VETIVER SYSTEM TECHNOLOGY FOR SOIL AND WATER CONSERVATION;

A Review of the Contemporary Application in Nigeria.

Izuchukwu Okafor*[1], Prince Onyenwaku[2]

1. Department of Agricultural and Bioresources Engineering, Federal University of Technology, Owerri, Nigeria.
Email: okafor.izuchukwu910@gmail.com Tel: +2348107380306
2. Nigeria Erosion and Watershed Management Project (AB-NEWMAP)
Abia State Project Management Unit (PMU)
Email: princeonyenwaku@yahoo.com Tel: +2348064423806

Abstract

Vetiver System Technology (VST) has currently gained popularity in both applications as a soil and water conservation tool in most tropical countries of the world. The acceptability of this unique green technology that involves the use of vetiver grass for environmental conservation and stabilization services has captured the attention of many scholars in different disciplines mainly those in agriculture, environment, and engineering. One of the key interests of these scholars as expatiated in this work is to validate the performance efficiency of vetiver systems applications. Hence, this review shows the contemporary level of VST adoption in Nigeria for soil and water conservation applications in the last decade (2010-2020). The observations made affirmed that the past decade has witnessed low adoption of VST by Nigerian farmers, soil and water conservationists, and engineers due to; limited availability of the plant materials, lack of sufficient training resources for the education of the populace on the unlimited benefits accruable from the adoption of the technology and political apathy. As a way of reducing these anomalies, significant efforts have been made by major environmental stakeholders in the country by way of training and sensitization of the public especially the vulnerable downstream inhabitants on the need to localize the technology for maximum adoption, make it easily accessible to interested farmers, environmentalists, and engineers. It is worthy to note that accelerated up-scaling of the technology is achievable in Nigeria if the identified challenges are constructively addressed.

Keywords: vetiver grass; vetiver system technology; soil and water conservation; environmental degradation.

1. Introduction

Environmental degradation is a serious issue of global concern which currently has been the major driver of the existential emergency of climate change. In a bid to avert the looming adverse impact of environmental lapses, nature constantly beckons on humanity to take responsibility for ensuring the sustainability of her ecosystems. The most recent of such calls is seen in the Initiative of ***Friday for future cum school strike for the climate*** as pioneered by Greta Thunberg and other teenagers across the globe. Similarly, ***The Vetiver Network International (TVNI)*** promotion of vetiver systems for environmental protection is also a way of answering such a call.

*Corresponding Author

Soil erosion is one of the most significant forms of environmental degradation which to a greater extent facilitates global food shortage and makes most global lands vulnerable to further erosive activities orchestrated by local agents peculiar to different geographical locations (Junge *et al.*, 2008; Oku, Aiyelari, and Asubonteng, 2015). Apart from the fact that soil erosion interferes seriously with mass food production, it destroys infrastructure and highways (Egwuonwu *et al*., 2013)**.**

The ecological menace of erosion regarding the Nigerian case has been identified as a major disaster that threatens the landmass of the country. Over 6,000km^2 of land are affected by erosion and about 3,400km^2 are highly exposed causing yield reductions of between 30% and 90% in southern Nigerian farmlands and as much as a 5% drag on agricultural GDP (Okafor, 2020; Merem *et al.*, 2019). Aside from the worsening conditions of fragile geologic makeup of soil types in the area especially in the south, more than 90% of the land area is limited by sheet, rill, and gully erosion (Merem *et al*. 2019). The most seriously affected areas include the southeastern state communities; Nanka, Agulu, and Oko all in Anambra State. Merem et al. (2019) believed that gully erosion is not the only visible form of erosion in Nigeria irrespective of the notable imprint it leaves on its path, it is a substantial existential emergency because more than 1.6% of the entire land area of Eastern Nigeria is occupied by gullies. This is quite significant in the zone considering that it has the largest population concentration of 500 people per km^2 in Nigeria (Igwe, 2012). This is a confirmation of the fact that soil and water challenges are not an emerging issue in Nigeria rather it is as old as the country.

The United Nations report shows that the global population is expected to reach 8.5 billion people by 2030 and 9.7 billion people by 2050 (UN., 2015), this projected exponential indices of the global population in the most simplified terms implies the placement of more demand on agricultural productivity in the coming decades. Invariably, establishing a sustainable balance between global food production and the projected global population growth requires an increase in agricultural production and its commensurate yield to the tune of about 70% by 2050 (FAO, 2011). To achieve this, one of the critical factors of production that comes to mind is the land. This fixed factor of production will in conventional perspective be subjected to intense production pressure to meet these ever-growing demands on it for the attainment of global food security. When this reasoning is juxtaposed with the workings of a living system for which a typical arable land is, it will be clear that the performance efficiency of such a system will greatly be a function of its health status.

From the fundamental study of matter, for a system to be in a balanced state, there must exist equal and opposite reactions. It is in the tenet of this principle that the past decade has witnessed concerted efforts directed toward addressing the menace of soil and water degradation by way of adoption of various soil and water conservation techniques in other to promote equilibrium of ecosystem services and functions to man. In a view to selecting the most viable of these techniques which satisfy the global desire for a pollution-free environment, the need to understudy the correlations that exist between ecosystem and existential emergencies of environmental degradation and crisis became paramount. Some of the pathways followed to establish the needed correlations involved comparison of green technologies (biological techniques) for environmental sustainable application and the use of civil engineering structures that have gained preference over the years as soil and water conservation tools. The output of such comparison unmasked the catastrophic impacts of poor designs and construction irregularities of civil engineering structures as experienced in most watershed projects for the last decade (Nasrin, 2013; Arifuzzaman *et al*., 2013; Chikwue et al., 2020). In the same vein, the former showed capacity in delivering an economical benefit/cost ratio making it a good alternative to partially replace civil structures. Currently, in most tropical countries of the world, soil and water conservation projects are embracing green technologies either as a sole option or as a complementing option especially in bio-engineering which is strongly advocated for by many soil and water conservation experts. This has proved to be a more sustainable and eco-friendly solution this time when the world is threatened by adverse climate change effects.

It will be of interest to note that the most remarkable of these green technologies adopted in ecosystem management and conservation projects is vetiver system technology (VST) as suggested in study reports from Africa, Australia, Asia, and others. This technology is the science of vetiver system applications. It is based on the use of vetiver grass especially *Chrysopogon nigritana* (domiciled in Africa) and *Chrysopogon zizanioides* (domiciled in Asia) which happens to be the most outstanding of its numerous species recognized for having great characteristics suitable for soil and water conservation applications (Truong, 2011; Oku et al.,2016; Okafor, 2020). The adoption of VST has opened a scholarly gap in knowledge which can be significantly reduced through regular review of studies centered on vetiver system technology (Babalola, Jimba, Maduakolam and Dada, 2003).

2. Vetiver Grass from a Glance

Vetiver grass is a perennial grass of the Poaceae family, native to India. This grass has a shoot and root architecture. The roots of the grass are the most important part of it that contribute to soil and water conservation. The vetiver grass roots occur in huge spongy mass which contributes to its erosion-fighting ability (Islam, Bhuiyan and Hossain, 2008). The numerous numbers in which the roots occur are not its only peculiar quality for effective soil stabilization but it also accounts for its strength (Machado *et al.*, 2015; Likitlersuang et al., 2009). It is pertinent to note that the compatibility of vetiver grass for most bioengineering applications is based on the fundamental principle that fine root structure rarely interferes with the integrity of infrastructures. Vetiver grass can tap into soil moisture far below the reach of most crops. The depth of vetiver grass root penetration into the soil measures about 3m according to the National Research Council which explains its resilience in the critical conditions of drought (NRC, 1993). Other outstanding merits of vetiver grass are the ability to maintain an orderly planting array; a quality that makes it suitable *for* enhancing the aesthetics of the environment. High resistance to pest and disease infestation is also a glaring attribute of the grass. Under certain conditions most of its seeds are sterile especially *Chrysopogon zizanioides; a species* mostly adopted for soil and water conservation projects. The sterile nature of its seeds implies that it rarely constitutes a weed where it is planted.

Over the years, different vetiver grass species have been studied but it is pertinent to note that all known species of vetiver differ in their potential to solve specific challenges. One of the contemporary proofs of the variable potential of vetiver species is seen in Oku, Nnamani, Itam, Truong, and Akrofi-Atitianti (2016) where they stated that literature and research on the potentials of African Vetiver species (*Chrysopogon nigritana*) are limited, particularly in the treatment of contaminated water compared to the Asian species; *Chrysopogon zizanioides*.

Vetiver grass is known to contribute to wealth creation in the areas where it is been applied. Prakasa (2015) attested to the fact that the production systems of vetiver grass in the Western Ghat region of India contributes greatly to the livelihood of small farmers. In erosion, earthquake, and hurricane-prone areas, it has demonstrated significant resilience making it a viable option for controlling the detrimental impacts of such occurrences within the environment (Gnansounou, Alves and Raman, 2017). According to the vetiver network international (TVNI), vetiver grass is the most researched non-agricultural and non-industrial plant ever reported in the literature. The grass is also known to thrive in the tropics and subtropics while also extending its geographical adaptability to the border of the temperate zones.

3. Scholarly Perceptions of Vetiver Grass Applications for Soil and Water Conservation in the Last Decade

A research study in Haiti related to vetiver applications, policy recommendations, and potential large-scale applications provided an insight into the growing penchant for vetiver systems application in soil and water conservation projects among farmers. Such inclination was exemplified in the attitude of over 900 Haiti farmers who actively participated in a vetiver plantation and management programmes-*Agri-plus* conducted in Haiti (Gnansounou, Alves and Raman, 2017). The reports of this programme showed remarkable deliverables from vetiver grass application which is not only limited to a reduction in the nation's soil loss index from arable lands but also accounted for increased land productivity.

The exceptional characteristics of vetiver grass root systems in the Ethiopian context played great roles in reducing soil erosion cum runoff, while also improving soil fertility, soil moisture conservation, and terrace formation (Junge *et al*., 2008). Some of these distinguishing features of vetiver grass that facilitated its successful performance in reinforcing the soil structure in Ethiopia includes its rooting system which allows for deep penetration into the soil; it ability to form a tightly knitted network that binds subsurface soil together and its ability to retarding of overland flow when planted in hedge-like arrays. The cumulative effect of these qualities promotion water infiltration into the soil. Vetiver root systems are known to influence the physical and biological properties of soil. This is following the findings of the Royal Society (TRS. 2020) that plants and crops with denser and finer root systems bind the soil more effectively than thicker and sparse root systems, and thereby increase soil stability.

Similarly, the success of vetiver system applications in the state of Kerala in India represents an attestation of the effectiveness of vetiver system technology in the area of soil and water conservation (Joseph, Haridasan, Akhildev and Kumar, 2017). Beyond the integration of the vetiver system in the field for conventional functions, the system has been justified as a very cost-effective and efficient ecological disaster risk-reduction technology. It can address both long term and short term risks associated with ecosystem development. Successful application of the vetiver systems reduces different types of natural hazards such as landslides, mudslides, road bund instability, and erosion.

Wolde (2015) believed that to achieve these deliverables of vetiver systems application, there is a need to ensure that vetiver hedgerows are properly established where it is adopted as a conservation tool. Similarly, Wolde stated that such systems are known to reduce soil loss to acceptable levels (< 3 tons/ha) and runoff by as much as 70% depending on slope and soil type. This is the basic philosophy of most soil and water conservation techniques. It brings to notice the positive effects of vetiver systems in the area of soil moisture improvement and crop yields, particularly on shallow soils. Giving these findings, it would not be out of place to say that a clear understanding of the correlation that exists between vetiver hedgerows and improvement of groundwater recharge accrues from deepened revelations of vetiver system technology (Nasrin, 2013).

In Bangladesh, the cohesion and angle of internal friction of vetiver grassed embankment were studied using the infinite slope method of slope stability analysis, from the analysis the result, Nasrin (2013) stated that vetiver grass plantation can increase the factor of safety of the embankment by 1.50 times. This implied a 150% increment of the embankment stability (a function of the shear strength) due to the application of Vetiver system technology.

The Australian perspective to vetiver system technology can be assessed from the performance of the vetiver grass during the "**summer of disaster**" (December 2010- March 2011) which resulted in a flooded area equivalent to the land area of France and Germany combined. As reported in most literature, some of the underlying conditions identified as paramount to the effective performance of this green technology in Australia include good design and proper implementation of the vetiver systems (Truong, 2011). The benefits of vetiver in Australia during the period in view were cost-effectiveness and quick response. For these reasons, the popularity of vetiver grass applications for environmental management has grown to a remarkable extent.

In studying the status of vetiver system technology as a technique for soil and water conservation in Lay Armachiho Woreda watershed, soil erosion was identified as one of the most severe problems affecting the agriculture sector in that area of east Africa. As a way of proffering a lasting solution to the effect of erosion in the area, a biological control measure; *vetiver system technology* was adopted (Teshome, 2016; Jiru and Wari, 2019). The evaluation of the performance of the biological measure showed that the systematic use of vetiver grass for multiple applications provided an opportunity for beneficial soil management and preservation of the natural environment.

Similarly, a study on the implementation and effect of vetiver grass on soil erosion in Somodo watershed, southwestern Ethiopia resonated with an opinion that extols the adoption of physical and biological soil and water conservation measures in the watershed which involve bund construction and vetiver grass plantation (Tesfaye, Debebe, and Yakob, 2018). The result of such measures according to Edem and Gideon (2017) showed increased soil fertility, increased production yield, reduction of the slope of the area, and reduction of severe erosion in the watershed as the dominating deliverables.

4. Contemporary Application of Vetiver System Technology in Nigeria

Vetiver grass has been reported to be effective in erosion control **(**Babalola *et al.*, 2003). Torrential rainfall is one of the pronounced erosion drivers in Nigeria particularly in the South while the wind is the dominant agent in the North of the country. Fundamentally, the two factors vetiver systems are applied to address while demonstrating its mechanical, ecological, and hydrological functions as a bioresource are erosivity and erodibility. Soil erosion occurs when erosivity exceeds the erodibility of the soil. It will be of interest to note that soil erodibility is a measure of the susceptibility of soil particles to detachment and transport by rain splash and overland flow while erosivity is a function of rainfall intensity, duration, frequency, distribution patterns, and other profound rainfall characteristics

Oshunsanya and Aliku (2017) constructively conducted a study to validate vetiver grass as a tool for sustainable agriculture at the University of Ibadan-Nigeria. The findings validated the popular opinion of environmental scholars that vetiver grass plays a vital role in watershed protection given its performances records in slowing down runoff and spreading it harmlessly on the farmland, recharging groundwater, reducing siltation of drainage systems cum water bodies, and reduction of the rate at which agrochemicals are deposited into water bodies and for the rehabilitation of degraded soils.

.

An investigation of the influence of vetiver grass strips (VGS), vetiver mulch (VGM) and composted vetiver prunes (veticompost) on soil quality of an eroded land in the Institute of Agricultural Research and Training, Ibadan-Nigeria according to Are, Adelana, Dolapo Adeyolanu, Oyeogbe and Adelabu (2012) showed that vetiver system either as VGS, VGM or veticompost resulted in soil quality build-up as well as reduced soil erodibility in an erosion-prone land. They also noted that although the resistive capacity of VGM and veticompost in trapping sediments was lower than that of vetiver strip (VGS), the application of vetiver mulch and veticompost had a higher impact on soil quality than VGS.

Vetiver system is known to improve soil nutrients for cropping (Babalola *et al.,* 2007). Figure 1 shows the setup of a study conducted to assess the effectiveness of vetiver buffer strips in mitigating degradation on a landscape of 45% slope and the effect of such vetiver system technology on specific crops yield in southern Nigeria showed that vetiver buffer at 5m interval significantly reduced runoff, soil losses and increased yields of the crops (maize and cassava). Also, vetiver showed dual potentials in climate change adaptation and GHGs emission mitigation, sequestering carbon and nitrogen, and enhancing water use efficiency when compared with traditional farmers' practice of cultivation (Oku, Aiyelari, and Asubonteng, 2015).

Figure: Experimental setup with vetiver buffer serving as an erosion control measure in Cross River state-Nigeria (Oku *et al.,* 2015)

Oku, Asubonteng, Nnamani, Itam, and Truong (2015) in a study conducted in Nigeria to assess the potential of native African vetiver grass species in addressing the perils of wastewater stabilization and management brought to knowledge the substantial effectiveness of *Chrysopogon zizanioides* and *Chrysopogon nigritana* in improving the pH and removing contaminants such as Biological Oxygen Demand (BOD) and Chemical Oxygen Demand

(COD), pH, nitrate, phosphate, cyanide, lead, zinc, iron, cobalt, cadmium, Arsenic and manganese from the wastewater under study. Besides, they reported that although the efficiency of the African species; *Chrysopogon nigritana* was at its peak only for a short time (first 2 days) of treatment, it was seen to effectively remove more contaminants than its Asian counterpart; *Chrysopogon zizanioides* during this period. In extolling the efficiency of Chrysopogon *zizanioides* in wastewater treatment, Oku *et al.* (2015) stated that when the treatment time increased from 4 to 6 days, *Chrsopogon zizanioides* species became more effective when compares to the African Species. Little wonder why they recommended that both species should be used together to gain further benefit from their complementary attributes.

In response to the myriad of problems of environmental degradation and gully Erosion in Nigeria, especially in the southeast, the federal government in consultation with the states decided on the need for a holistic approach that gave birth to the concept of Nigeria Erosion and Watershed Management Project (NEWMAP); a world bank assisted project. This project has taken the lead in catchment development plans implementation across nineteen (19) catchment states within Nigeria according to the NEWMAP success story (www.newmap.gov.ng). This project has witnessed the incorporation of vetiver grass in most of her bioremediation designs. Most reports from NEWMAP environmental social and management plans have shown that the agency approaches the environmental challenges with multiple solutions (NEWMAP., 2017). These solutions revolve around civil works as well as re-vegetation using deep-rooted plants especially vetiver grass to stabilize gully erosion imprints in most project catchments. The adoption of this erosion mitigation alternative is to significantly control run-off and prevent washing away of soil at different strata; a function vetiver root system is known for. Ogudu-Asa, the Isuikwuato community is one of the NEWMAP project communities. The catchment management plan for this community expressively recommended the bioengineering approach as the most viable option to provide a lasting solution to soil and water-related challenges in the catchment. This approach refers to a combination of biological and engineering-based tools, methods, and constructs to control erosion, protect soil, and stabilize slopes using vegetation. Some methods that have been patronized in the previous decades are live fascines, bamboo fencing, the use of palisades, grassing using carpet grass (*Axonopus fissifolius*), and indiscriminate planting of cash crops (citrus, cashews, and raffia palms on contoured areas).

In the NEWMAP context, due to the distinct nature of the contemporary soil and water-related anomalies, the interference of the most traditional biological approaches with the integrity of adjoining structures gave a reason for considering a more lateral definition of bioengineering as the use of vetiver grass technology, other economical beneficial plants and civil engineering structures (NEWMAP., 2019) in achieving stable soil and water conservation systems. The choice of vetiver grass for a complementary role is because hard infrastructure (reinforced concrete structures) are known to provide immediate protection. Vegetation needs time to effectively provide the maximum strength required for sustainable soil stabilization. Conversely, vetiver grass is known to improve soil shear strength in a short time when compared to other plants adopted for bioengineering (Edem and Gideon, 2017; Truong, 2000). Thus, the combination of physical and vegetative measures offers a combination of immediate and long term protection to civil works at erosion sites.

Constructive engagement of some stakeholders in NEWMAP confirmed that the rationale behind the incorporation of vetiver system technology in her projects is to effectively control erosion while maintaining a stable and safe environment. In a bid to deliver this mandate, most of her project sites spread across its over 19 catchment states have enjoyed the applications of vetiver grass for numerous applications ultimately geared towards erosion control and environmental sustainability. Some of the areas where VST has been effectively applied in most NEWMAP are embankment/ engineered slope stabilization, erosion control, and soil amendment for agronomical purpose as seen in figure 1.

On engineered slope stabilization and erosion control, the Umuda-Isingwu community in Abia State, Nigeria is one of the project sites where VST has been successfully implemented. Although for this project community the solution was designed to accommodate both civil engineering structures, the rate of vetiver systems application and its output was profound (Chikwue *et al*., 2020)**.** Another area where remarkable work is currently on-going on slope stabilization using VST in 9th Mile Enugu state. Figures 2 and 3 below show the output of such an initiative.

Figure 2: NEWMAP Gully Erosion Remediation Site in Umuda-Isingwu Community of Abia State-Nigeria before and after remediation.

Figure 3: On-going remediation activities in the 9th Mile area of Enugu state (www.newmap.gov.ng)


Figure 4: Reclaimed Atakpa site in Cross River State using VST and Reinforced Concrete structure (www.newmap.gov.ng)

5. Reasons why vetiver grass and other biological technologies have not been fully adopted in Nigeria and way forward for the last decade.

Irrespective of the outstanding performances of vetiver grass that makes it a topsoil and water conservation tool, studies have shown that documentation of these achievements has been a problem (Tesfaye *et al*., 2018). While most scholars have validated the effectiveness of VST for soil and water conservation applications in Nigeria, the acceptance rate of this biological solution has been undermined by the low availability of training aids to accelerate the sensitization of both rural and urban areas on its benefit. This has resulted in poor education on both local and international environmental laws and how such laws can be incorporated into watershed development plans.

Political apathy towards a low-cost solution is another factor that has affected the adoption rate of the vetiver system in the country. Successors of most administrations find it difficult to consolidate initiatives of past administrations. This inaction is mainly experienced where there are diverging political views.

Corruption is another factor that has significantly affected the application rate of the biological solution to soil and water conservation. Stakeholders to most conservation projects find it difficult to promote low-cost biological solutions like vetiver systems over high-cost inert construction due to self-centered reasons.

Lack of sufficient supplies of these plant materials as reported by Ejiogu and Offor (2009) is a major challenge. The majority of the farmers do not find it convenient to adopt vetiver systems technology due to difficulties in sourcing the materials.

Currently NEWMAP through her Abia state project management units (SPMU) in collaboration with the ministry of environment and forestry organized series of workshops for its project communities to advocate for community-based adoption of the biological solution to soil erosion control. The workshop is expected to increase the rapid spread of vetiver grass beyond interstate borders given that all participants were empowered with substantial training resources and plant materials.

6. Conclusion

The effective adoption of vetiver system technology globally as a viable soil and water conservation tool in the last decade can be attributed to scholarly testimonies of its demonstration of resilience in most tropical parts of the world that seems not to be the case in Nigeria. As the world continues to engage in sustainable actions to carbon footprints on our environment, reduce soil loss, guarantee food security for the teeming global population, and ultimately to reduce climate change impact, vetiver system technology will continue to be a viable option in achieving this goal. It is also pertinent to note that there is a need for public-private partnership in Nigeria in the area of project funding, information sharing about the technology, documentation of performance results, promotion of research and development of innovations related to VST, fighting against corporate malpractices in project selections and political apathy. Unless current changes and altitudes reflect these recommendations, accelerated up-scaling of technology in Nigeria may not be feasible.

Acknowledgments

Mr. Dick Grimshaw of The Vetiver Network International (TVNI) your contribution to the promotion of vetiver systems globally and other soil and water best management practices were instrumental to the success of this work.

References

Are, K. S., Adelana, A. O., Adeyolanu, O. D., Oyeogbe, I. A., and Adelabu, L.2012. Comparative effects of vetiver grass (Chrysopogon zizanioides) strips, vetiver mulch, and veticompost on soil quality and erodibility of a sloping land. Agricultura. Tropica. Et. Subtropica. Vol. 45 (4), 189-198.

Arifuzzaman, Anisuzzaman, Rahman, M., and Farhana Akhter, F. 2013. Vetiver as a green and economical technology to protect river bank in Bangladesh. International Journal of Civil Engineering and Technology (IJCIET*)*, Vol. 4 (5), 143-151.

Babalola, O., Jimba J.C., Maduakolam O., and Dada, O. A.2003. Use of vetiver grass for soil and water conservation in nigeria. In: Proceedings of Third International Conference on Vetiver and Exhibition Guangzhou, China; 293-309.

Babalola, O., Oshunsanya, S. O., and Are, K. 2007. Effects of vetiver grass (Vetiveria nigritana) strips, vetiver grass mulch and organomineral fertilizer on soil, water and nutrient losses and maize (Zea mays L.) yields. Soil and Tillage Research. Vol 96. 1- 2, 6 – 18.

Chikwue, M., Okafor, I and Ofoma, A. 2020. Agronomical stabilization of umuda-isingwu erosion site using vetiver grass. American scientific research journal for engineering, technology and sciences (ASRJETS), Vol. 72(1),181-196

Edem, I.D., Gideon, I.K.2017. Evaluation of soil changes resulting from the application of (Vetiveria nigritana) grass technology on a sloppy urban farm in Uyo, Akwa Ibom state. MOJ Eco. Environ. Sci. Vol. 2, 61-66. DOI:10.15406/mojes.2017.02.00020

Egwuonwu, C. C., Okereke, N. A. A., Ezeanya, N.C.; Nzediegwu, C. and Okorafor, O.O. 2013. Characterization of erodibility using soil strength and stress-strain indices for soils in some selected sites in Anambra State. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS). Vol. 4(2), 333-340

Ejiogu, A.O and Offor, I.R. 2009. Assessment of the use of vetiver grass (Vetiveria zizanioides) in sheet erosion management in Imo state. 9th Global Conference on Business & Economics (GCBE), Cambridge University, Cambridge, UK

FAO. 2011. World livestock: livestock in food security. Rome

Gnansounou, E., Alves, M.C., and Raman, K.J. 2017. Multiple applications of vetiver grass-a review. Int. J. Environ. Sci. Vol. 2, 125-135.

Igwe, C.A. 2012. Chapter 8 Gully Erosion in Southeastern Nigeria: Role of Soil Properties and Environmental Factors. www.cdn.intechopen (accessed October 9, 2019)

Islam, M.P., Bhuiyan, M.D., and Hossain, M.Z. 2008. Vetiver grass a potential source for rural development in Bangladesh. Agricultural Engineering International: The CIGR E-Journal,Vol. 5, 1-16.

Jiru, B.E., and Wari, N.B. 2019. Role of vetiver grass (Vetiver zizanioides L.) for soil and water conservation in Ethiopia. International Journal of Agricultural Economics,Vol.4,87-93.DOI:10.11648/j.ijae.20190403.11

Joseph, J.K., Haridasan, A., Akhildev, K., and Pradeep Kumar A. P. 2017. Applications of vetiver grass (Chrysopogon zizanioides) in ecosystem-based disaster risk reduction - studies from the kerala state of India. J. Geo. Nat. Disast., Vol, 7,192. DOI:10.4172/2167-0587.1000192

Junge, B., Abaidoo, R., Chikoye, D., and Stahl, K.2008. Soil conservation in Nigeria past and present on-station and on-farm initiatives. Soil and Water Conservation Society, Ankeny, Lowa; 21-25.

Likitlersuang, S., Lohwongwatana, B., Vanno S., and Boonyananta, S. (2009). Laboratory investigation of vetiver root reinforcement for slope protection. Scientific Research Journal. Vol. 3(8), 21-23

Machado, L., Holanda, F.S.R., Silva, V. S., Maranduba, A. I. V., and Lino, J.B.2015. Contribution of the root system of vetiver grass towards slope stabilization of the São Francisco River. .Semina: Ciências Agrárias, Londrina, Vol. 36 (4), 2453-2464.

Merem, E. C., Twumasi, Y., Wesley, J., Alsarari, M., Fageir, S., Crisler, M., Romorno, C., Olagbegi, D., Hines, A., Mwakimi, O. S., Nwagboso, E., Leggett, S., Foster, D., Purry, V., and Washington, J. 2019. Analyzing land use and change detection in eastern nigeria using gis and remote sensing. American Journal of Geographic Information. Vol. 8(2): 103-117.
DOI: 10.5923/j.ajgis.20190802.06

Nasrin, S. 2013. Erosion control and slope stabilization of embankments using vetiver system. Dissertation. Bangladesh: Bangladesh Univ. of Eng. and Tech.

National Research Council. 1993. Vetiver Grass: A Thin Green Line Against Erosion. National Academy Press, Washington DC, USA https://doi.org/10.17226/2077.

NEWMAP. 2017. Environmental and social management plan of Umuda Isingwu/Umuagu Ibeku gully erosion complex. Catchment Report, Umuahia.

NEWMAP. 2019. Final Ogudu-Asa Isuikwuato catchment management plan. Environmental and Social Management Plan, Abia state.

Okafor, I.O. 2020. Embankment stabilization in southeastern Nigeria using vetiver grass; a case study of Umuagu-Umuda Ibeku in Umuahia North L.G.A of Abia State. www.vetiver.org (accessed June 23, 2020)

Oku, E. E, Aiyelari, E. A., and Asubonteng, K. 2015. Using vetiver technology to control erosion and improve productivity in slope farming. United Nations University Institute for Natural Resources in Africa; UNU_INRA, Accra, Ghana.

Oku, E., Asubonteng, K., Nnamani, C., Itam, M and Truong, P.2015. Using native African species to solve African wastewater challenges: an in-depth study of two vetiver grass species. Sixth International Conference on Vetiver.

Oku, E., Nnamani, C. V., Itam, M. O., Truong, P., and Akrofi- Atitianti, F .2016. Potential of an African vetiver grass in mitigating waste water. United Nations University Institute for Natural Resources in Africa; UNU_INRA, Accra, Ghana.

Oshunsanya, S. O., and Aliku, O. O. (2017). Vetiver Grass: A Tool for Sustainable Agriculture. Vetiver Grass: A Tool for Sustainable Agriculture. http://dx.doi.org/10.5772/intechopen.69303 (accessed October 10, 2020)

Prakasa Rao E.V.S. 2015. Vetiver production for small farmers in India. Switzerland: Springer International Publishing; 337-343. DOI: 10.1007/978-3-319-16742-8_10

Project Implementation Manual .2013. Nigeria Erosion and Watershed Management Project, World Bank.

Tesfaye, G., Debebe, Y., and Yakob, T. 2018. Implementation and effect of vetiver grass (Vetiveria zizanioides) on soil erosion in Somodo watershed, South-Western Ethiopia. J. Bio. Agric. Healthcare. 8:1-4.

Teshome, Y.J. 2016. The status of vetiver grass as a technique for soil and water conservation in Lay Armachiho-woreda. Glob. J. Crop, Soil Sci. Plant Breed, 4:162-170.

The Royal Society.2020. Soil structure and its benefits, an evidence synthesis. www.royalsociety.org/soil-structure-benefits (accessed July 15, 2020)

Truong, P. 2011. How vetiver system technology performs during the summer of disasters in Australia. www.vetiver.org (accessed June 12, 2020).

Truong, P.N.2000.Vetiver grass for mine site rehabilitation and reclamation. Proc. Remade Land Int. Conference, Fremantle, 85-86.

UN. 2015. World population prospects. Department of Economic and Social Affairs Population Division, New York: USA. www.esa.un.org (accessed October 9, 2019)

Wolde, Z. 2015. Assessment of the role of the vetiver grass system in soil and water conservation at the Kuraz sugar development project. Int. Inv. J. Agric. Soil Sci. Vol. 3, 21-25.