Efficient C sequestration and benefits of medicinal vetiver cropping in tropical regions

Munnu Singh, Neha Guleria, Eranki Prakasa Rao, Prashant Goswami

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RESEARCH ARTICLE

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Munnu Singh · Neha Guleria · Eranki V. S. Prakasa Rao · Prashant Goswami

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Abstract The increase of atmospheric CO_2 concentration is a major cause of global warming. This issue may be effectively addressed through sequestration of carbon in plants and soils. Here we studied the potential of vetiver, *Vetiveria zizanioides* L., to sequester carbon in field plots in Bangalore, India. Vetiver is a perennial and economically viable crop growing in tropical and subtropical regions. Vetiver has medicinal and aromatic properties. Vetiver shoot and root C amounts were measured. Results show that vetiver sequesters 15.24 Mg C ha^{-1} year^{-1} in shoot and roots, much higher than that for lemongrass with 5.38, palmarosa with 6.14, and trees with 2.92. In addition the benefit/cost ratio of vetiver, 2.3, is higher than that of rice, 1.97. We estimate that vetiver cropping could sequester 150 Tg per year in India, which is nearly 46 % of C emissions in India.

Keywords Plant systems · Carbon sequestration · Climate change · Global warming · Sustainability · Vetiver

1 Introduction

Rising levels of CO_2 leading to global warming have triggered a search for methods to control and possibly lower the levels of atmospheric carbon; such controls, especially till new carbon-friendly technologies are developed and implemented, could be critical for sustainability. Plant systems provide efficient solutions, and among various methods, sequestration of carbon in biomass and soil has been proposed to be a potential solution (Smith 2008). Soil C sequestration is expected to account for about 90 % of the total global mitigation potential available in agriculture by 2030 (Smith et al. 2008). While there has been considerable interest in carbon sequestration through iron fertilization in the oceans, which helps the growth of algae which in turn fixes atmospheric CO_2, there are concerns regarding feasibility and ecological impacts (Strong et al. 2009). Although land-based carbon capture and storage (CCS), where CO_2 is captured and stored underground in rock formations, has been suggested, the future of such measures is still debated due to the high cost (Noorden 2010). Thus, forest and agricultural lands may play a key role in the overall strategy in carbon sequestration.

A host of processes and measures for C sequestration on land have been proposed. Essentially, they involve soil restoration and woodland regeneration; farming practices: no-till farming, cover crops, improved grazing, etc.; nutrient management: manuring, sludge application, etc.; water management: conservation and harvesting, efficient irrigation, etc.; and land management: agroforestry, energy crops on spare lands, etc. (Lal 2004). Conversion of arable agriculture to perennial plants (trees, grasses, shrubs) also contributes to C sequestration; for example, conversion to permanent grasses increased soil organic carbon to 18 t ha^{-1} (Powlson et al. 2011).

It is, however, important to carefully identify the plant/crop for land-based C sequestration. Success with land-based C sequestration also critically depends on avoiding conflict between economic interest and long-term environmental concerns.

M. Singh · N. Guleria
Research Centre, CIMAP (Central Institute of Medicinal and Aromatic Plants), Bangalore 560 065, India

E. V. S. Prakasa Rao (✉) · P. Goswami
CSIR Centre for Mathematical Modelling and Computer Simulation, Bangalore 560 037, India
e-mail: evsprakasarao@gmail.com

E. V. S. Prakasa Rao
e-mail: evsprao@cmmacs.ernet.in

At the same time, some earlier estimates of the potential of land-based carbon sequestration need closer examination for possible revision.

The present study examines the effectiveness of a perennial aromatic grass, vetiver (*Vetiveria zizanioides*), for its sustainable C sequestration potential since it produces high biomass and can be fitted in the existing cropping and agroforestry systems (Fig. 1). Vetiver grows in tropical and subtropical parts of the world, in a wide range of climatic and soil conditions; its wide adaptability and multiple uses make it an ideal candidate for C sequestration. Vetiver, as a potential candidate for C sequestration, has been suggested before (Lavania and Lavania 2009); however, a quantitative analysis supported by field data has been missing, although some recent attempts indicate the C sequestration potential of vetiver (Taranet et al. 2011). Further, assessment of a crop for C sequestration needs to be done with reference to the regional parameters. In the present work, field studies have been conducted to estimate biomass production and C sequestered by vetiver in a semiarid tropical region in south India. Along with vetiver, two other aromatic grasses were also planted for comparative evaluation: lemongrass (*Cymbopogon flexuosus*) and palmarosa (*Cymbopogon martinii* var. *motia*), both economically important aromatic grasses (Prakasa Rao 2007).

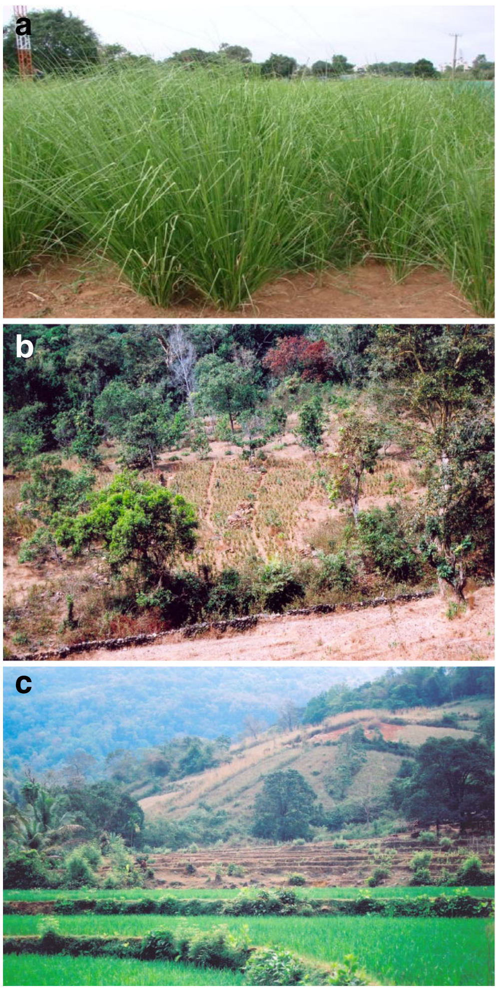

Fig. 1 **a** A field view of the vetiver plantation at CSIR CIMAP, Bangalore, India. Vetiver is a perennial grass which grows in tropical and subtropical parts of the world. This grass grows in a wide range of climatic and soil conditions and at different temperatures (−15 to >55 °C), soil pH (<3 to >10), and annual rainfall (<300 to >5,000 mm), is tolerant to salinity and prolonged waterlogged conditions, and is resistant to pests and diseases. **b** Vetiver plantation in interspaces of a social forestry system in the western Ghats region of south India. Such sites provide non-obstructive, eco-friendly implementation of vetiver plantation for carbon sequestration. **c** Vetiver cultivation near forests on hill slopes (rice cultivation in the foreground) in the western Ghats area of south India. Vetiver has been incorporated in the existing cropping systems of this region for both economic and environmental benefits

2 Materials and methods

2.1 Field site and soil characteristics

The field studies have been conducted during 2010–2011 at the Central Institute of Medicinal and Aromatic Plants, Research Centre, Bangalore, India, a constituent laboratory of the Council of Scientific and Industrial Research, India (CSIR). The field site (Bangalore) is located at an altitude of 930 m, at 12° 59′ N, 77° 35′ E; its climate is semiarid tropical with mean annual temperature of 24^{0}C and mean annual precipitation of 924 mm. The soil is a red sandy loam, classified as *Kandiustalfs*, with pH 6.15, E.C. 0.09, organic carbon ranging from 0.37 to 0.69 %, available nitrogen 195 kg ha^{-1}, Olsen's available P 12.5 kg ha^{-1}, and exchangeable K 109 kg ha^{-1}.

2.2 Agronomic procedure

Adjacent field plots measuring 200 m^2 were used for the three crops. Standard agronomic practices were followed in cultivation of these crops (Patra et al. 2004; Prakasa Rao 2007). Five sample plants were harvested at random periodically, at 15-day intervals, up to 360 days to study biomass accumulation pattern and for carbon analysis. Finally, the crops were harvested as one harvest of vetiver after 1 year, two harvests of lemongrass (8 and 12 months after planting), and four harvests of palmarosa (3, 6, 9, and 12 months after planting) along with roots, and the total biomass yields were estimated based on harvests taken from 7.29 m^2 plots each.

2.3 Plant harvest

Though vetiver, lemongrass, and palmarosa are perennial in nature, periodic harvesting of lemongrass (two to three cuts per year) and palmarosa (three to four cuts per year) is done for economic reasons, which restricts biomass accumulation and C sequestration unlike in vetiver where the harvest can be taken after 1 year.

2.4 Experimental design, processing, and analysis

Shoot and root biomass were recorded, and total values are presented. The samples of shoot and root were dried in an oven (at 80 °C) to constant weight to derive dry matter production. The dried samples were ground to pass through a 0.2-mm mesh and were analyzed for carbon content (Walkley and Black 1934). Carbon accumulated in shoots and roots were derived from the values of C concentration and dry matter. Fresh herb (lemongrass and palmarosa) and fresh roots (vetiver) were distilled in a Clevenger-type apparatus (Langenau 1948) to estimate essential oil content. Essential oil yields were calculated based on essential oil concentration (percent) and fresh herb/root biomass yields. The field study was conducted in a randomized block design with three replications, and the data were subjected to analysis of variance. Estimation of the significance of difference between means was based on probability of $P<0.05$, and critical difference values are presented in the figures.

Herbs, after extraction of essential oil in the case of lemongrass and palmarosa and harvested shoots in the case of vetiver, were converted to vermicompost following standard methods (Puttanna and Prakasa Rao 2003). Conversion ratio of the dry herb residue and vetiver shoot biomass to vermicompost, 40 %, and organic C in the compost, 26 % C, was used to arrive at C recycled into soil when applied. Soil samples at two depths, 0–15 and 15–30 cm, were collected from vetiver plots at the end of the study period. Organic C in the soil samples was estimated (Walkley and Black 1934). C sequestered in the soil was calculated separately for both the depths, and total C sequestered was presented. The economics of vetiver, lemongrass, and palmarosa cultivation and benefit–cost ratios for their oil production were calculated.

Spread of root is measured as the approximately circular horizontal spread when the root mass is placed on a smooth horizontal surface with the tip of the stem touching the surface.

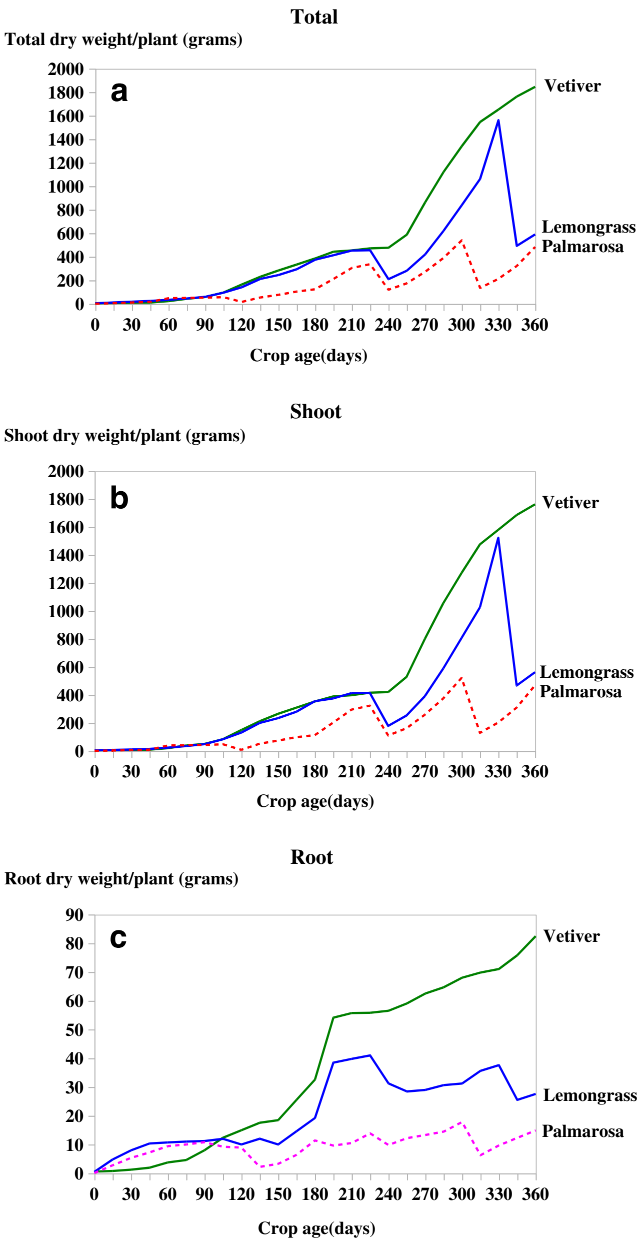

Fig. 2 Growth curves for three aromatic grasses: vetiver, lemongrass, and palmarosa during a crop cycle of 360 days, starting September 2010, for accumulation of dry matter (**a**) total, (**b**) in shoot, (**c**) in root. Each *curve* represents the average of five plants harvested at the specified time from randomly selected field points. **a** CD at 0.5 % (crop)=17.87 and CD at 0.5 % (crop × interval)=89.35. **b** CD at 0.5 % (crop)=62.089 and CD at 0.5 % (crop × interval)=310.445. **c** CD at 0.5 % (crop)=6.623 and CD at 0.5 % (crop × interval)=33.114

2.5 Preparation of carbon balance sheet in the cultivation and distillation of aromatic grasses

Distillation of the aromatic grasses for the extraction of essential oils requires 6.75 tons of firewood which contains 56.1 % organic carbon for approximately 30 tons of fresh herbage. Therefore, it is estimated that $6.75\times56.1/100=3.78$ tons of organic carbon is produced during distillation process in lemongrass and palmarosa and 2.8 tons in the case of vetiver roots.

Separate field plots of vetiver were maintained in the experimental area to study soil organic carbon (SOC) for

Table 1 Comparative carbon content (percent), dry matter production, and C sequestration by three aromatic grasses

Crop	Carbon (%)		Dry matter ($Mg\ ha^{-1}\ year^{-1}$)		C sequestered ($Mg\ ha^{-1}\ year^{-1}$)		
	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

Table 2 C sequestration in biomass and in soil by some trees, arable cropping systems, and three aromatic grasses including vetiver

Vegetation type	Mean C sequestration in biomass (Mg ha^{-1} $year^{-1}$)	Mean C sequestration in soil (Mg ha^{-1} $year^{-1}$)
Trees (Kaul et al. 2010; Jana et al. 2009)	2.92	1.90
Arable cropping systems (Kukal et al. 2009; Witt et al. 2000; Santos et al. 2011)	6.31	0.32
Vetiver	15.24	5.75
Lemongrass	5.38	3.08
Palmarosa	6.14	2.79

Table 4 C sequestration in soil by vetiver in different soil layers of a 5-year growth period (the control case represents normal cultivated plots not cropped with vetiver)

Time period (years)	C sequestration in soil (Mg ha^{-1} $year^{-1}$)		
	0–15 cm	15–30 cm	Total
1.5	1.60 (0.80)	0.68 (0.68)	2.28
4	1.74 (0.99)	1.33 (0.85)	3.07
5	3.31 (1.39)	2.44 (1.12)	5.75
control	– (0.70)	– (0.64)	

Figures in parentheses are soil organic carbon (percent)

periods of up to 5 years. Also, vetiver plantations in the western Ghat region of south India were studied to assess the feasibility of vetiver cultivation in forest areas and along with existing cropping systems.

3 Results and discussion

A comparison of shoot and root biomass of the three grasses has shown that vetiver possesses higher potential than lemongrass and palmarosa to absorb CO_2 (Fig. 2). Particularly, vetiver has higher root biomass which makes it a larger reservoir of carbon. The spread of roots at the end of 8 months was 1,848, 1,170, and 925 cm^2 in vetiver, lemongrass, and palmarosa, respectively. 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 is an indication of its potential for higher C sequestration rates. Total C sequestered in shoots and roots was higher in vetiver than in lemongrass and palmarosa (Table 1).

Comparative evaluation of different plant systems for carbon sequestration has shown that vetiver possesses higher C sequestration capacity than the other systems such as common food crops and trees in various parts of India and elsewhere (Table 2).

A major concern in implementation of a land-based carbon sequestration system in agriculture-dependent countries is economic consideration (Smith 2008), and the potential of biological C sequestration can be effectively realized if small-scale and distributed activities which provide returns to farmers from various sources can be harnessed (Lehmann 2009). Vetiver can provide alternate sources of income from its essential oil and from its use in handicrafts, traditional medicine, and compost (Prakasa Rao et al. 2008). The economic returns from vetiver can be higher than many conventional options (Table 3); further, vetiver can be grown in areas not suitable for conventional food crops (Fig. 1b, c). Vetiver can be incorporated in agro- and social forestry systems and in degraded lands. Recycling of vetiver residues can be adopted by such measures as their conversion to vermicompost; our field estimates have shown that 18 Mg vermicompost from vetiver can be produced which added 4.7 Mg C ha^{-1}.

The soil planted with vetiver in another long-term field study has shown soil organic C of 1.39 % in 0–15 cm depth and 1.12 % in 15–30 cm depth compared to 0.70 and 0.64 %, respectively, in the cultivated soil at the end of 5 years (Table 4). These results are encouraging when compared to other studies where land management, grazing land management, and restoration of organic soil and degraded lands sequestered 0.3 to 0.8 t C ha^{-1} $year^{-1}$ (Smith et al. 2008)

Table 3 Comparative economics of production of three aromatic plants and rice

Crop	Fresh biomass (Mg ha^{-1} $year^{-1}$)	Essential oil (%)	Benefit cost ratio	Organic carbon produced during distillation (Mg ha^{-1} $year^{-1}$)	Net carbon sequestered (Mg ha^{-1} $year^{-1}$)
Vetiver	4.25 (roots)	0.8	2.3	2.8	12.44
Lemongrass	27.7	0.8	1.97	3.78	1.6
Palmarosa	30	0.5	2.75	3.78	2.36
Rice (Chengappa et al. 2003)	–	–	1.97		

and increases of SOC from 0.1–0.2 to 1.1 % in tropical ecosystems (Lal 2004).

Our estimates show that if 10 % of estimated 107.83 m ha of degraded lands in India are put to vetiver systems, nearly 150 Tg C $year^{-1}$ can be sequestered which is about 46 % of total C emissions in India. Many other countries such as China (Xia 2003), Brazil (Pereira 2011), and the USA (Truong 2000) have large land areas where vetiver can be cultivated with potential contribution to mitigation. Our studies have shown that vetiver systems have a large potential to sequester C and at the same time provide sustainable solution for livelihoods of farmers.

4 Conclusion

We examined a plant system, the vetiver system, in the field to evaluate its C sequestration potential. It has been found that the vetiver system has high potential to sequester carbon in its shoot and root biomass, and the values are higher than many arable crops, trees, and other perennial aromatic grasses such as lemongrass and palmarosa. Besides C sequestration, vetiver provides sustainable solutions as economic returns to farmers and soil conservation.

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