the nation is experiencing reduced oil revenues as a consequence of global decrease in oil price (Ojide et al. 2012). This will raise more revenue for Nigeria at this time when oil prices are generally low.

Nigeria losses over 1 billion naira revenue through gas flaring (Campbell 2004; Fluenta 2019) that would have contributed immensely to the nation's economy if the gas was properly captured (Buzcu-Guven and Harriss 2012). Between November 2016 and November 2017, Nigeria flared over 300 billion standard cubic feet of gas which was sold at an exchange rate of 360 naira to 1 dollar with a domestic supply rate of 1.50 USD per 1000 standard cubic feet of gas. This suggests that the nation lost a whooping sum of over 160 billion naira which could have improved her economic base (NNPC 2017). Rules and regulations governing gas flaring in Nigeria are not adequately adhered to by oil-producing companies because such laws are weakly enforced and the penalty levied on defaulters is insignificant (N10 per standard cubic feet). Oil companies in Nigeria lack modern infrastructure needed for gas capture (Okorie 2018); they perceive that such equipment is expensive, and hence its use may not be economically viable. Ironically, there has been increased preference and demand for cooking gas over other sources of fuel, yet, the colossal waste of gas flaring is still been practiced. Locally and internationally, efforts are therefore needed to ensure that regulations governing gas flaring are strictly adhered for the good of man and the environment (Otitoloju and Dan-Patrick 2010).

The composition of the flared natural gas determines the type of pollutants emitted (Fawole et al. 2016). Gas flaring emits greenhouse gases that warm the atmosphere, causing climate change (Ukala 2011); also other precursor gases, volatile organic compounds (VOCs), polyaromatic hydrocarbons (PAH), particulate matter, and black carbon from gas flares often contaminate air, soil, and water (Giwa et al. 2014). More than 200 notable toxins have been reported to emanate from gas flares including hydrogen sulfide, toluene, benzene, sulfur dioxide, nitrogen oxide, xylene, and so on (ICF 2006). Particulate matter and precursor gases are among the most toxic pollutants that affect plants and man (Giwa et al. 2014; Yaduma et al. 2013). It releases over 40 billion kilowatts of heat daily into the atmosphere (Ukala 2011). Other pollutants released during gas flaring are soot, organic carbon, particulate matter (Guttikunda and Calori 2013; Giwa et al. 2014; Zhou et al. 2014), and heavy metals (Kampa and Castanas 2008). One percent of global warming arises from gas flaring which contributes over 300 Mt of CO_2 into the atmosphere (IPCC 2014a; Amaechi and Biose 2016). Though the practice of gas flaring has been significantly reduced in some countries, Nigeria is yet to record a significant decline despite numerous government strategies (Ite and Ibok 2013); hence, its devastating effects are still felt (Giwa et al. 2014; Oyedepo 2014). Nigeria has lost so much money as a result of gas flaring since the commencement of oil exploitation (Odumugbo 2010). Nigeria loses well over 2 billion dollars as a result of gas flaring yearly (Campbell 2004). This income would have contributed positively to the nation’s economy if the gas was properly captured (Buzcu-Guven and Harriss 2012). Gas flaring is responsible for loss of energy resources in oil companies. It affects art works, paints, and monuments (Abua and Ashua 2015; Amadi 2014; Anomohanran 2012; Donwa et al. 2015; Iyorakpo and Odibikuma 2015; Nkwocha and Pat-Mbano 2010; Olukoya 2015; Ubani and Onyejekwe 2013). It affects the general well-being of the Niger Delta dwellers, both psychologically and otherwise (Nriagu et al. 2008). Noise from flare stalks could also affect man and other living things residing around the area. This could lead to loss of some important species or even outright extinction. Pollutants emitted from gas flares are more concentrated at locations close to the flare site. Those farther away from flare sites have reduced pollutant concentrations (Ojeh 2012). Though gas-flared effects are majorly felt within 450 m radius of flare stack, factors like stack height, flare velocity, temperature, and wind speed affect its impact (Ojeh 2012). When there are notable variations in wind speed and direction, locations close to flare stack may have less concentration of pollutants, while farther locations may have more. Gases can be flared from either a high or low pressure valve, and this affects the concentration of gas emitted and also the noise generated. Global Emission Inventory stated that flaring releases three times more soot than gasoline-driven vehicles (Weyant et al. 2016). It is responsible for the disorientation of water bodies like seas and oceans, for example, for over 40 years now, the ice level of the artic sea has significantly diminished (IPCC 2013). This rise in sea level is a consequence of global warming (Bernstein et al. 2007).

The Niger Delta area of Nigeria occupies more than 7% of the nation’s total land mass with not less than 20 million inhabitants (Tawari and Abowei 2012). The nation has onshore and offshore natural gas reserves located in nine states, namely, Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo, and Rivers. They comprise a total of 185 local government areas, housing over 800 oil-producing wells and gas operation facilities (Osuji and Onojake 2004). Niger Delta environment is constantly being polluted by activities such as gas flaring, crude oil pollution, pipeline and tanker leakages, and so on (Tawari and Abowei 2012). All these pollutants have over the period altered the ecosystem balance, crop development, and human health. They have also been found to affect microbial activities in the area (Sonibare et al. 2010). A greater percentage of rural dwellers in the Niger Delta engages in different agricultural activities especially fishing and farming as means of livelihood. Unfortunately, gas flaring has negatively affected their survival since it has negatively impacted soil, water, and the environment at large. Gas-flared areas have an elevated ambient temperature as a result of the huge amount of heat (above 45 billion kilowatts) that is released daily from gas-flared points (Aaron 2006). Crops cultivated 2 km away from gas-flared points are usually scorched by the heat emitted from the gas flares (Anomohanran 2012). Particulates from gas flares can spread as far as 2.61×10^6 km away from flare points (Ede et al. 2011). A study conducted by Gobo et al. (2009) revealed that these pollutants could trigger onset of eye, skin, and respiratory diseases. Prolonged exposure to gas flares has been reported to negatively affect blood hematological parameters (Adienbo and Nwafor 2010). Ovuakporaye et al. (2012) also reported presence of skin and respiratory diseases in residents of gas-flared areas as a result of long-term inhalation of gas-flared fumes. Gaseous pollutants from gas flares such as nitrogen and sulfur oxides are responsible for acid rain. Acid rain corrodes roofing sheets and walls of buildings. Smog that results from the reaction of nitrogen oxides and hydrocarbons in the presence of UV radiation creates poor visibility (Ana et al. 2009). Other diseases reported to be prevalent in gas-flare areas include respiratory disease, eye and skin disorders, skin cancers (Ana et al. 2009), lung cancer (Ana 2011), and so on. Between 2015 and 1965, a period of 51 years, it was reported that an approximate gas quantity of over 900 bcm and 17 bcm every year with carbon monoxide being the most abundant gas was emitted (Giwa et al. 2019). Elevated levels of deleterious heavy metals have been observed in the air of the Niger Delta area. For instance, Olobaniyi and Efe (2007) reported 0.56 mg/l of lead in the area. Gas flaring has been reported to reduce yield of crops (Dung et al. 2008; Odjugo 2007; Odjugo and Osemwenkhae 2009; Olisemauche and Avwerosuoghene 2015), induce soil pollution evidenced by increased PAH deposits in soils (Sojinu et al. 2010), and be responsible for various health defects (Bhatia and Wernham 2009; Ekpoh and Obia 2010). The people of the Niger Delta perceive that gas flaring affects their health status and disturbs ecosystem balance generally (Edino et al. 2009).

Living things rely majorly on plants for their survival. The much needed energy and nutrients required by human body for its biochemical processes can be majorly derived from plants. Herbivorous animals (goat, sheep, grass cutters) and omnivorous animals (rat, squirrel, mice) depend on plants for their survival. Plants also provide shelter in the form of vegetation cover for animals that live on land. Cassava and oil palm are among common plants that are often found near gas stacks. The growth (Ozabor and Obisesan 2015) and yield (Achi 2003) of these crops are often affected by gas flaring. Over 70% of the Niger Delta dwellers are convinced that gas flaring has negatively affected their agricultural activities (Adewale and Mustapha 2015), hence their income source. Data obtained from a study in an oil community, Ebedei in Delta, has shown that gas flaring is affecting production of tuber crops such as yam, potato, and cassava including plantain and okra as well (Ozabor and Obisesan 2015). Acid rain arising from gas-flared pollutants is poisonous to plants. It could even lead to death of plants and hence loss of vegetation cover (Amadi 2014). This could further expose the soil to erosion. Symptoms expressed by plants when attacked by acid rain include shedding of leaves, yellow leaves, loss of photosynthetic ability, and even early death (Efe 2011). Acid rain has a more deleterious effect on plants and vegetation that are closer to gas-flared system. Efe (2011) documented that acid rain has negative impact on growth and development of common staple food crops and even cash crops such as rubber. The soil has not been spared from the impacts of acid rain as it has led to loss of important nutrients needed for plant survival. Other researchers including Jacobson (1984), Neufeld et al. (1985), and Efe (2010) have all documented the effect of acid rain on different plant species; and water quality (Ogunkoy and Efi 2003; Efe and Mogborukor 2008). Plants are important sources of medicine because they possess phytochemicals and other bioactive compounds that are of great pharmaceutical importance (Epidi et al. 2016a, b). The medicinal potential of a plant is a function of its bioactive composition. In another study, Anacletus et al. (2014) and Ifemeje (2015) reported changes in nutritional and phytochemical content of some common edible vegetables such as fluted pumpkin, H_2O leaf, scent leaf, and bitter leaf. In a similar study, Ujowundu et al. (2013) reported changes in phytochemical (phytate, tannin, alkaloid, and cyanogenic glycoside), proximate composition (ash, moisture, carbohydrate, and proteins), micronutrients (Ca, Na, Mg, K, and P), and vitamins (A, C, and E) in African breadfruit and Bambara groundnuts cultivated near flare sites. Phytochemical (flavonoid, tannin, alkaloid, saponin) and trace metals (Pb, Fe, Cd, Zn) of fluted pumpkin could be altered by gas flaring. Okeke and Okpala (2014) reported decreased soil nutrient in two gas-flared communities (Eket and Izombe) of the Niger Delta area.

Since the era of industrial revolution, man has been faced with the challenge of handling the problems arising from excessive crude oil exploitation, gas flaring, and climate change. Methane and carbon dioxide are the most notable greenhouse gases that are responsible for global warming and climate change. Methane has been found to be the most toxic greenhouse gas because it has the ability to induce global warming (86 times) more than CO_2 (IPCC 2013). To reverse global warming temperature to below 2 °C obtained during the pre-industrialization era by the year 2050, there is need to consciously reduce the volume of crude oil exploited. A certain percentage of fossil fuel, for example, about 50% natural gas with 30% crude and 80% coal, needs to be consciously left unexploited in the earth's crust to avoid undue changes in the earth's environment (McGlade and Ekins 2015; UNFCCC 2015; Zhao and Alexandroff 2019). At the 48th Intergovernmental Panel on Climate Changes conference, following close evaluation of climate change data, scientists came up with a global warming temperature target of 1.5 °C by the 2035 (IPCC 2018). It is therefore imperative to seek urgent ways of reducing greenhouse gas emission as well as seeking other sources of energy for man (Rhodes 2019). The World Bank Global Gas Flaring Reduction Initiative (GGFR 2015) has launched several international and national programs including "Zero Routine Flaring by 2030" Initiative to reduce gas flaring rates. Other bodies that launched campaigns for reduction in gas flaring include the 1992 United Nation Convention on climate change and 1997 Kyoto protocol (Malumfashi 2007). Despite all these strategies, significant changes are yet to be recorded (Elvidge et al. 2009; Fawole et al. 2016), and climatic risk is becoming more pronounced.

Climate change has gained important recognition because of its increased risks and widespread effects. It has become an issue of concern, discussion, and debate in various news media of the world. Its effect on the agricultural sector seems to be at its peak. Farmers are more aware of its existence and risks. It has affected their livelihood and general well-being, thus making adaptation measures very imperative. Climate change is a global environmental threat that consciously or unconsciously affects living and non-living things (Patz et al. 2007). Climate change is an alteration in the state of the climate over a period of 10–30 years or more, depending on man-made activities. The United Nations Framework Convention on Climate Change (UNFCCC) stated that climate change is greatly dependent on human activities that alter the atmospheric equilibrium as well as natural climate change overtime (FAO 2008). Climate change is a global phenomenon that has affected man and his environment (IPCC 2014a, b). Climatic changes manifest in the form of weather variations in temperature and precipitation. Adaptation and mitigation strategies are needed in tackling climate change impacts. Climate adaptation has to do with the capacity to manage variations in climate to minimize possible risks, explore new opportunities, or even both. Most African countries like Nigeria are more susceptible to climate change challenges because they are less aware, suffer more exposure, and have reduced potential for adaptation. Changes in climate are greatly affecting agriculture because it is a substantial source of revenue for the nation. Low level of education, poverty, insufficient infrastructure, and poor planning has contributed to increased exposure to risks in climate. It is therefore said to be involuntary in action and not limited to any particular geographical location. It can increase the virulence of disease-causing organisms (pathogens and pests) and also introduce new alien diseases arising from man-made activities or nature. Climate change could be a short or prolonged change in weather parameters that are already being experienced or forecasted as induced by anthropogenic emissions of noxious gases such as carbon dioxide (Parry et al. 2007). Climate change effects are already being felt globally and even in Africa (Creech et al. 2014). There are variations in climate change impacts from one location to another; for example, in some African countries, there have been cases of increased rainfall pattern and drought (Creech et al. 2014). These variations affect weather forecasting as there are hardly records of regularity in pattern of climatic parameters (Keller 2009). Variations in climatic factors such as increase in temperature and CO_2 affect plant's nutritional quality and its phytochemical composition and invariably the animals that consume such plants. It could also lead to increase incidence and severity of epidemics (EU 2015).

Farmers, their households, and stakeholders in agriculture are at greater risk of climatic change since their activities are rain dependent (Pearce et al. 1996). Agriculture is a major source of employment for Niger Delta dwellers. Adaptation to climatic vulnerability is now a major challenge to farmers, researchers, and policy makers. Most adaptation strategies are geared toward eradication of poverty among households (Mertz et al. 2009). Most farmers are already using their local and traditional practices in trying to adapt to the changes in climate with its associated risks. Climate change adaptation refers to all the steps put in place over many decades to enable a system cope with perceived or actual challenges imposed by climate change (Fankhauser 2017). There is need to put up remediative measures to help recover the ecosystem from prolonged environmental pollution and eradicate associated diseases. To enable residents of Niger Delta remain in their localities and retain their occupation as farmers, it is necessary to seek good and durable adaptation strategies. Many adaptation practices have been employed in most communities. A strategy that will likely be of immense importance is one that will improve the soil productivity of the gas-flared areas. For adaptation to be effective, the reality of climate change impacts must be appreciated (Deressa et al. 2011). The way and manner farmers view climate change determines their approaches toward handling its associated challenges. Their behavioral changes to climate change will influence adaptation options and its effects (Adger et al. 2009). Therefore, a close assessment of farmer's perception of climate risks and their specific adaptation measures will foster better understanding of their local exposure to climate risks, the farmer's adaptive capacity to cope with climate change, as well as to enhance policy formulation to tackle challenges that climate change pose on farmers. Intergovernmental Panel on Climate Change (IPCC) has postulated that the adverse effects of climate change will impact many lives globally in the years to come. Trends in rainfall are expected to drift from normal to abnormal with some areas having less rainfall while others have excess. Maturation time of crops will also be affected by increased temperatures especially in the tropics in the next 10 years. This will ultimately affect global food security and health of man (IPCC 2014a).

As a way to make agricultural activities sustainable in the Niger Delta in the face of climate risks, scientists have attempted different procedures with specific interest in those with little or no side effects to the ecosystem. Biochar is a good example of such material that has been used for soil enrichment with great potentials for soil remediation. Biochar is a biomolecule that is used to amend soils with a view to improving its biological and physical characteristics. It is made by pyrolysis of biomass at temperature range of 204–482 °C in the presence of little or no oxygen (Swanson 2013). Biochar is rich in carbon (Lehmann and Joseph 2009). It has the immense advantage of being of biological origin. Biochar improves soil physical and chemical properties, fertility, and nutrient availability (Houben et al. 2013). It reduces bioavailability of heavy metals to plants and organisms by adsorbing them (Al-Wabel et al. 2014). It also stabilizes carbon in the soil, reduces the carbon dioxide in the atmosphere (Fang et al. 2015), and reduces greenhouse gas emission (Galloway et al. 2008). Its advantage over other sources of carbon is that it keeps carbon long in the soil (Nguyen et al. 2008). Biochar is more durable and effective compared to other carbon sources; it lasts for up to 10,000 years when applied to soil. Stability of biochar depends on its pyrolysis temperature, source material, and soil type (Lehmann and Joseph 2009). Biochar helps in the breakdown of polyaromatic hydrocarbon and adsorbs heavy metals, making them biologically unavailable (Gorovtsov et al. 2018). When biochar is used as a carbon source in soils, the quantity of greenhouse gases emitted decreases by 12% yearly (Woolf et al. 2010). It is a good remediation material that reduces water loss and improves nutrients of soil (Woolf et al. 2010). Use of biochar for agricultural purposes has proven to be a good climate change adaptation practice in the face of threating global warming and climate change (Lehmann et al. 2006; Woolf et al. 2010). Biochar use is not only is environmentally friendly but also alkalinizes soil (O'Neill et al. 2009) and improves crop growth and development (Graber et al. 2010). Biochar improves soil fertility and has great potential for restructuring the ecosystem. It also increases nutrient bioavailability (Wang et al. 2012), leading to production of healthier crops as well as growth of important microorganisms (Bailey et al. 2011; Smith et al. 2010). It improves soil physicochemical properties like organic carbon, cation exchange capacity, and pH (Lehmann 2007). Under normal conditions, carbon dioxide is released from decaying plant matter and serves to balance the carbon cycle. The mechanism of action of biochar is that it forms a strong bond with carbon making it assume a very stable configuration and hence slows the process of decomposition. Biochar use traps carbon in the soil while hindering its migration into the atmosphere in the form of CO_2. This is therefore a good adaptation process for farmers in gas flaring areas of the Niger Delta region. This will reduce soil water loss and increase soil carbon concentrations and food security (FAO 2008). Biochar has the ability to adsorb toxins, making it unavailable for plant uptake (Sohi et al. 2009). Akachukwu et al. (2018) reported that biochar application enhanced the mineral content of *Telfairia occidentalis* that was cultivated on gas-flared polluted soil. This chapter compared and evaluated the farmers' perception of gas flaring and effect of biochar on heavy metal composition of *Telfairia occidentalis* leaves cultivated on gas-flared polluted soils and non-gas-flared soils.

Materials and Methods

Study Area

This research was conducted with soils collected from two locations, gas-flared area in Ohaji/Egbema L.G.A of Imo State (longitude N 05° 33.5′ and latitude E 06° 45.2′) and non-gas-flared area of Ikwuano L.G.A in Abia state (Longitude N 05° 28.5′ and Latitude E 007° 32.5′) at a depth of 0–20 cm using a sterile auger. The soil was stored in clean jut bags and transported to the greenhouse of the National Root Crops Research Institute, Umudike, Abia State. All the soil samples were collected in April.

Sociodemographic Data

Well-structured questionnaires were administered randomly to vegetable farmers in the two study sites to assess their perception of gas flaring and its effects on vegetable cultivation and farmers' livelihood.

Biochar Preparation

Biochar was prepared from sun-dried palm bunches by pyrolysis at 450 °C in a drum kiln. After cooling, it was milled to finer particles, sieved with a 3 mm^2 mesh, and subsequently stored in a clean dry bag until it was ready for use (Karamesouti and Gasparatos 2008).

Soil Preparation and Biochar Application

Four kilograms of the soil was weighed into clean plastic container. Biochar was applied to the soils at a rate of 0 t ha^{-1}, 7.1 t ha^{-1}, 13.9 t ha^{-1}, 20.9 t ha^{-1}, and 28.0 t ha^{-1} in three replicates. The soils and biochar were properly mixed, watered, and allowed to mineralize for 2 weeks.

Procurement, Cultivation, and Growth Indices of *Telfairia occidentalis*

Mature and viable seeds of *T. occidentalis* were obtained from a local market at Ndoro, Ikwuano L.G.A, Abia state, Nigeria. Two seeds were cultivated per container and watered once every 2 days. The growth parameters were measured at an interval of 2 weeks. Matured leaves were harvested after 8 weeks of germination, and samples were air-dried and used for heavy metal determination. Growth indices were measured at 2 weeks interval for 8 weeks. Plant height was measured with the aid of a ruler. Stem diameter was measured with the aid of a vernier caliper, while number of leaves was gotten by counting.

Heavy Metal Determination

A quantity of 0.2 mg of leaf sample was weighed into dry digestion tubes. Five milliliters of nitric acid was added, swirled, and allowed to stand overnight. Tubes were placed into a digestion block with the temperature gradually increasing from room temperature to 120 °C over about 2 h with periodical swirling of each tube. Thereafter, the temperature was increased to 180 °C until about 0.5 cm^3 of liquid remained. The digestion tubes were removed from the block and cooled at room temperature. The digest was diluted with ultrapure water, homogenized with a vortex mixer, and allowed to stand for a few hours prior to analysis. The heavy metal concentration was determined using an inductively coupled plasma optical emission spectrometer (ICP-OES) (Optima 8000, Perkin Elmer).

Data Analysis

The data obtained was analyzed using the Statistical Package for Social Sciences (SPSS) version 21.0 for Windows. Mean comparison was done using one way analysis of variance (ANOVA). Duncan multiple test was used to separate means. Significant values were set at $p \leq 0.05$. Data is presented as mean ± standard deviation (SD).

Results and Discussion

Figure 1 shows the result of effect of gas flaring on vegetable cultivation and farmers' livelihood. In all the study sites, more than 60% of vegetable farmers were female while approximately 40% were male. In the gas-flared area (test), almost all the farmers (97%) had knowledge of gas flaring while 62% only knew about gas flaring in the control. This could be because of the absence of gas flaring in

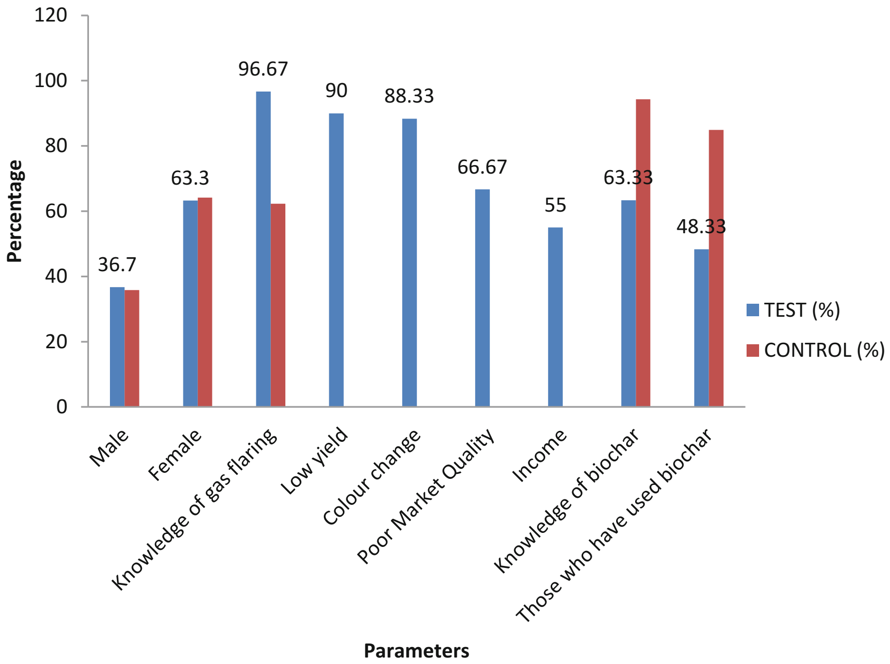

Fig. 1 Effect of gas flaring on vegetable cultivation and farmers' livelihood

the control area. Also, farmers in the test area had knowledge of biochar (94%) and had also used it (85%) unlike the control area where fewer farmers (63%) knew about biochar and had used it (48%). More than 50% of the farmers from the test area had experienced low yield, color change, poor market quality, and income reduction as a result of gas flaring activities. This could have impacted negatively on the farmers' standard of living, causing discouragement and lack of interest in farming and invariably affect food security. It could also be a subtle cause of youth restiveness that is prevalent in the Niger Delta area. There were no bar charts for control area possibly because of the absence of gas flaring in the control area.

Table 1 shows the growth indices of *T. occidentalis* grown on the gas-flared soil and non-gas-flared soil for 8 weeks. Plant height is an important physiological property useful for assessing the growth and cell differentiation in plants (Silva et al. 2019). It is also an expression of how well a plant is able to optimally utilize soil available nutrients. There was general increase in plant height as the weeks progressed from 2 to 8 weeks for vegetables grown on GFTO and NGFTO, respectively. However, the vegetables grown on the gas-flared soils (GFTO, test) showed higher plant height than those grown on the non-gas-flared soil (NGFTO, control). The 0 t ha^{-1} had no evidence of growth after the first 2 weeks. The 7.1 t ha^{-1} group had the highest initial plant height (25.77) for the test vegetable, while the 28.0 t ha^{-1} group had the highest (25.87) for the control. The pattern of plant height obtained is similar to that of maize plant treated with *Daniella oliviera* wood biochar reported by Aminu and Shamsuddeen (2019). Stem diameter of test vegetables was higher than the control in a non-dose-dependent manner and also reduced with increase in number of weeks in both the test and control vegetables; however, their differences were not statistically different. Dispenza et al. (2016) obtained a dose-dependent increase in stem diameter for substrates of *Euphorbicia* treated with 20%, 60%, and 80% conifer wood biochar. Number of leaves increased with increase in weeks (Okonwu and Mensah 2012).

Table 2 presents the heavy concentration of *T. occidentalis* leaves cultivated on biochar-remediated soils from gas-flared and non-gas-flared area. The Fe and Zn concentrations of the gas-flared *T. occidentalis* (GFTO) decreased from 13.9 t ha^{-1} to 28.0 t ha^{-1} biochar while that of the non-gas-flared *T. occidentalis* (NGFTO) decreased from 0 t ha^{-1} to 20.9 t ha^{-1} biochar. There was no significant ($p > 0.05$) difference in Fe concentration between the GFTO and NGFTO except for the 13.9 t ha^{-1} biochar group that was markedly increased in the GFTO vegetable. No significant difference was observed in Cu concentration for GFTO and NGFTO for all the groups except for the 7.1 t ha^{-1}, 13.9 t ha^{-1}, and 20.9 t ha^{-1} biochar groups that were significantly lower for NGFTO compared to the control. Lead (Pb) and Cr concentrations were significantly ($p < 0.05$) higher for GFTO from 7.1 t ha^{-1} biochar, while its concentration decreased from 7.1 t ha^{-1} to 20.9 t ha^{-1} biochar compared to their control. Cobalt concentration was highest for GFTO treated with 7.1 t ha^{-1} biochar while that of 28.0 t ha^{-1} GFTO had the least. In the NGFTO, the cobalt concentration decreased from 7.1 t ha^{-1} to 20.9 t ha^{-1} biochar. Cadmium concentration in both the GFTO and NGFTO decreased with increasing biochar concentration. Nickel concentration was highest in the GFTO-treated with 7.1 t ha^{-1}

Table 1 Effect of biochar remediation on the growth parameters of *T. occidentalis* cultivated on gas-flared and non-gas-flared soils

Parameter	Biochar rate ($t\ ha^{-1}$)	2 weeks		4 weeks		6 weeks		8 weeks	
		GFTO	NGFTO	GFTO	NGFTO	GFTO	NGFTO	GFTO	NGFTO
Plant height (cm)	0	$18.50 \pm 6.01^{bc*}$	0^{d}	34.57 ± 3.44^{c}	27.97 ± 4.24^{c}	$34.5 \pm 2.29^{c}*$	47.9 ± 4.85	36.63 ± 0.82^{b}	60.77 ± 6.20^{a}
	7.1	$25.77 \pm 3.39^{a*}$	9.67 ± 0.577^{c}	$45.4 \pm 3.77^{b}*$	25.07 ± 0.81^{c}	$62.60 \pm 2.59^{a}*$	41.17 ± 5.53^{a}	68.4 ± 5.11^{a}	58.50 ± 3.91^{a}
	13.9	22.73 ± 0.92^{ab}	22.00 ± 2.00^{b}	48.97 ± 3.11^{b}	38.00 ± 5.63^{b}	44.07 ± 4.15^{b}	43.57 ± 4.29^{a}	49.35 ± 4.65^{b}	49.17 ± 3.06^{b}
	20.9	22.17 ± 3.18^{ab}	21.3 ± 1.21^{b}	$56.97 \pm 2.97^{a}*$	42.53 ± 2.41^{b}	$63.05 \pm 1.50^{a}*$	50.83 ± 5.97^{a}	68.17 ± 4.16^{a}	57.43 ± 6.19^{a}
	28.0	16.00 ± 0.35^{c}	25.87 ± 3.32^{a}	56.03 ± 2.44^{aa}	$4b9.00 \pm 1.32^{a}$	63.97 ± 5.35^{a}	50.33 ± 6.43^{a}	75.3 ± 15.89^{a}	63.50 ± 1.32^{a}
Stem diameter (cm)	0	$4.81 \pm 0.93^{a}*$	0^{d}	3.54 ± 0.40^{a}	3.51 ± 0.49^{ab}	$3.44 \pm 0.86^{a}*$	2.79 ± 0.25^{c}	$3.06 \pm 0.47^{a}*$	2.71 ± 0.19^{a}
	7.1	$4.72 \pm 0.61^{a}*$	3.84 ± 0.035^{c}	$3.48 \pm 0.22^{a}*$	2.64 ± 0.75^{b}	$3.18 \pm 0.36^{a}*$	2.90 ± 0.34^{bc}	$3.37 \pm 0.42^{a}*$	3.03 ± 0.08^{a}
	13.9	5.13 ± 0.36^{a}	4.63 ± 0.01^{ab}	$3.76 \pm 0.26^{a}*$	2.59 ± 0.69^{b}	$3.12 \pm 1.17^{a}*$	3.64 ± 0.35^{a}	$3.28 \pm 0.53^{a}*$	3.13 ± 0.54^{a}
	20.9	$4.75 \pm 0.69^{a}*$	4.92 ± 0.40^{a}	$3.87 \pm 0.85^{a}*$	4.31 ± 1.09^{a}	$4.03 \pm 0.91^{a}*$	3.43 ± 0.24^{ab}	$3.79 \pm 1.15^{a}*$	2.99 ± 0.54^{a}
	28.0	$4.56 \pm 0.63^{a}*$	4.19 ± 0.41^{bc}	$3.66 \pm 0.92^{a}*$	3.8 ± 0.55^{ab}	$3.63 \pm 0.53^{a}*$	3.55 ± 0.42^{a}	$3.30 \pm 0.21^{a}*$	3.60 ± 0.64^{a}
Number of leaves (cm)	0	4.00 ± 0.00^{a}	0^{d}	5.67 ± 1.53^{b}	5.00 ± 1.73^{a}	7.67 ± 2.08^{a}	8.67 ± 0.58^{bc}	9.67 ± 1.15^{a}	12.00 ± 1.00^{ab}
	7.1	$4.00 \pm 0.71^{a}*$	$1.00 \pm .000^{c}$	8.67 ± 2.08^{a}	5.33 ± 1.53^{a}	10.00 ± 2.00^{a}	9.00 ± 1.00^{abc}	10.67 ± 2.89^{a}	10.33 ± 1.16^{ab}
	13.9	3.00 ± 1.41^{a}	2.67 ± 0.578^{b}	6.00 ± 1.00^{ab}	6.67 ± 1.15^{a}	8.33 ± 2.08^{a}	8.00 ± 1.73^{c}	9.50 ± 1.50^{a}	8.67 ± 2.52^{b}
	20.9	4.00 ± 0.71^{a}	3.67 ± 0.57^{a}	8.33 ± 1.15^{ab}	7.33 ± 1.15^{a}	8.67 ± 2.08^{a}	10.33 ± 0.58^{ab}	12.00 ± 2.00^{a}	12.67 ± 2.52^{a}
	28.0	3.00 ± 1.41^{a}	3.67 ± 0.57^{a}	7.33 ± 1.15^{ab}	7.67 ± 1.53^{a}	9.33 ± 1.15^{a}	10.67 ± 0.58^{a}	12.33 ± 1.15^{a}	12.00 ± 1.00^{ab}

Values are mean $\pm$ standard deviation of triplicate determinations.
Values with different superscript on the same column are significantly different ($p < 0.05$) while values marked asterick (*) are significantly different from their controls.

Table 2 Effect of biochar remediation on the heavy metal concentration of *T. occidentalis* cultivated on gas-flared and non-gas-flared soils

Heavy metal ($mg\ kg^{-1}$)	GP 0 ($0\ t\ ha^{-1}$)	GP I ($7.1\ t\ ha^{-1}$)	GP II ($13.9\ t\ ha^{-1}$)	GP III ($20.9\ t\ ha^{-1}$)	GP IV ($28.0\ t\ ha^{-1}$)
Fe (GFTO)	103.25 ± 9.73	108.57 ± 12.03^{a}	$135.80 \pm 20.06^{a*}$	97.74 ± 27.26^{a}	93.48 ± 9.73^{a}
Fe (NGFTO)	126.14 ± 6.56^{a}	98.15 ± 2.51^{bc}	97.79 ± 3.31^{bc}	89.24 ± 3.73^{c}	117.56 ± 10.50^{ab}
Cu (GFTO)	0.55 ± 0.05	0.58 ± 0.06^{a}	$0.72 \pm 0.11^{a*}$	0.52 ± 0.14^{a}	0.50 ± 0.50^{a}
Cu (NGFTO)	0.67 ± 0.03^{a}	0.52 ± 0.01^{bc}	0.52 ± 0.09^{bc}	0.47 ± 0.02^{c}	0.62 ± 0.06^{ab}
Zn (GFTO)	20.65 ± 1.95	21.71 ± 2.41^{a}	$27.16 \pm 4.01^{a*}$	19.55 ± 5.45^{a}	18.70 ± 1.95^{a}
Zn (NGFTO)	25.23 ± 1.31^{a}	19.63 ± 0.50^{bc}	19.56 ± 3.49^{bc}	17.85 ± 0.75	23.51 ± 2.10^{ab}
Pb (GFTO)	0.26 ± 0.02^{bc}	0.37 ± 0.01^{a}	0.30 ± 0.01^{bc}	0.32 ± 0.03^{ab}	0.24 ± 0.02^{c}
Pb (NGFTO)	0.32 ± 0.02^{a}	0.25 ± 0.01^{bc}	0.25 ± 0.04^{bc}	0.23 ± 0.01^{c}	0.30 ± 0.03^{ab}
Cr (GFTO)	2.66 ± 0.25^{bc}	3.77 ± 0.14^{a}	2.99 ± 0.09^{bc}	3.23 ± 0.30^{ab}	2.41 ± 0.25^{c}
Cr (NGFTO)	3.25 ± 0.17^{a}	2.53 ± 0.06^{bc}	2.52 ± 0.04^{bc}	2.30 ± 0.10	3.03 ± 0.27^{ab}
Co (GFTO)	6.51 ± 0.61^{bc}	9.21 ± 0.34	7.31 ± 0.21	7.88 ± 0.72^{ab}	5.89 ± 0.61
Co (NGFTO)	7.95 ± 0.41^{a}	6.18 ± 0.16	6.16 ± 1.10	5.62 ± 0.24	7.41 ± 0.66
Cd (GFTO)	0.06 ± 0.01^{c}	0.08 ± 0.00^{a}	0.07 ± 0.00^{bc}	0.07 ± 0.01^{ab}	0.05 ± 0.01^{c}
Cd (NGFTO)	0.07 ± 0.00^{a}	0.06 ± 0.00^{bc}	0.06 ± 0.01^{bc}	0.05 ± 0.00	0.07 ± 0.01^{ab}
Ni (GFTO)	3.08 ± 0.29	4.36 ± 0.16^{a}	3.46 ± 0.10^{bc}	3.73 ± 0.34^{ab}	2.79 ± 0.29
Ni (NGFTO)	3.77 ± 0.20^{a}	2.93 ± 0.07^{bc}	2.92 ± 0.52^{bc}	2.66 ± 0.11	3.51 ± 0.31^{ab}

Values are mean ± standard deviation of triplicate determinations.
Values with different superscript (a, b, c) on the same row are significantly different ($p < 0.05$) while values marked asterick (*) are significantly different from their controls.
GFTO, Gas-flared *Telfairia occidentalis*; NGFTO, Non-gas-flared *Telfairia occidentalis*

biochar and lowest for the 28.0 t ha^{-1} biochar-treated group, while the NGFTO treated with 20.9 t ha^{-1} biochar had the least nickel concentration. Biochar administered to the two soils reduced uptake by plants as shown by our result. Human beings are often exposed to heavy metal contamination through the food chain as they are transferred from soil to plants (Khan et al. 2010). They cause serious health challenges when their concentrations exceed the normal threshold (Al-Wabel et al. 2014). Some heavy metals are known to alter normal body metabolism, disrupt transfer of hereditary materials from parents to offsprings, and affect proper growth and development of fetus (Ali et al. 2013). Heavy metals such as chromium, copper, cadmium, and lead are well known for their toxicity when consumed at concentrations beyond the permissible limits (Dursun 2006; Kurniawan et al. 2006). Copper contamination can cause gastrointestinal cancer in humans (Turkdogan et al. 2003). Cadmium toxicity is responsible for kidney damage and can cause “itai-itai” in man. Zinc is an essential element that is toxic at higher concentrations (Baccio et al. 2005). Chromium is harmful to plants and animals; chromium (IV) ion alters soil biological activities and is carcinogenic (Javied et al. 2009). Cobalt causes bone marrow hyperplasia, acute poisoning, allergic reactions, seizures, and paralysis of nervous system. Lead is very poisonous; it affects the cardiovascular system and causes stroke and cognitive impairment (Evangelou et al. 2007). Our finding has shown that heavy metal adsorption by the *T. occidentalis* leaves decreased as the rate of biochar application increased with 20.9 t ha^{-1} being the most effective. This result suggest that using biochar to cultivate this vegetable could lead to production of better quality vegetables, reducing the prevalence of heavy metal toxicity and hence improving nutrition of the consumers.

Conclusion

The chapter has shown that vegetable farming is mostly engaged by females. Biochar use enhanced the growth parameters and reduced heavy metal uptake by the plants. Therefore, biochar use should be encouraged to remediate heavy metal polluted soils, to ensure maximum crop yield and food security. Increased sensitization is needed to encourage the use of biochar in gas flaring polluted areas to ensure that good quality vegetables are available for consumers.

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