Some Thoughts on the Potential Contributions of Vetiver System in Mitigating Climate Change

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Abstract

In past years in TVNI the role of Vetiver System in relation to Climate Change was brought up several times. So far there is a strong realisation that – whatever Vetiver System would do to mitigate Climate Change – it already has an impressive suite of positive benefits. It betters the environment, through reduced soil loss and related soil moisture and fertility improvements, and improved water quality (including applications to adapt to climate change) and this is by far the most important.

Yet, Vetiver can have important bonus features when used for the production of biofuel or for atmospheric carbon sequestration and soil carbon capture and storage.

Concerning biofuel, some of its use is already evident (bio-fuel in coal-fired furnaces), and some is in development (bio-fuel in ethanol plants and recently developed gasification installations) but in need of further development support before it can be economically viable. Yet, this definitely seems to have potential.

Concerning atmospheric carbon sequestering and soil carbon capture and storage there is a great need for more research, as the promise of carbon sequestration is not negligible, given Vetiver's enormous capacity to produce biomass, and its impressive deep root system that can possibly capture more than any other grass. But most research is about grassland grasses – Vetiver is not that kind of grass. Or about trees – Vetiver is not a tree. Yet it has to fit in the databases on carbon sequestration and storage that are currently developed.

Technologies, methodologies, algorithms to be improved to allow measurement of Carbon sequestration, and Carbon capture and storage by Vetiver. This requires observations under different climate and soil conditions, as well as different applications of Vetiver Systems. India and China are well placed for this, having some good research institutions and a wide range of growing conditions.

1. INTRODUCTION

For the writing of this article the author had not enough time to prepare, as a result some aspects normally required in scientific reporting are as yet inadequately (some inconsistencies in terminology, inconsistent use and errors with units of measurement, and some references not being presented or verified). Yet, the whole point of this article is the call for more research and development – by more qualified professionals (than this writer), with sufficient time to produce reliable findings.

This article has in most of the sections suggestions for further research, and/or further development of already existing good practices using Vetiver for bio-fuel.

2. BIO-FUEL

Biofuel from Vetiver grown as a field crop

In nearly all applications of using Vetiver, as 'Vetiver System', the grass is planted as a dense hedge, typically placed on contour lines or (when farms are small) on boundaries of a field. This applies for on-farm applications, bio-engineering for protection of slopes (infrastructure), and artificial wetlands. Perhaps the odd exceptions are just two: the floating Vetiver for treatment of waste water in ponds, and the planting of Vetiver as a field crop, for biofuel.

As a field crop, producing about 100,000 plants/ha (0.3x0.3m spacing) it provides 130 tonne of dry biomass on soils of reasonable depth and fertility. On saline soils in the Dominican Republic dry Vetiver biomass production is reported at 70 tonne/ha.

Not displacing food crops for fuel production

Vetiver is well placed as a potential furnace feedstock, and has the added advantage in that it could be grown on marginal lands. In the example explained below, from the Dominican Republic, Vetiver is grown on saline soils. Also in northern and north-west India and Pakistan there are huge areas of saline irrigated land with high water tables (marginal to agriculture because of poor drainage that has led to saline soils and ground water). Vetiver could be grown on large scale, produce high yields with very little supplementary irrigation, to be used for biofuel in ethanol plants, in conventional coal-fired furnaces (as in the Dominican Republic example), or in the latest state-of-the art gasification installations that have recently been developed for woodchips.

Additionally Vetiver would help rehabilitate this saline land so that it might again be used for profitable purposes. This actually happened in the 1950s on Ussar lands in Uttar Pradesh where Vetiver was used to rehabilitate saline land where little else would grow.

In some parts of India it is traditional to move hand-cut sugar cane and grass to nearby cane and paper processing plants. There would be little difference in doing the same for Vetiver.

2.1 *Cellulosic Ethanol*

In the USA research is being carried out on plants such as Miscanthus, switchgrass, and corn as potential feedstock for cellulosic ethanol plants. The table below shows the characteristics for an ideal biomass fuel.

TABLE I

Characteristics of an ideal biomass energy crop present (+) in corn, short rotation coppice and *Miscanthus*, developed in part from Long (1994)and Khosla (2006).

Crop characteristic	Corn	Short-rotation coppice	*Miscanthus*
C_4 photosynthesis	+		+
Long canopy duration		+	+
Perennial (no need for annual tillage or planting)		+	+
No known pests or diseases			+
Rapid growth in spring to out compete weeds		+	+
Sterile; prevent 'escape'			+
Stores carbon in soil (soil restoration and carbon sequestration tool)		+	+
Partitions nutrients back to roots in fall (low fertilizer requirement).			+
Low nutrient content i.e. < 200 mg MJ^{-1} nitrogen and sulphur (clean burning)		+	+
High water use efficiency	+		+
Dry down in field (zero drying costs)			+
Good winter standing (harvest when needed; zero storage costs)		+	+
Utilizes existing farm equipment	+		+
Alternative markets (high quality paper, building materials and fermentation)	+	+	+

Source: http://www.aces.uiuc.edu/DSI/MASGC.pdf

Vetiver grass meets all the characteristics of *Miscanthus sp.* and more. Most importantly it is a drought tolerant, long-term perennial crop that needs only moderate inputs to be productive.

2.2 *Coal-fired furnaces for electricity*

When a medium-sized power plant adds biomass to its mix, its global warming emission reductions are equivalent to taking 17,000 cars off the road (source: Natural Resources Defence Council, http://www.nrdc.org/air/energy/renewables/biomass.asp).

Vetiver has an energy value of 7,000 BTU/lbs compared to petroleum – 18,000; coal 12 – 13,000; dry wood 8,500; and sugar cane bagasse 4,000 BTU/lbs. These non-Vetiver biomass sources are used as feedstock to generate electricity.

The advantages of Vetiver feedstock over other fuels are:

1. As it is entirely renewable and in the burning process does not add net carbon amounts to the atmosphere. Taylor Moore: replacing 1 mega-Watt coal-fired power by biomass power offsets ±6000 t (6 million kg) CO_2/year;
2. CO_2 reduction from coal power plants can be expensive ($100 -200/tonne for some methods), but co-firing biomass with coal (coal in quantities as small as 15% of the biomass) gives 95% cost reduction compared to using coal only;
3. biomass has much lower Sulphur content than even low Sulphur coal (which is costlier than regular coal), so there will be less SO_2 & nitrous oxide release into atmosphere;
4. Nitrous oxide emissions from biomass are also expected emission in smaller concentrations than from coal firing processes; Source: http://www.nau.edu/~soc-p/ecrc/biomass.html
5. Coal mines can release gases for a long period; for a Vetiver farm this is only temporary, when the field is established (the crop remains permanently, so no annual ploughing is required).

Boucard's biofuel case (a 50 Mw power plant in Barahona, Dominican Republic)

- Under tropical conditions, under irrigation or good annual rainfall 70 up to 80 t/ha.year dry Vetiver leaves are produced;
- as it is never a good idea to burn wet fuel (energy is used to evaporate the water, and steam reduces furnace temperature), Vetiver is dried prior to burning, to reach a moisture content of about 10%, that takes 3-4 days sun drying;
- planting Vetiver for fuel is one of the easiest and safest farming operations: unlike sugarcane, Vetiver plantation needs no re-planting, it can be harvested annually at any time of the year, has no diseases or weather damage, and production can go on for more than 20 years, by just adding fertilizer;
- owning land and farming operation, once the plantation is established, Boucard estimates production of Vetiver biomass costs to be below US$15/tonne;
- baling is done with a standard hay baler; after 3-4 days of sun drying moisture is reduced to 10%;
- Dry grass calorific value: 7,000 btu /pound (about half of that of coal)
- Modern thermal power plant needs about 1000 tons/day of Vetiver bales to produce 50 Megawatts (or 500 tons/day coal import from Columbia, providing 13,000 btu/lb)
- 1000 tons of Vetiver bales more than equal 500 tons coal, to be harvested from 12.5 ha field in one day; so, **to run a 50 Mw plant 365d/year requires 4,563 ha, surrounding the plant;** unlike sugarcane, Vetiver does not need re-planting as it simply grows back, with natural rainfall, and can be harvested any time of the years

for 20 years or more (just add some fertilizer). The raw cost of producing 1 ton of Vetiver biomass fuel is no more than US@ 15/ton, once the plantation is established.

To produce 293 kWh (1 MMbtu or one million btu) it costs (in 2009):

- Vetiver dry leaf: 7000 btu/lbs dry leaf, so we need 142.9 lbs (64.4 kg) to produce 1 MMbtu
- If cost of 1 ton (2000 lbs, or 907 kg) Vetiver fuel is US$15: 1 MMbtu costs 142.9 lbs*US$15/2000 lb = US$1.07 /MMbtu
- Cost if coal: 14,000 btu/lbs as cheapest fuel costs US$45/ton (in the US) → US$1.60 /MMbtu
- Cost if crude petroleum: only $100 /barrel (a barrel = 42 gallons or 336 lbs): 1 ton (2000 lbs) /336 lbs = 5.95 barrels /ton x $100 = US$595 /ton crude petroleum, which has ±18,000 btus /pound → 1,000,000 /18,000 = 55.5 lbs. It takes only 55.5 lbs crude petroleum to produce 1 MMbtu, but 55.5 lbs * US$595/2000 lbs = US$16.5 /MMbtu.

Vetiver is the most lucrative use for tropical farmland, producing electricity at US$0.12 per Kw/h. (Source: Guéric Boucard, personal communication, 2009).

If somebody in the third world ever figures this out, one of the biggest problems will be to insure that food crops are not displaced for fuel production.
Currently the writer of this article (Elise Pinners) is working in Busia County, Western Kenya, where the trend is that farmers replace not-so-lucrative food-crops with sugarcane. Meanwhile, (hydro-)electricity is imported from Uganda at an ever increasing price.

R&D on combustion

More research on perspectives and constraints is required. Some estimates indicate that if income from biomass for fuel is combined with credits for carbon offsetting, economic rates of return would be in the order of 15%. These estimates are made a few years ago when oil prices were lower.

There are two challenges that need further research:

1. Vetiver's high nitrate absorption does not all go into the air in negative way, if primary N combustion product is elemental nitrogen (N_2, which is the bulk of the atmosphere). But: poor combustion can lead to all sorts of noxious compounds. Much of knowledge about combustion is directly applicable to Vetiver, but some practical research may be needed to check noxious compounds emission. The factors that affect results of combustion are:
   - N content of foliage: in Vetiver this is not particularly high;
   - How the grass is "cured", and how it is burned in coal-fired units
   - Impact of silica on furnaces.
   - Silica in foliage: in Vetiver levels are higher than in many other grasses, increasing with age, and variable per genotype; it is consolidated in leaf as mineralized

"phytolith" (shape unique to a species). Silica (& other minerals) can create ash disposal burden in combustion as well as aerial fly ash deposition, plus silica itself can serve as a flux in combination with other elements than can wreak havoc in furnaces. So silica is a downside to burning Vetiver (compared to Miscanthus), but how serious is that?

And: possibly complex silicate salts capture and precipitate some of heavy metals, sulphur compound, nitrous oxides in mixed combustion reaction, preventing them from escaping through the stack. This is relevant for large furnaces and combustion systems, where there is great concern for emissions. Another plus for Vetiver?

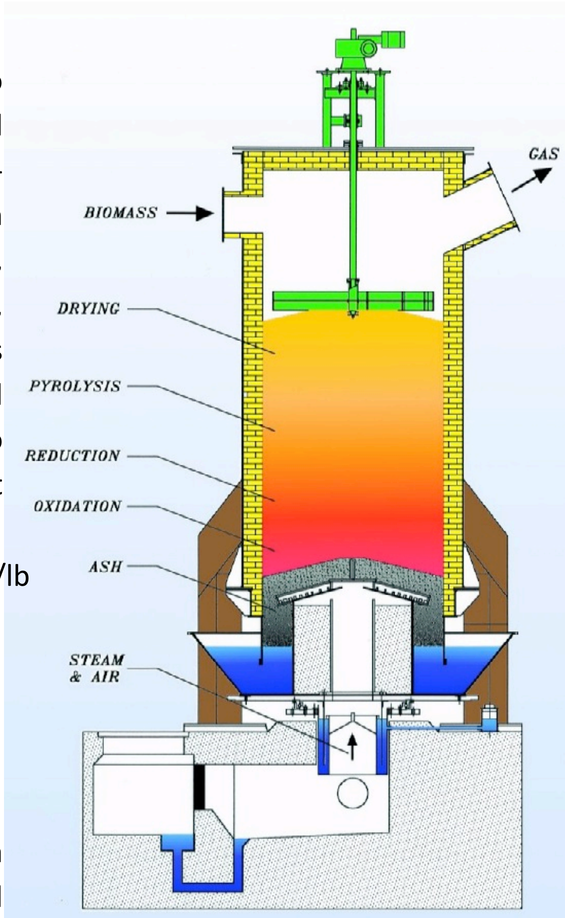
2. Silica affecting the furnace: Vetiver forms a glassy type of "klinker" which stays in furnace with ash (complex oxides & salts). Vetiver contains so much silicates (more than in Miscanthus), it tends to flux firebrick by lowering the melting point of brick. This is why furnaces in Texas (where spent wood from extraction process was burnt at very high temperatures >2000F), had to go to a brick with 70% alumina content, to prevent "fluxing". Cheap bricks with only 50% alumina melt like butter. High alumina bricks are costly and there are thousands of bricks in a large furnace.

2.3 New technology gasification for electricity

In Kenya an initiative is in preparation to use Vetiver (grass bales) as an alternative biofuel in a wood chip to electricity plant (BTE: biomass-to-electricity). The initiative is from The African American Environmentalist Association (AAEA), in cooperation with National Clean Fuels (NACF), and Dyson Engineering and Technical Services (DET Services). Vetiver grass would be gasified with the methane burned in a turbine engine to produce electricity. A comparison of heat content shows:

- Petroleum has on the average 18,000 btu/lb
- Coal has 12-13,000 btu/lb
- Dry wood has 8,500 btu/lb
- Sugar cane bagasse has 4,000 btu/lb
- Dry Vetiver Grass has 7,000 btu/lb.

The source of Vetiver grass bales is to be a combination of nearby farming of Vetiver and delivery from other farms; a combination with sugarcane bagasse may also be tried.



Sketch of updraft gasifier (source: Volund Systems, Waste and Energy Technologies)

The idea is still in a very early stage and a feasibility study is being prepared.

Gasifiers generally run on a portion of the supplied feedstock as well as converting the balance of it to a fuel for other applications. Biofuel-generated gas is a syngas that is produced by thermal gasification of biomass. It is the result of two high-temperature reactions (1,292 °F): an exothermic reaction where carbon burns to CO_2 but is then reduced partially back to CO where carbon reacts with steam, producing carbon monoxide (CO), molecular hydrogen (H_2), and carbon dioxide (CO_2). In several gasifiers, the actual gasification process is preceded by pyrolysis[1], where the biomass or coal turns into char, releasing methane (CH_4) and tar rich in polycyclic aromatic hydrocarbons (PAH). Other gasifiers are fed with previously pyrolysed char. Biofuel-generated gas is flammable because of the carbon monoxide, hydrogen, and methane content. A gasifier takes biomass as fuel and is burned incompletely in a fire box, producing solid ashes and soot (which have to be removed periodically from the gasifier). The gas can then be filtered for tars and soot/ash particles, cooled and directed to an engine. Most of these engines have severe purity requirements of the gas, so the gas often has to pass through extensive gas cleaning in order to remove or convert (i.e. to "crack") tars and particles. The removal of tar is often accomplished by using a water scrubber. Exhaust gas emission levels from an internal combustion engine is significantly lower on biofuel gas than on petrol. Especially low are HC emissions. A normal catalytic converter works well with biofuel gas, but even without it, emission levels less than 20 ppm HC and 0.2% CO can be easily achieved by most automobile engines.[2]

Source: Technology Brief, "Toxicity of Wastewater Generated From Gasification of Woodchips, Lund Institute of Technology.[3]

3. CARBON SEQUESTRATION, CAPTURE AND STORAGE

There are two areas describing carbon sequestration:

1. **Sequestration of carbon** (from the air) which is - simply put - a way to offset carbon emission elsewhere. Natural vegetation when in a balanced, normal life cycle does sequester as carbon as well as emit carbon – so that would be neutral. By replacing a particular vegetation by Vetiver there are several ways in which more carbon will be sequestered than emitted. This is explained in 2.1.
2. **Carbon capture and storage** (from the vegetation into the soil). This is explained in 2.2.

[1] Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen. Pyrolysis typically occurs under pressure and at operating temperatures above (800 °F).

[2] Wood Gas, Wikipedia.

[3] **Other fuel ideas were discussed in** Marco Forti's comment on 'flash pyrolysis':
http://www.facebook.com/groups/9168832759/
http://www.thermalnet.co.uk/docs/G%20Brem,%20Flash%20Pyrolysis%2004.03.06Lille.pdf

3.1 Carbon sequestration

Vetiver is one of the world's most unique plants in its range of applications, and also has to be one of the world's best carbon sequesters. Vetiver's advantage over other candidates are best summarised when referring to its high potential for biomass production in combination with its other characteristics that support a wide range of applications.

From a spatial perspective the carbon sequestration can be classified as:

1. ***Increasing biomass on-the-spot***: where Vetiver is planted (in the soil or floating) it replaces vegetation with less biomass, on (mostly) barren land e.g.:
   a. planted on degraded lands;
   b. vegetating mining sites;
   c. decontamination of polluted water in artificial wetlands or floating on ponds with polluted water (in wetlands it is due to its biomass roughly twice as effective as Kikuyu grass);
   d. planted on infrastructure slopes, e.g. road- and railway embankments and gullies that would otherwise be poorly vegetated or paved with any combination of stones and concrete (sand, cement steel)
   e. replacing the inadequate (outdated) engineering structures for soil conservation (e.g. the constructed contours that typically are not so well vegetated).
2. ***Increasing biomass, boosting a more bio-diverse organic productivity it its vicinity***, as it supports rehab of vegetation through reduced runoff and improved water retention, e.g.:
   a. supporting re-vegetation of mining sites, polluted and otherwise degraded areas;
   b. supporting vegetation (or even farming) on infrastructure slopes e.g. roadsides and gullies;
   c. boosting production (biomass) on-farm.
3. ***Off-site impact***: with a more bio-diverse organic productivity, and its extensive, deeply penetrating root system (also penetrating hard layers) there is also a benefit for ground water recharge, which supports increasing organic productivity further down in a catchment, as well as reducing farm and infrastructure flood damage, mitigation of this has its consequences for emission of GH gases.

Once this more-carbon-retaining vegetation found its new balance, there seem to be no further gains, but taking a closer look at above description we see further potential:

Ad 1c: Apart from the biomass, the water decontamination is itself highly beneficial for reducing GH gas: it prevents emission of CH_4 and NH_3 and N_2O.

Ad 1d: Replacing conventional engineering (using mined materials) with bio-engineering implies a clear reduction of carbon emissions through transport (replacing far away resources by locally grown resources) and by avoiding mining of materials, requiring vegetation removal.

Ad 1e: The digging up soil e.g. for contour bunds is having its own negative impact, as with ploughing a field: it causes release of soil carbon and more noxious greenhouse gases that would otherwise be kept mineralised in the soil. **Hedge establishment does not require much digging and being permanent, trapped sediments are kept buried** so they don't otherwise oxidize.

Ad 2a: These degraded areas are also a potential for planting Vetiver for biofuel, replacing non-renewable sources that emit CO_2 and more harmful GH gases (CFCs, SO_2 & nitrous oxides). If growing any plants for biofuel, do this under the most productive, sustainable conditions – Vetiver System underpins this.

Ad 2b: As in 1d.

Ad 2c: On-farm biomass production can be further enhanced when considering that:

- Vetiver mulch can be used to soil temperatures down, allowing higher levels of mineralisation of carbon (carbon sink) and preventing oxidation of other GH gases;
- permanent Vetiver hedges maintain a better (predator) insect balance, which supports practices of conservation farming or minimum tillage that are favourable to keeping soil carbon locked up;
- Vetiver's deep rooting system absorbs nitrates from lower levels in a field (that would otherwise end up in oceans, and then through de-nitrification be returned to the atmosphere), bringing the nitrates (and potassium and phosphates) back into the biomass.

As shown above, classification of different ways in which Vetiver System has an impact on greenhouse gas emission requires a good understanding not only of the grass itself and its spatial impact (on-the-spot, in the vicinity, and off-site), but also of the System: how the propagation, establishment and maintenance of the grass is managed, and its potential for large-scale use.

Research by CIAT (Colombia) has shown that deep-rooted tropical grasses in South America can sequester carbon with a biomass production of 100 to 500 t/ha.year. These grasses do not have Vetiver's massive root system. When research is carried out we will probably find this estimate to be low. At 60,000 plants/ha, Vetiver could sequester carbon at 150 t/ha.year (a 'conservative estimation' according to the source). One linear kilometre of Vetiver hedgerow (6,000 plants) would sequester carbon at 15 t/year, that is 2.5 kg/plant. Taking one square meter (0.3x0.5m spacing) of Vetiver, it would sequester carbon at 15 kg/m^2.year; this is 4.5 times more carbon than a fast growing poplar trees per unit area (fast growing poplars spaced 1x3m sequester carbon at about 10 kg/tree.year or 3.3 kg/m^2.year or 33 t/ha.year). Of course this is all very tentative, but the estimates are conservative; knowing what we do know about Vetiver there would seem to be excellent potential, and a research program is recommended.

Other, more comparative research[4] shows Vetiver producing 30.18 t/ha.year dry matter in comparison with lemongrass (11.07 t/ha.yr) and palmarosa (11.76 t/ha.yr). The Caron sequestration in biomass was 15.24, 5.38 and 6.14 t/ha.yr respectively.

Tropical grasses can store Carbon from 3 to 14 t/ha.year (CIAT, Fisher et al, Nature 2002 & other sources). *Andropogon guyanus* (Vetiver close relative, also a deep-rooting tropical grass) stores 53 t/ha.year CO_2 o.m. (CIAT 1995). But Vetiver has a more massive and deeper root system than Andropogon *and* huge biomass above the ground. One reason is Mycorrhiza association. Based on that we speculate that Vetiver's Carbon storage is 70 t/ha.year. Taking that 1 km of Vetiver hedge is equivalent to 800 m^2 (considering that the width of a hedge is between 0.4 and 2 metres, to be conservative we take a width of 0.8m) or 0.08 ha. But any measure will be highly variable, quite unlike forest on depleted soils. The number of plants in a 1 km of hedge is 6000 (based on 16.7 cm/clump in the row or 6 plants/metre).

This leaves us with a puzzling wide variety of estimations on carbon sequestration from 15 to 70 to 150 t/ha.yr. **More research is needed.**

Currently there's no handy way to measure carbon uptake or conversion under Vetiver:

- lack of site uniformity, and
- even in well-documented cases "hard numbers" can be specious.

Only counting aerial biomass gives an 'unfair' outcome:

- Vetiver has a regular foliar turn-over (harvested or not);
- not trimming plants is (in most applications) also poor management.

There are specific research questions related to different applications:

- Vetiver wetlands: how much methane (NH_3) can be recovered?
  a. Treatment of raw sewage (black water) and/or septic tank overflow, compared to of conventional water treatment method(s)
  b. in slums, rural areas, refugee camps where the method replaces the 'no-sanitation' option
  c. treating waste dump leachate.
- Vetiver ponds (along boundaries and on pontoons): idem?
- **Reinforcing carbon capture in reforestation** on poor (mostly degraded, inferior quality) soils: how much is the carbon capture potential?

For reference, two new methodology elements are being assessed under the Verified Carbon Standard (VCS) methodology approval process:

1. Methodology for Sustainable Grassland Management (SGM) (FAO)
2. Methodology for Soil Carbon (The Earth Partners).

Also see methodology elements under development and the VCS methodology approval process.

[4] Biomass Production and Carbon-Sequestration By Vetiver In Comparison With Lemongrass And Palmarosa and Their Economic Feasibility In A Semi-Arid Tropical Climate, M Singh et.al.

3.2 From sequestration to carbon capture and storage

Carbon capture and storage is a step further, in which carbon-retaining vegetation is captured in the soil, and retained in a more stable, mineral form: Soil Organic Carbon (SOC). A good overview of the different pools of carbon can be found at: https://s3.amazonaws.com/soilquality-production/fact_sheets/4/original/Biol_-_Labile_Carbon.pdf

Vetiver System contribution to carbon capture and storage in soils requires assessment of different pools of carbon in the soil, and different ways in which VS contributes to increasing those pools and avoiding reduction in others. Literature indicates that root derived soil carbon accumulation is being estimated by scientific studies across the globe under both grassland and forests, either in the tropics or in temperate areas. In most cases Vetiver System is not applied in a grassland or forestry setting, but on-farm, for infrastructure protection, rehab of degraded of polluted soils and treatment of waste water.

For carbon to truly be sequestered i.e. captured and stored in the soil, it must be transformed to mineralized carbon aided by the microbial activity in the soil associated with the root zones. One of the reasons for high Vetiver plant vigour is a result of its Mycorrhiza association. This association is one of the reasons Vetiver hedgerows produce such high amounts of biomass. Some of that biomass can result in high amounts of carbon added to the sequestered soil carbon pool.

Under cultivation systems a very significant part of the labile fraction is lost to oxidation (removed with the crop itself). So hedgerows of Vetiver, unless used for mulching as well, are not going to have much direct impact on the other 90% to 92% of the field within a cropping system. Looking only at the direct impact (as in 2.1: 'on-the-spot'), its carbon sequestration is about 1 $kg/m^2.yr$ (Lavania). Then we consider the wider meaning of 'Vetiver System', putting it within the context of good management of soil fertility, increasing organic matter in the rest of the field. Otherwise the hedge is only compensating for a fraction of the much larger fraction being lost from between the hedges.

We need to learn a lot more about Vetiver's ability to sequester carbon and how much, under different climate and soil conditions. Scientists in China, India and elsewhere would be advised to investigate Vetiver's potential. US scientists are working on *Miscanthus sp* and switchgrass because they are known high biomass North American grasses. We should be doing the same for Vetiver.

Biological Nitrogen Fixation can explode in soils with high organic carbon, along with P and K availability, thus cutting the need for synthetic (fossil) fertilizer and all the fossil carbon its production spews. The ability of Vetiver to retain and enhance high-carbon soils in a stabilized agricultural system is a qualitative and quantitative advantage, regardless of what farming system you use behind it, e.g., if you want to incorporate biochar, all the better, but if you want to really utilize the biochar, you better keep it on-site.

Linking into the Kew grass database, Vetiver publications in Google scholar since 2009, provides some very interesting information, though sadly much is behind the pay-wall of academia.

One that isn't is a 2009 "Commentary" by Umesh Lavania for the Indian Academy of Sciences' *Current Science*: "Sequestration of atmospheric carbon into subsoil horizons through deep-rooted grasses – Vetiver grass model" (*Current Science* 97(5): 618-619). They conjecture Vetiver could sequester up to 1 $kg/m^2.yr$ carbon, close to the figure estimated by other sources. The figure may be already high, and it still doesn't include carbon retained in trapped sediments (Vetiver's "hidden contribution": a feature not shared by other plants under consideration? – see 2.1).

3.3 Biochar

Biochar (old charcoal, a highly concentrated carbon compound) has recently received a lot of attention; The Economist magazine, in ***Biochar Could Enrich Soils and Cut Greenhouse Gases As Well*** (29 August 2009, Science and Technology section, p. 69), reported the recent North American Biochar Conference at the University of Colorado, about the virtue of various ways of making biochar from different raw materials, and how big the benefits would be. Two major issues came to light:

1. **Beneficial effects**, when biochar be properly incorporated into the soil, would include:
   - Remaining in the soil for a long time, improving soil fertility, reducing leaching of nitrate, phosphate and potassium to ground water;
   - Biochar containing soils release less methane and nitrous oxide than untreated soils, probably because biochar acts as a catalyst for the destruction of these two gases; as these are more potent greenhouse gases than CO_2 this effect should help combating global warming considerably;
   - The biochar making process creates beneficial by-products: heat, syngas for fuel and a heavy oil, which can be used as an energy source.
2. **Major concerns** were also raised:
   - Use of existing farm land, or virgin land for biochar crops
   - Tillage would release CO_2 and methane
   - Growing switchgrass for biochar may do more harm than good; garden waste and forestry off-cuts are better.

Vetiver could be the best option, having all the benefits and none of above concerns:

1. Producing very high biomass, up to 130 t/ha.year under subtropical conditions and probably higher in the wet tropics, with a high carbon content of 45%.

2. Tolerating a wide range of climatic conditions: tropical (55^{0}C) to sub-temperate (-14^{0}C as long as the ground is not frozen), drought, flood, prolonged submergence (3months)
3. Growing Vetiver grass does not compete for farmed land as it can be grown on waste land or highly degraded agricultural lands or (tolerating heavy metals) in mine rehabilitation areas or (tolerating pollutants) in artificial wetlands and ponds to treat and dispose of industrial, municipal and domestic wastewater
4. As a perennial crop, there is only minimal release of greenhouse gases due to tillage.

3.4 Capturing Carbon, Methane and Nitrous Oxide from waste water

As with biogas, also the use of Vetiver for absorption of waste water deserves more serious attention. For a reference on this, see the presentation of Singh (August 2009?): Evaluating and quantifying Carbon Sequestering, GHG Emission Reduction, … through a community development project in Punjab, India. M.P. Sing, B. Tech.(Civil); M.I.E. (Mech.), Earthizenz & India Vetiver Network
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4. CONCLUSION: MORE RESEARCH IS NEEDED

Technologies, methodologies, algorithms to be improved to allow measurement of Carbon sequestration, and Carbon capture and storage by Vetiver. This requires observations under different climate and soil conditions, as well as different applications of Vetiver Systems. India and China are well placed for this, having some good research institutions and a wide range of growing conditions.

More general questions for research are:

- Plug in Vetiver in overall data structure developing on grasses
  a. broader research on grasses (versus trees)
  b. observational & experimental trial comparisons among candidate species and Vetiver (make practical judgments on utility of Vetiver, using physiological & morphological indicators e.g. energy efficiency, nutrient partitioning, biomass production & turnover, water infiltration).
- Adding Vetiver to (comparative) research scenarios already underway with other grasses (fairly inexpensive, short time-frame, practical):
  a. nitrification cycle: what are CH_4, N_2O, NH_3 and SO_2 absorption quantities for Vetiver (compared to other plants), in different conditions (using Vetiver for

different methods of: a. waste water treatment, b. infrastructure e.g. embankments of roads, railways, rivers, canals, and c. on-farm uses including mulch, fodder, etc.).

b. CO_2 mineralisation, for different conditions: quantities for roots and leaves.

Under current day advanced remote monitoring procedures it might also be feasible to provide carbon credit income to other users of Vetiver planting it for land protection, slope stabilization etc.

CDM technology for which VS can be relevant:

Ref.	**Methodologies Title**	**Options with VS, research**
AMS-I.A.	Electricity generation by the user	Vetiver biomass for bio-fuel: small furnaces ?
AMS-4I.D.	Grid connected renewable electricity generation	Idem – large scale (see Boucard example)
AMS-III.A.	Agriculture	SWC, mulching, reducing oxidation in soil
AMS-III.H.	Methane and other GH gas recovery in wastewater treatment	VS wetlands as secondary treatment of household waste water
AMS-III.I.	Avoidance of methane production in wastewater treatment through replacement of anaerobic lagoons by aerobic systems	Idem?

Everything counts, but this is crucial:

- **emphasizing the rooting depth**, with the assumption that (bio-available) carbon from roots **below plough-zone depth** (where most out-gassing occurs, regardless whether you plough or not) became immobilized and perhaps eventually mineralized. This gives Vetiver an enormous "direct" edge over other grasses that have been proposed for mass plantings. Taking an average plough zone of 20 cm deep, comparing that with a depth of some 1 metre (80% of the roots of Vetiver are in the first metre, still another 20% beyond that depth) one can see the significance of Vetiver's rooting system.
- **comparisons with other plants**: the Vetiver hedge is **retaining x-tons of topsoil** that would be lost if other interventions are used: this is perhaps the most important bonus of Vetiver System, sequestration-wise.
- the ability for new humus to form in stabilized debris behind hedges.

Yet, so far we say that Vetiver's carbon contributions are just bonus features to its already enormous suite of positive benefits, providing individuals with flexible tools, mobilize local resources to protect themselves from climatic fluctuations and other natural disasters. This help-yourself quality is more important than sequestration, in the long run, because if we managed to bury the entire earth in a meter of new high-carbon topsoil, this would mitigate CO_2 increases only for a few years at best.

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APPENDIX: Energy units for dummies

Quantities

- 1.0 joule (J) = one Newton applied over a distance of one meter (= 1 kg m^2/s^2).
- 1.0 joule = 0.239 calories (cal)
- 1.0 calorie = 4.187 J
- 1.0 gigajoule (GJ) = 10^9 joules = 0.948 million Btu = 239 million calories = 278 kWh
- 1.0 British thermal unit (Btu) = 1055 joules (1.055 kJ)
- 1.0 Quad = One quadrillion Btu (10^{15} Btu) = 1.055 exajoules (EJ), or approximately 172 million barrels of oil equivalent (boe)
- 1000 Btu/lb = 2.33 gigajoules per tonne (GJ/t)
- 1000 Btu/US gallon = 0.279 megajoules per liter (MJ/l)

Power

- 1.0 watt = 1.0 joule/second = 3.413 Btu/hr
- 1.0 kilowatt (kW) = 3413 Btu/hr = 1.341 horsepower
- 1.0 kilowatt-hour (kWh) = 3.6 MJ = 3413 Btu
- 1.0 horsepower (hp) = 550 foot-pounds per second = 2545 Btu per hour = 745.7 watts = 0.746 kW

Energy Costs

- $1.00 per million Btu = $0.948/GJ
- $1.00/GJ = $1.055 per million Btu

Some common units of measure

- 1.0 U.S. ton (short ton) = 2000 pounds (lbs)
- 1.0 imperial ton (long ton or shipping ton) = 2240 pounds
- 1.0 metric tonne (tonne) = 1000 kilograms = 2205 pounds
- 1.0 US gallon = 3.79 liter = 0.833 Imperial gallon
- 1.0 imperial gallon = 4.55 liter = 1.20 US gallon
- 1.0 liter = 0.264 US gallon = 0.220 imperial gallon
- 1.0 US bushel = 0.0352 m^3 = 0.97 UK bushel = 56 lb, 25 kg (corn or sorghum) = 60 lb, 27 kg (wheat or soybeans) = 40 lb, 18 kg (barley)

Areas and crop yields

- 1.0 hectare = 10,000 m^2 (an area 100 m x 100 m, or 328 x 328 ft) = 2.47 acres
- 1.0 km^2 = 100 hectares = 247 acres
- 1.0 acre = 0.405 hectares
- 1.0 US ton/acre = 2.24 t/ha
- 1 metric tonne/hectare = 0.446 ton/acre
- 100 g/m^2 = 1.0 tonne/hectare = 892 lb/acre
  - for example, a "target" bioenergy crop yield might be: 5.0 US tons/acre (10,000 lb/acre) = 11.2 tonnes/hectare (1120 g/m^2)

Biomass energy

- **Cord:** a stack of wood comprising 128 cubic feet (3.62 m^3); standard dimensions are 4 x 4 x 8 feet, including air space and bark. One cord contains approx. 1.2 U.S. tons (oven-dry) = 2400 pounds = 1089 kg
  - 1.0 metric tonne **wood** = 1.4 cubic meters (solid wood, not stacked)
  - Energy content of **wood fuel** (HHV, bone dry) = 18-22 GJ/t (7,600-9,600 Btu/lb)
  - Energy content of **wood fuel** (air dry, 20% moisture) = about 15 GJ/t (6,400 Btu/lb)
- Energy content of **agricultural residues** (range due to moisture content) = 10-17 GJ/t (4,300-7,300 Btu/lb)
- Metric tonne **charcoal** = 30 GJ (= 12,800 Btu/lb) (but usually derived from 6-12 t air-dry wood, i.e. 90-180 GJ original energy content)
- Metric tonne **ethanol** = 7.94 petroleum barrels = 1262 liters
  - ethanol energy content (LHV) = 11,500 Btu/lb = 75,700 Btu/gallon = 26.7 GJ/t = 21.1 MJ/liter. HHV for ethanol = 84,000 Btu/gallon = 89 MJ/gallon = 23.4 MJ/liter
  - ethanol density (average) = 0.79 g/ml (= metric tonnes/m^3)
- Metric tonne **biodiesel** = 37.8 GJ (33.3 - 35.7 MJ/liter)
  - biodiesel density (average) = 0.88 g/ml (= metric tonnes/m^3)

Fossil fuels

- **Barrel of oil** equivalent (boe) = approx. 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. "Petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 liters); about 7.2 barrels oil are equivalent to one tonne of oil (metric) = 42-45 GJ.
- **Gasoline:** US gallon = 115,000 Btu = 121 MJ = 32 MJ/liter (LHV). HHV = 125,000 Btu/gallon = 132 MJ/gallon = 35 MJ/liter
  - Metric tonne gasoline = 8.53 barrels = 1356 liter = 43.5 GJ/t (LHV); 47.3 GJ/t (HHV)
  - gasoline density (average) = 0.73 g/ml (= metric tonnes/m^3)
- **Petro-diesel** = 130,500 Btu/gallon (36.4 MJ/liter or 42.8 GJ/t)
  - petro-diesel density (average) = 0.84 g/ml (= metric tonnes/m^3)
- Note that the energy content (heating value) of petroleum products per unit mass is fairly constant, but their density differs significantly – hence the energy content of a liter, gallon, etc. varies between gasoline, diesel, kerosene.
- Metric tonne **coal** = 27-30 GJ (bituminous/anthracite); 15-19 GJ (lignite/sub-bituminous) (the above ranges are equivalent to 11,500-13,000 Btu/lb and 6,500-8,200 Btu/lb).
  - Note that the energy content (heating value) per unit mass varies greatly between different "ranks" of coal. "Typical" coal (rank not specified) usually means bituminous coal, the most common fuel for power plants (27 GJ/t).
- **Natural gas:** HHV = 1027 Btu/ft3 = 38.3 MJ/m^3; LHV = 930 Btu/ft3 = 34.6 MJ/m^3
  - Therm (used for natural gas, methane) = 100,000 Btu (= 105.5 MJ)

Carbon content of fossil fuels and bioenergy feedstocks

- **coal** (average) = 25.4 metric tonnes carbon per terajoule (TJ)
  - 1.0 metric tonne **coal** = 746 kg carbon
- **oil** (average) = 19.9 metric tonnes carbon / TJ
- 1.0 US gallon **gasoline** (0.833 Imperial gallon, 3.79 liter) = 2.42 kg carbon
- 1.0 US gallon **diesel/fuel oil** (0.833 Imperial gallon, 3.79 liter) = 2.77 kg carbon
- **natural gas (methane)** = 14.4 metric tonnes carbon / TJ
- 1.0 cubic meter **natural gas (methane)** = 0.49 kg carbon

- carbon content of **bioenergy feedstocks:** approx. 50% for woody crops or wood waste; approx. 45% for graminaceous (grass) crops or agricultural residues.