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The Effects of Vetiver Grass (*VetiverZizanodes*L.) on Soil Fertility Enhancement, Soil Water Conservation, Carbon Sequestration and Essential oil Productions A: Review

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Abstract: *Vetiver (VetiverzizanioidesL.) is a perennial grass is one such species that could be grown all across the globe from tropical to Mediterranean climate. The grass fits well in ecosystem service which contributing to regional and global economies for its multifarious environmental application and offers sustain able opportunities for carbon sequestration. Vetiver is the high tolerance of a wide range ofextreme soil conditions, such as high and low pH, high aluminum, high salinity, and highsodicity. Vetiver grass is a very simple, practical, inexpensive, low maintenance and very effective meansof soil and water conservation, sediment control, land stabilization and rehabilitation. It is alsoenvironmentally friendly and when planted in single rows it will form a hedge which is veryeffective in slowing and spreading runoff water, thereby reducing soil erosion, conserving soilmoisture. In addition, the extremely deep andmassively thick root system of vetiver grass binds the soil and at the same time makes it verydifficult for it to be dislodged under high water velocity. the use of vetiver grass improved soil quality through improving CEC, soil moisture content, soil organic matter, total nitrogen, available phosphorus and available potassium contents.Carbon sequestration implies capture and secure storage of Carbon that would otherwise be emitted to or remain in the atmosphere. Carbon sequestration is an efficient strategy to mitigate climate change. Vetiver holds prominence as one of the world's best carbon-sequestering plants. Four mature vetiver plants would sequester the same amount of atmospheric carbon as one fast-growing poplar tree, the best of all trees for carbon sequestration. Vetiver oil and its fractions are heavily usedfor blending in oriental types of perfumes, cosmetics and aromatherapy. It also hasantifungal, antibacterial, anticancer, anti inflammatory and antioxidant activities, opensthe way to application in the pharmaceuticalindustry.*

Keywords: *Carbon sequestration, organic matter, rehabilitation, soil erosion, vetiver*

1. Introduction

Vetiver grass (*Vetiverzizanioides*L.) is a perennial tufted plant that is native to Indiawhich widely promoted by the World Bank for soil and water conservation, beginning in India in the mid-1980s (Ghosh and Bhattacharya, 2018). The grass can grow up to 2 m inheight and has a massive fine root system that can reachdepths down to 2 to 6 m in the first year of establishment Vetiver grass, a perennial grass with deep root system and has high biomass production and has unique morphological characteristics. It has the ability to resist adverse environmental condition, absorb and tolerate extreme levels of nutrients. Vetiver grass is highly tolerant to adverse edaphic conditions such as high soil acidity and alkalinity, saline, sodic, magnesic, Aluminum and Manganese toxicities (Mathew*et al.*, 2016)

Current vetiver grass applications include soil and water conservation in agriculturallands, steep slope stabilization, mine, contaminated and saline lands rehabilitation and recently wastewater treatment. This is due to its uniquemorphological, physiological and ecological characteristics that permit it to adapt to a wide rangeof climatic and soil conditions (Hamidifar, 2018). Vetiver grass can establish itself in hostileconditions and creates micro-climates that permit a variety of other indigenous plants to prosper.As a result, the system is now increasingly being used vetiver for these purposes in over 120 countries (Liu*et al.*, 2016).

vetiver grass helps to conserve soil and water and rehabilitate the soil. It isassumed that it is an important role to reduce CO2 in the atmosphere. Vetiver grass planting in the agricultural areas will accumulate carbon into the soil by photosynthesisprocess. It adsorbs carbon into plant components. The dead plants will be decomposed andreleasing carbon back into the soil. It stores as soil organic matter. Therefore, appropriatemanagement of soil and plant in planting vetiver grass system is an important process toincrease soil carbon storage. Since most agricultural areas are rain fed agriculture, havingwater shortage, conserving soil moisture by vetiver grass will be appropriate. Therefore, agood soil management increases soil organic matter storage (Nopmalai*et al.*, 2015)

Essential oil extracted from the roots ofVetiver has aromatic and biological properties and canbe employed in a wide range of applications (Chahal*et al.*, 2015).Vetiver oil and its fractions are heavily usedfor blending in oriental types of perfumes,cosmetics and aromatherapy. It also hasantifungal, antibacterial, anticancer, antiinflammatory and antioxidant activities, opensthe way to application in the pharmaceutical industry (Shabbir *et al.*, 2019).The objective of this paper is to review the multipurpose uses of vetiver grass on soil fertility management, soil water conservation, carbon sequestration and essential oil production at different growing areasfor the ecological restoration of degraded lands.

2. TOLERANCE TO ADVERSE SOIL CONDITIONS

Vetiver is the high tolerance of a wide range of extreme soil conditions, such as high and low pH, high aluminum, high salinity, and high sodicity. Different research experiments showed that Vetiver can grow well on the soils with pH ranging from 3.3 – 9.5 rates. Particularly, Vetiver showed excellent growth on old gold tailings (pH = 2.7) and bauxite mine tailings (pH = 12) in Northern Queensland, Australia. Vetiver can grow on the soils with aluminum saturation level (ASL) of 68-86%, however the grass did not survive at ASL of 90% with soil pH of 2 (Truong and Baker, 1997). The study in Vanuatu recently indicated that Vetiver can thrive on highly acidic soils with ASL of 87% (Truong and Danh, 2015). Vetiver can grow on saline soils with ECseup to 47.5 dS m^{-1}, its salinity threshold is at ECse = 8 dS m^{-1} and soil ECse values of 20 dS m^{-1} reduce yield by 50%. Vetiver grass was also demonstrated to be able to grow in seawater with salinity ranging from 0 - 19.64 dS m^{-1},equivalent to 0 - 11 % salt. For this reason, Vetiver is classified to agroup of highly salt tolerant crop and pasture species grown in Australia. In addition, the growth of Vetiver grass on the soil with exchangeable sodiumpercentage (ESP) up to 48% was not adversely affected, while thevalue of ESP higher than 15% considered to be strongly sodic (Danh *et al.*, 2009).

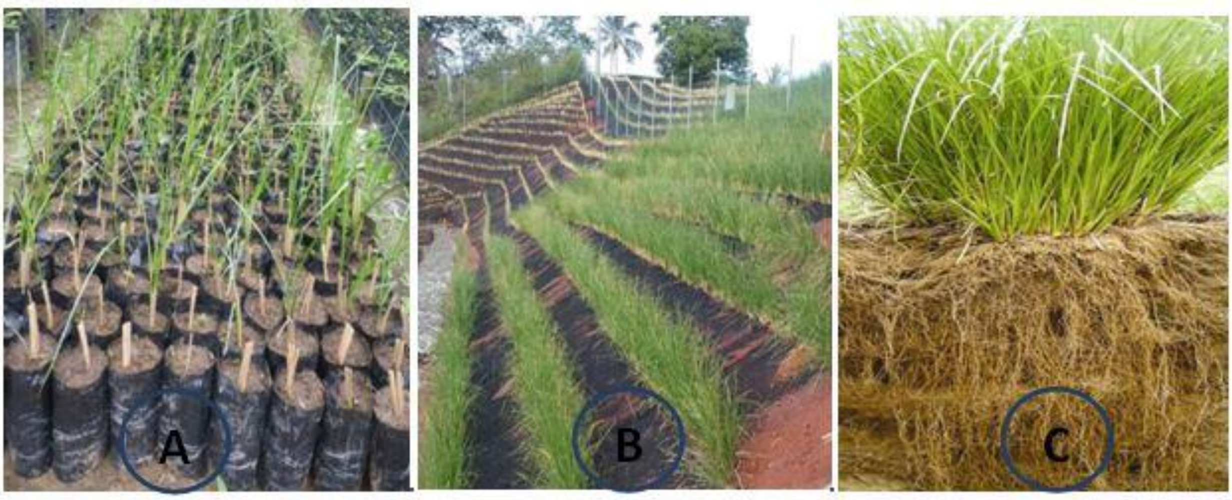

Figure1. *A=vetiver at nursery site, B= vetiver on sloppy soil to control soil erosion C= vetiver root structure*

3. SOIL AND WATER CONSERVATION

Biological measures are an effective method of soil conservation, and nowadays, especially the vetiver system is getting popular and more accepted by the rural community since it is costeffective and easily manageable. In addition, it can be used with structural and agronomic measures. Vetiver grass is a very simple, practical, inexpensive, low maintenance and very effective meansof soil and water conservation, sediment control, land stabilization and rehabilitation. It is alsoenvironmentally friendly and when planted in single rows it will form a hedge which is veryeffective in slowing and spreading runoff water, thereby reducing soil erosion, conserving soilmoisture and trapping sediment and farm chemicals on site. In addition, the extremely deep andmassively thick root system of vetiver grass binds the soil and at the same time makes it verydifficult for it to be dislodged under high water velocity (Truong, 2015). The very deep and fast growing root system also makes vetiver very drought tolerant and highly suitable for steep slope stabilization.Most of the evidence suggests that other soil water conservation structures so far implemented could reduce soillosses. The contribution of vetiver grass in solving soil erosionwhich created through runoff is internationally recognizedbecause around 120 countries have been already using it forcontrolling soil erosion and reducing runoff because vetiver grass has unique characteristics (Liu*et al.*, 2016). Vetiver grass, due to its unique morphological and physiological characteristics, has been widelyknown for its effectiveness in erosion and sediment control (Mathew*et al.,* 2016). The use ofvegetation as a bio-engineering tool for land reclamation, erosion control and slope stabilizationhave been implemented for centuries and its popularity has increased remarkably in the lastdecades. Vetiver's soil binding root system and its ability to form dense hedgerows is unmatchedby any other plant used for on-farm erosion control. In addition to reducing surface erosion onsloping land, vetiver's massive root system also contributes to slope stability. Its stiff stems froma form a dense hedge that reduces water velocity, allows more time for water to infiltrate the soil,and, where necessary, divert surplus runoff waterwhen planted on the contour, vetiver grass forms a protective barrier across the slope, whichslows the runoff and causes sediment deposition (Hamidifar *et al.*, 2018).

Figure2. *Vetiver grass on soil and water conservation on degraded land*

4. THE ROLE OF VETIVER ON SOIL FERTILITY

Nopmalai *et al*. (2015) reported that the amount of organic matter (OM), phosphorus, potassiumand pH at 0-15 cm depth, was increased significantly different, the amountof organic matter (OM), phosphorus, potassium and pH at 0-15 and 15-30 cm depth.At the end of experiment (24 months), OM was increased in all treatments(Table 1 and 2). The increasing in OM in the soil is derived from decomposing of biomassmulching (leaves) and roots at belowground.It was found that in sugar apple plantation mulching with cut leaves of vetiver grass, increased soil fertility. Since using its cut leaves to mulch the soil surface promoted the natural balances. These were such as increasing soil organic matter and nutrients. In addition, it increased the amount of soil microorganism and fauna, resulted to be living soil. The cut leaves of 4 months age vetiver grass mulched the soil surface, decomposed and released plant nutrients to the soil. It was average phosphorus 0.2 % and potassium 1.3% of dry weight (Chairoj and Roongtanakiat, 2004).

Table1. *Effect of vetiver grass on soil physicochemical parameters*

Parameters	Without vetiver grass	With vetiver grass
Total N (%)	0.24	0.32
Available phosphorous (ppm)	20	26

The available potassium (meq/100g)	0.087	0.134
The bulk density (gm/cm3)	1.39	1.29
CEC (meq/100 gm)	27.48	36.98
Organic matter content (%)	2.7	4.3

Source: Gesesse *et al.* (2013)

Gesesse *et al.* (2013) reported that the use of vetiver grass improved soil quality through improving CEC, soilmoisture content, soil organic matter,total nitrogen, available phosphorusand available potassium contents.This is due to the fact that vetiver grasses form hedges or a livingporous barrier, which slows andspreads runoff water and trapssediment (Table 1).

Table2. *Soil chemical properties at before and after planting vetiver grass*

Soil depth (cm)	Before experiment				After experiment			
	pH	OM (%)	P (mg kg^{-1})	K (mg kg^{-1})	pH	OM (%)	P (mg kg^{-1})	K (mg kg^{-1})
0-15	4.7	1.12	5.0	36.7	5.7	1.26	11.00	45.00
15-30	5.3	0.90	2.0	29.1	5.2	1.04	9.16	32.30
30-50	5.2	1.14	1.0	34.3	5.3	1.17	11.06	33.96

Source: Nopmalai *et al*. (2015)

However, a proven solution to erosion and loss of water, soil and nutrient has been found with vetiver grass. In Nigeria, studies have shown that vetiver grass strips have demonstrated locally their efficiency in curtailing soil erosion and improving crop yield. About 70%reduction in soil loss, runoff by about 130% and 50%increased maize grain yield with vetiver grass strips at20 m interval when compared to a control. According to the reports of the research of (Ewetola 2017), the grass shows its efficiency in reducing runoff, soil loss, and nutrient and improved crop yield (Figure 3).

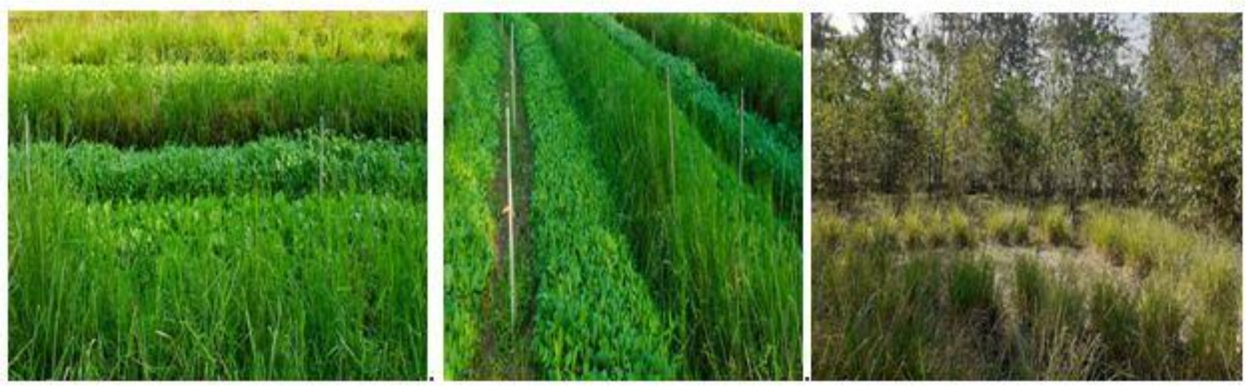

Figure3. *The role of vetiver gras on soil fertility enhancement*

5. Benefits on Carbon Sequestration

Carbon sequestration implies capture and secure storage of Cthat would otherwise be emitted to or remain in theatmosphere. C sequestration is an efficient strategy to mitigateclimate change. Vetiver holds prominence as one of theworld's best carbon-sequestering plants (Nopmalai *et al*., 2015). Four mature vetiver plants would sequester the same amount of atmosphericcarbon as one fast-growing poplar tree, the best of all trees forcarbon sequestration(Table 3). As an example, one 'carbon footprint' would be negated by planting 50 to 60 vetiver plants, or approximately 8 m of vetiver hedgerow (Lakshmi and Sekhar, 2020).Vetiver's have enormous capacity to produce biomass and its impressivedeep root system that can possibly capture more carbon than any other grass.Soil carbon derived from plant biomass by photosynthesis process converting CO_2gas or inorganic carbon in the atmosphere to organic carbon in plant biomass. The deadparts of plant falling to the ground, will be decomposed by soil microorganism and transformed to organic carbon storage in the soil. Therefore, plants including vetiver grass, on the global are capable to reduce the global warming by photosynthesis process (Taranet *et al.*,2012).

Table3. *C- sequestration by different species (normalized to 12 month crop cycle)*

Tree/Crop/Cropping System	C- sequestration (mega grams ha-[1] year-[1])
Albizzialebbek	1.04
Tectoniagrandis	1.33
Artocarpusintegrifolia	1.21
Shorearobusta	0.87
Poplar	8
Eucalyptus	6
Teak	2
Vetiveriazizanioides	15.24
Lemongrass	5.38
Palmarosa	6.14
Vetch-maize-oat- soybean-wheat-soybean	7.26
Oat-Maize -Wheat-Soybean	8.56
Vetch-Maize-Wheat-Soybean	7.58
Ryegrass-Maize -Rygrass-Soybean	8.44
Alfalfa-Maize	7.52
Rice-rice	1.54-2.48(residues)
Maize-rice	2.1-3.51(residues)

Source: *Santos et al. (2011)*

The growth curves of the three grasses show that while the biomass of lemongrass and palmarosa tends to saturate toward the end of the study, vetiver seems to accumulate biomass at higher rates which isan indication of its potential for higher Carbon sequestration rates. Total C sequestered in shoots and roots was higher in vetiver than in lemongrass and palmarosa (Table 4) (Singh *et al.*, 2014).

Table4. *Comparative drymatter production and C- sequestration by aromatic grasses*

Crop	Carbon (%)		Drymatter (Mg ha-1 year-1)		C – sequestered (Mgha-[1] year-[1])		
	Shoot	Root	Shoot	Root	Shoot	Root	Total
Vetiver	50.53	50.27	28.62	1.56	14.46	0.78	15.24
lemongrass	44.45	48.14	10.5	1.57	4.83	0.55	5.38
palmarosa	52.77	43.49	11.11	0.65	5.86	0.28	6.14

Source: Singh *et al.* (2014)

6. ESSENTIAL OIL OF VETIVER

The aromatic roots of vetiver (Vetiveriazizanioides) yield `Oil of vetiver which has been highlyvalued by perfumery industry since ancient times. This essential oil finds diverse applications in perfumery, cosmetics and chewing tobacco industry. Besides, the oil also holds its place in the traditionalsystem of medicine as carminative, stimulant and diphoretic (Anonymous, 1976).A plant that is extensively used in the cosmetic, perfumery andfood industries and has potential application in the pharmaceutical industry is vetiver (VetiveriazizanioidesL.). The plant, originatingfrom India, is a tall, tufted, perennial, scented grass with a straightstem, long narrow leaves and a lacework root system that is abundant, complex, and extensive. Since ancient times, vetiver grass has been used as a fragrant material and in traditional medicinebecause its roots contain essential oils with aromatic and biological properties. The oil and its constituents are used extensivelyfor blending in oriental types of perfumes as well as in other cos-metic and aromatherapy applications (Danh*et al* ., 2009).Essential oil of vetiver is composed of morethan 100 components that are mainly sesquiterpenes and their derivates. The mainconstituents of vetiver oil comprise of:sesquiterpene hydrocarbons and their alcoholderivatives- vetiverols such as, khusimol, khusinol, carbonyl derivatives-vetivones (ketones)such as, vetivone, khusimone and three carbonylcompounds, such as β vetivone, α -vetivone andkhusimone (Chahal *et al.*, 2015). Among the odorous components in vetiver oils from different sources, khusimol,β-vetivone, α-vetivone are the major constituents,and their presence is often considered as thefingerprint of the oil, are also present in the oilgiving characteristic odour of Vetiver oil.Also, economically important active principles of vetiver were α-vetivone (2.19-5.53%), β-vetivone (3.12-4.82), β-eudesmol (6.44-8.06) and khusimol (14.92-26.94) (Ramana, 2009).Twenty eightcomponents of chemical components of 79% in the essential oilobtained from dry root of vetiveron different years was indicated in (Table 5).

Table5. *Essential oil content and its chemical constituents of vetiver during 2008 and 2009*

Parameters		Years	
		2008	2009
Essential oil content (%)		0.78	0.70
RT	Components		
55.85	8,9-dehydro-cycloisolongifolene	1.83	0.13
56.54	cadina-1(10),4-diene	1.12	0.31
56.91	ar-curcumene	2.72	0.11
57.27	γ-cadinene	0.49	0.53
59.99	β- vetivenene	9.76	8.16
60.54	γ-gurjunene	1.34	2.83
61.82	ledene oxide	0.47	1.06
62.56	η-himachalene	0.14	2.07
63.02	Valencene	0.18	0.30
63.51	$C_{15}H_{22}O$	0.64	0.28
63.99	γ-muurolene	2.85	1.77
64.63	b-eudesmol	0.33	1.11
64.78	β-guaiene	0.43	1.29
65.09	allaromadendrene oxide	0.96	0.34
65.44	δ-cadinol	2.59	2.24
65.77	Junipene	0.44	5.65
66.01	tau-muurolol	1.99	2.44
66.24	trans-caryophyllene	3.69	0.38
66.50	Cubenol	0.59	0.86
66.86	caryophyllene oxide	1.66	0.52
67.27	Khusinol	19.15	15.67
67.45	8-cedren-13-ol	2.72	2.35
68.68	$C_{13}H_{18}O$	3.18	2.54
70.06	β-gurjunene	3.20	5.24
71.97	thujopsene-13	3.80	6.00
73.47	dehydro-aromadendrene	7.34	9.66
75.01	β-vetivone	2.64	2.55
76.52	α-vetivone	3.17	3.54
	Total identified	79.42	79.93

Source: Kirici *et al.* (2011)

7. Conclusions

Vetiver grass, a perennial grass with deep root system and has high biomass production and has unique morphological characteristics. It has the ability to resist adverse environmental condition, absorb and tolerate extreme levels of nutrients. Current vetiver grass applications include soil and water conservation in agriculturallands, steep slope stabilization, mine, contaminated and saline lands rehabilitation and recently wastewater treatment. This is due to its uniquemorphological, physiological and ecological characteristics that permit it to adapt to a wide rangeof climatic and soil conditions. Vetiver's promise of soil carbon capture carbon sequestration is immense, given Vetiver's enormous capacity to produce biomass, and its impressive deep root system that can possibly capture more carbon than any other grass. The aromatic roots of vetiver (Vetiveriazizanioides) yield Oil of vetiver which has been highlyvalued by perfumery industry since ancient times. This essential oil finds diverse applications in perfumery, cosmetics and chewing tobacco industry. Besides, the oil also holds its place in the traditionalsystem of medicine as carminative, stimulant anddiphoretic. Vetiver grass technology has been applied globally for controlling soil erosion, carbon sequestration, stabilizing land and water resources and enhanced soil fertility in order to improve crop growthand yields.

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