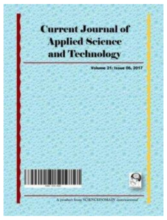

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Standardizing Row Spacing of Vetiver for River Bank Stabilization of Lower Ganges

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Authors' contributions

This work was carried out in collaboration between all authors. Authors KG and SS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors KB and SS managed the analyses of the study. Authors KB and SP managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To find out the feasibility of Vetiver grass in different row-spacing with special reference to soil erosion control, impact on soil fertility and water conservation at the erosion-prone barren banks of the Bhagirathi River in Nadia district of West Bengal.
Methodology: The experimental treatments comprised of five different spacing arrangements (90, 75, 60, 45 and 30 cm) for Vetiver rows. For recording biometric observations plant height, number of tillers/plant and root length vetiver plants were taken accordingly (January 2017 to May 2017). Physico-chemical changes of experimental soil, water holding capacity, surface-runoff and soil conservation efficiency of each month were measured during the brief period of experimentation.
Results: The study revealed that Vetiver has significant role in stabilization of erosion-prone river bank. Growing of Vetiver with indigenous nutrient supply of soil resulted in depletion soil fertility status initially. Planting of Vetiver with closer row spacing (30 cm) proved to be significant for quick stabilization of river bank, but as a long-term measure, wider row spacing (75 cm) is advocated for optimum growth and biomass production of this perennial grass.

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Conclusion: From the present study it may be concluded that Vetiver has significant role to play in stabilization of erosion-prone river bank of lower Ganges. An initiative may be taken to promote Vetiver cultivation along the embankment of the river Ganges as a natural and cost-effective bio-engineering tool.

Keywords: Vetiver; spacing arrangement; soil and water conservation; nutrient status; river embankment.

1. INTRODUCTION

Soil stabilization is one of the major challenges in agricultural production in many parts of the world, especially in developing nations like India where land degradation and soil erosion has become common threat to human lives and vegetation. The detachment of soil particles from the landmass and the transportation of the loosened material elsewhere, perhaps one of the most terrifying threats, are confronting mankind today [1]. During the last 40 years, nearly one-third of the world's arable land has been eroded and the loss continues at a rate of more than 10 million hectares per year [2,3]. Soil degradation in India is a pervasive problem and likely to be increased bit-by-bit if a preventive and remedial measure is not taken. According to the India Government's harmonized database, 120.7 M ha of land is degraded, 70% of which is due to water erosion [4]. Degradation of agricultural land by soil erosion leads to loss of nutrient affluent surface soil, increased runoff from the more impermeable subsoil and decreased water availability to the plants. In present times, excessive soil erosion with the resultant accelerated rate of sedimentation in the reservoirs and decreased soil fertility has become a crucial environmental issue with disastrous economic consequences.

The commonly used physical measurements for soil and water conservation (soil and stone bunds), agronomic practices (minimum tillage, grass strips and agro-forestry techniques) and water harvesting technologies (tied ridges and check dam construction) were usually adopted to check soil erosion [5], but these practices are less adopted mainly for high-cost involvement and lack of skilled manpower. Practically, at the farmers level cheap, sustainable and technically feasible measure should be adopted for curbing down such erosion and degradation. Amongst the available technologies, *Vetiver* system is a very simple, practical, inexpensive, hardy and effective biological measure for soil and water conservation. From its very introduction by the World Bank in 1980s *Vetiver* grass (*Vetiveria zizanoides* L.*)*, as a bio-soil and water conservation method gained popularity and at present, almost 120 counties of the world are adopting and practicing it [6]. Scientific studies conducted worldwide for last 15 years have clearly revealed that the *vetiver* system has a wide array of applications mainly due to its unique morphological, physiological and ecological characteristics helping in adaptation to wide range of climate and soil conditions [7]. The Ganges, also Ganga, being a trans-boundary river of Asia stretches along 2525 km through India and Bangladesh. It is the third largest river in the world by discharge. Virtually, it is a lifeline to millions of Indians living along its course and depends largely on it for their daily needs. The Ganges basin of West Bengal consists of a wide range of soil types; some are highly erosion-prone. The river bank erosion not only allows the Ganges to grasp the dwelling and agricultural land along its both sides but also increases the siltation of this very river along with other rivers being connected with it. All such problems create the disastrous menace like flood. Since the agro-climatic conditions of West Bengal are favourable for Vetiver cultivation, Vetiver System Technology (VST) being a natural, green, feasible and cost effective solution, maybe a potential innovative viable approach for conserving soil and water as an alternative of hard engineering measures. Although, application of VST in controlling soil erosion and conserving water is an established tool; but to the best of the knowledge, no detailed studies have yet been conducted to investigate the effect of VST in river bank erosion prone areas of West Bengal. Therefore, the objective of the present study is to examine different row spacing of vetiver grass with reference to control of soil erosion, impact on soil fertility and water conservation aspects at the erosion-prone barren banks of the Bhagirathi River in Nadia district of West Bengal.

2. MATERIAL AND METHODS

2.1 Study Area

The field experiment was conducted on the erosion-prone barren river banks (medium sloppy land) of the Bhagirathi River at Bethuadahari, Nadia, West Bengal, India (23.4° N latitude and 88.5° E longitude, 14.0 meters above mean sea level). The soil is of sandy clay loam (27.4 % sand, 44.6% silt and 28.0% clay according to Hydrometer method) in texture with the following key properties for the 0−30 cm layer: pH 7.10 (in 1:2.5:: Soil: Water), organic carbon 0.65 % (Wet oxidation method), available N 0.045% (Hot alkaline KMnO4 Method), available P_2O_5 45 kg/ha (0.5 M $NaHCO_3$ extract), available K_2O 243.3 kg/ha (Neutral N NH_4OAc extract). A typical sub-tropical climate prevails in the experimental site. The average temperature of experimental period ranges from 17- 31°C. May and June were the hottest months with the mean maximum temperature ranging from 37°C, while the minimum, dropped down to as low as 9.4°C during January. During the period of experimentation the average relative humidity ranged from 92% - 65%. The annual precipitation of this experimental period was 1250.8 mm in the year 2017, about 80% of which was precipitated during the four months monsoon period (June to September).

2.2 Experimental Treatments and Measurements

The experimental treatments comprised of five different row spacing (90, 75, 60, 45 and 30 cm) for vetiver grass along with a barren bank (as control). The experimental design was randomized complete block with three replicates. Individual plot size for each treatment was 5.0 m × 4.0 m. The vetiver cultivar used in this experiment was a South Indian cultivar namely 'VS-9' (popularly known as *Vetiver System-9*). It is suitable for erosion control since it possesses thicker stem, less branching roots, high root biomass and oil yielder. Depending upon the location and management practices, the average life cycle of this cultivar is around 9 to 11 months. Since the experiment was performed at the barren-river bank, no preparatory tillage was given. Light planking was done to make smooth and levelled surface for planting vetiver slips. The disease-free rooted slips of vetiver were planted in the last week of December, 2016 with appropriate row spacing according to the treatments. A plant to plant distance of 15 cm was maintained irrespective of the treatments. A pre-sowing light irrigation was applied for easy establishment of slips. Three need-based irrigations were also given for proper growth and development of the crops. The first and second weed control was done manually with hand-held hoe at 30 and 60 DAP for good establishment of the crop. The vetiver was grown under complete inherent nutrient supply of the experimental soil. Any special plant protection measure was not taken as vetiver is almost free from any disease-pest incidence.

2.3 Plant Sampling and Biometric Observations

For recording observations on plant height, number of tillers/plant and root length, three vetiver plants were randomly selected from each plot and uprooted in the second week of each month and measurements were taken accordingly (January 2017 to May 2017).

2.4 Measurement of Physical and Chemical Properties of Soil

Physico-chemical changes of experimental soil (0-30 cm) were measured in each month of observations. Different physicochemical properties of these soil samples were determined by following the standard methods like bulk density as proposed by [8]; soil pH and organic carbon by [9]. Soil pH (soil: water :: 1:2.5) was measured at room temperature (25^{0}C) by using a direct reading conductivity meter (Model: Systronics, 363). Soil available N,P and K determined by following the methods of [10], [11] and [12], respectively. The water holding capacity (WHC) of the soil (0-30 cm) was measured with the help of Keen Rackzoskii's box as described by [13].

Total runoff was determined by analyzing the runoff hydrographs. After every rainfall event at 8.30 A.M. (IST), the runoff collected in silt collecting tanks was thoroughly mixed and immediately a representative sample was collected in bottles of 1000 ml capacity. Runoff so collected in sample bottle was taken and the silt was allowed to settle down. After draining the excess water, the soil was kept in the oven and dry weight (g) was taken. The soil loss was estimated in proportion with total runoff occurred rainfall event. From the individual event, the Soil Conservation Efficiency (SCE) in % was worked out using the following equation given by [14].

$$SCE\ (\%) = \frac{\begin{array}{c}Soil\ loss\ from\ control\ - \\ Soil\ loss\ from\ conservation\ measures\end{array}}{Soil\ loss\ from\ conservation\ measures} \times 100$$

The SCE (%) obtained from the individual event was summed to find out monthly SCE (%).

2.5 Statistical Analysis

The collected data were analyzed statistically by the analysis of variance (ANOVA) technique using the STAR Software version 2.0.1 (International Rice Research Institute, Philippines, 2013) at p=0.05. The Excel software (version 2007, Microsoft Inc., WA, USA) was used to draw graphs and figures.

3. RESULTS AND DISCUSSION

3.1 Growth Attributes of Vetiver

Significant variations were observed in different growth parameters of vetiver as influenced by variations in row spacing (Table 1). Throughout the entire period of experimentation, significantly higher plant height was recorded from the vetiver grass planted at wider row spacing than closer row spacing. Interestingly, plants sown at 90 cm row spacing produced taller plants than the other spacing options. The effects of plant density on plant height are very complex and depend on both environmental factors and plant architecture [15]. Generally plant height increases with increased plant population due to competition for light up to a certain point. On the other hand, increment in plant population due to closer spacing, may not increase, rather decrease plant height due to competition for water and nutrients but not light [16]. Similarly, in the present study, the plant height of Vetiver increased initially (January '17 – February' 17) with closer row spacing (30 cm) but at later stage vetiver planted with wider row spacing recorded higher plant height due to less intra-species competition for water and nutrients. But [17] found non-significant response of different spacing on plant height of Vetiver grown in Ibadan, Nigeria. In harmony to plant height, widely spaced Vetiver plants produced more number of tillers throughout the observation period (Table 1). The maximum number of tillers/plant was recorded from the Vetiver plants planted at 75 cm row to row spacing. Being a member of Poaceae family, Vetiver generally follows asymptotic response curve with increased plant density. As a result, when Vetiver planted at wider spacing, the production of tillers/plant also increased due to lack of appreciable competition for space, moisture, nutrient and light with neighbouring plants.

Root length of Vetiver increased as the age of the crop gradually progressed. Root length recorded at monthly interval was significantly (p=0.05) influenced by the different row spacing (Table 1). The grass planted at wider spacing produced longer root as compared to the closer spaced plants. The maximum root length throughout the observation period was recorded from the plants placed at 75 cm row spacing as compared to the other row spacing options. Wider row spacing helps to increase root length of vetiver due to lack of appreciable competition for space, moisture, nutrient and light with neighbouring plants [15].

3.2 Physico-chemical Changes of the Soil

The monthly variation in bulk density (BD) of the experimental soil as influenced by different row spacing of Vetiver is presented in Fig. 1A. The study revealed that irrespective of the row spacing, the BD values of experimental soil showed a constantly increasing trend as compared to the barren river bank. As Vetiver roots act as a good soil binding agent which resulted in better aggregation properties of the soil which ultimately helps to increase soil bulk density [18]. The lower value of bulk density in barren river bank soil may be attributed to decreased soil organic matter content brought due to the absence of a considerable amount of biomass which resulted in poor aggregation properties of the soil [19].

Planting of Vetiver grass has significantly changed soil pH as compared to the barren river bank. The soil pH recorded from experimental plots was found to be improved by adoption of Vetiver planting at different row spacing (Fig. 1B). Amongst the various spacing arrangements, planting at closer row spacing (30 cm) was the most effective. The feasible reason behind the lower pH values of the control plots may be due to more soil loss from these untreated plots. This was also confirmed by [20], who found that the higher amount of soil loss due to erosion might have removed the topsoil and exposed the subsoil to the surface resulting in lower pH. The low pH reflected in the unprotected plot might also be due to extensive leaching of basic cations from the top fertile soil layer and rapid development of acidity [21].

The water holding capacity of soil influences the availability of essential plant nutrients and promotes the root activities [18]. The studies in this regard indicated that the monthly water holding capacity of soil was increased by planting

Table 1. Monthly variation in growth attributes of vetiver as influenced by deferment row spacing

Row spacing	Plant height (cm)					Number of tillers plant^{-1}					Root length (cm)				
	Jan '17	Feb '17	Mar '17	Apr '17	May '17	Jan '17	Feb '17	Mar '17	Apr '17	May '17	Jan '17	Feb '17	Mar '17	Apr '17	May '17
90 cm	10.80	13.40	20.40	26.50	41.70	1.0	1.0	3.0	4.0	6.0	13.65	14.10	26.75	44.18	56.30
75 cm	10.30	13.20	19.30	22.00	37.50	2.0	2.6	4.0	6.0	7.0	14.75	18.83	32.78	53.10	66.50
60 cm	9.10	13.90	17.10	23.00	32.10	2.0	2.0	4.0	6.0	6.0	11.33	15.23	28.60	29.33	35.05
45 cm	10.00	15.10	16.30	18.00	27.30	2.0	2.1	3.0	4.0	5.0	11.38	10.73	21.23	24.25	28.10
30 cm	11.50	15.30	16.90	16.30	24.80	2.0	2.4	3.0	5.0	5.0	8.05	10.88	17.65	20.48	23.20
S.Em (±)	0.07	0.08	0.10	0.11	0.13	0.17	0.17	0.21	0.40	0.46	0.62	0.85	1.14	1.26	1.22
$LSD_{0.05}$	0.19	0.22	0.27	0.30	0.36	0.49	0.49	0.60	1.17	1.29	1.93	2.64	3.56	3.93	3.79

of Vetiver grass in barren river bank (Fig. 1C). Amongst the different treatments, the maximum increment of the water holding capacity was observed in plots where Vetiver was planted at 75 cm row spacing and it was followed by 90 cm row spacing. A strong positive correlation (R^2 = 0.61) was found between root length of Vetiver and water holding capacity of soil as clearly expressed in Fig. 2; where from it is evident that higher root length of Vetiver not only improves soil structure, soil aeration as well as chemical and biological environment of soil but also water holding capacity of it.

3.3 Soil and Water Conservation Potentiality

To measure Soil and Water Conservation potentiality of Vetiver grass, monthly runoff and Soil Conservation Efficiency (%) was worked out. A perusal of the results indicates that the minimum surface runoff and maximum Soil Conservation Efficiency (%) were recorded in the plots where Vetiver was planted at closer row spacing (30 cm) (Fig. 3A and 3B). It might be due to higher planting density which effectively resists the surface flow of rainwater than widely spaced Vetiver rows. Related observations regarding the effectiveness of Vetiver grass over Bahia grass and Daylily in controlling the soil runoff were also reported by [22]. [23] also reported that vetiver plantation can conserve soil and water to an extent of 42.4% and 53.7% respectively over without conservation measures. A positive correlation (R^2 = 0.40) was found between Plant height of Vetiver and Soil conservation efficiency as clearly expressed in Fig. 4; where from it is evident that higher plant height of Vetiver helps to improve Soil conservation efficiency of river embankment.

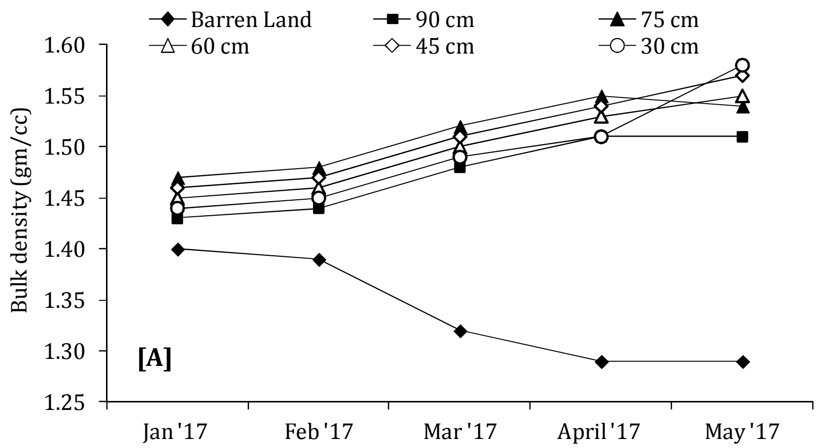
3.4 Fertility Status of Soil

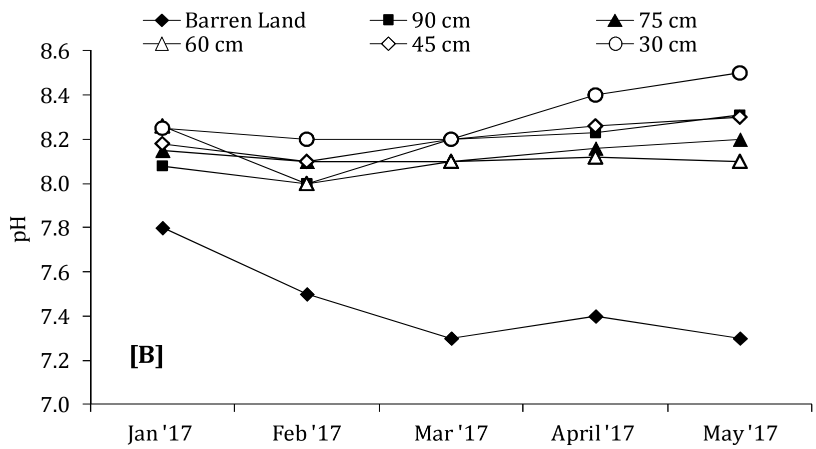
In the present study, as compared to the barren river bank, planting of Vetiver grass at different row spacing significantly affected soil fertility status (organic carbon and available NPK) of experimental soil.

The monthly variation in Soil Organic Carbon (SOC) content of experimental soil is presented in Fig. 5A. The maximum improvement of SOC was observed in the plots where Vetiver was planted at the closest row spacing (30 cm), whereas, the maximum depletion of SOC was observed in barren river bank. The results of the study are in conformity with the findings of [24] who observed increased organic carbon content with vegetative grass cover than the barren land. The depletion of SOC from barren river bank could probably be due to the removal of top soil layer through or accelerated oxidation reaction. Loss of organic carbon is known to affect several soil properties including deterioration in soil structure, low water content and accelerated runoff which ultimately resulted in soil erosion [25].

Growing of vetiver grass under complete inherent nutrient supply of soil significantly reduced soil available nitrogen content (%) of the experimental soil as compared to the barren river bank where available nitrogen content was more or less constant throughout the period of observation (Fig. 5B). Vetiver is a high nitrogen responsive crop and it can remove up to 740 kg N/ha within ten months [26,27]. [28] also reported from Philippines that Vetiver growth can be increased with the level of N supply up to 6000 kg/ha/year. As the present experiment was conducted in the erosion prone slopes of river bank, basal application of inorganic nitrogenous fertilizer would not be a feasible option due to chance of leaching. Thus at initial period of establishment, application of organic sources of nitrogen or bio-fertilizer may be adopted not only for optimum growth of Vetiver but also to maintain fertility status of the soil.

The study revealed that different row spacing of Vetiver had significant impact on available phosphorus (P) content of the river bank soil (Fig. 5C). The maximum depletion of available soil P throughout the observation period was recorded from the soil of widely spaced (90 cm) Vetiver plantation, whereas, that soil P content of barren river bank soil remained almost constant. Widely spaced vetiver produced larger root system due to less intra-species competitions which probably remove higher amount of soluble P from their root zone. [29] confirmed that the low levels of available P might be due to the constant removal of soluble P by the plants from the root zone. [27] also reported that vetiver crop could remove up to 110 kg P/ha within three months from a nutrient rich field. Amongst different row spacing options, relatively higher amount of available soil P was recorded in the plots having 30 cm Vetiver row spacing. It may probably be due to its high amount of organic carbon content as discussed earlier. According to [30], organic anions of various sources can reduce P-fixation by forming stable complexes with iron and aluminum ions of the soil.





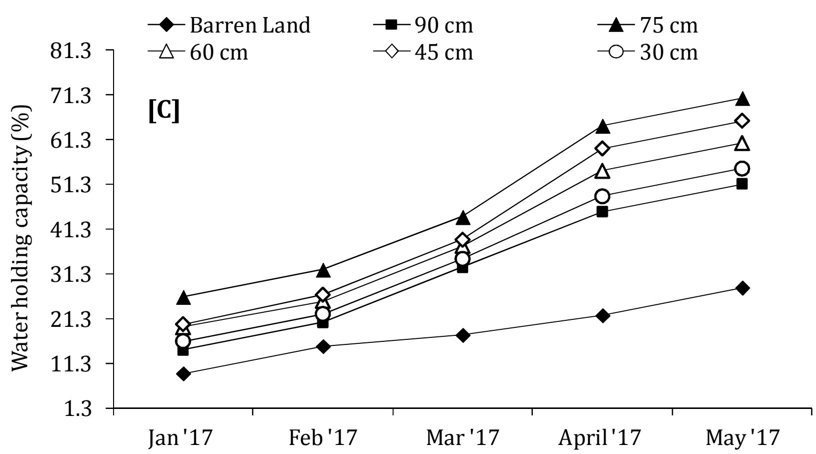


Fig. 1(A-C). Phyico-chemical properties of experimental soil as influenced by vetiver sown at different row spacing

Fig. 5D reveals that growing of vetiver in river bank with inherent nutrient supply is disadvantageous for the available potassium (K) contents of soil. A considerable depletion of available soil K towards the maturity of the Vetiver was observed, whereas, available K content at barren river bank soil remains comparatively at constant state. Such trend of

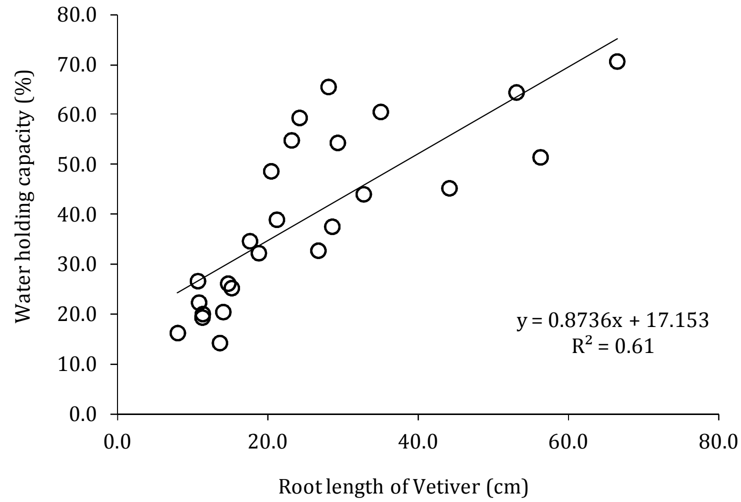
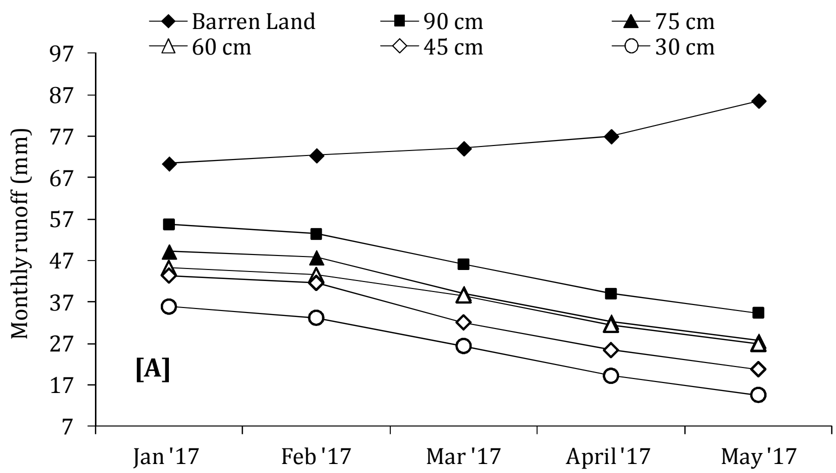


Fig. 2. Relationship between root length of vetiver and water holding capacity of soil



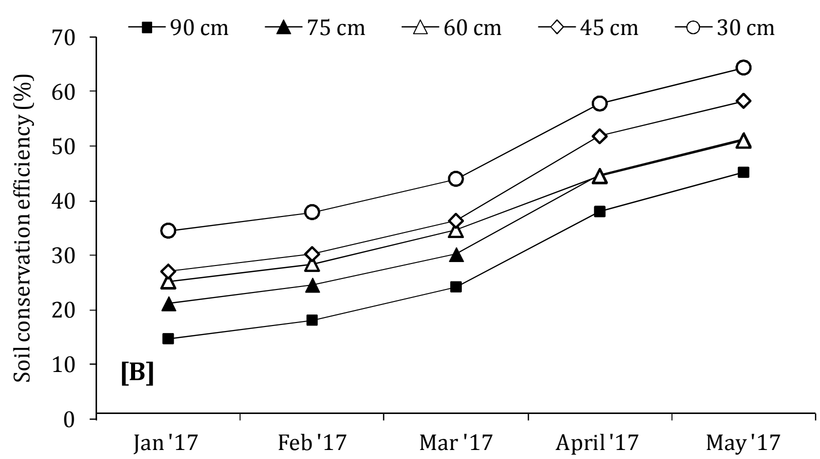


Fig. 3. Effect of row spacing of vetiver on (a) monthly runoff (mm) and (b) soil conservation efficiency (%)

gradual depletion of soil available K from Vetiver planted plot is found due to high K demanding nature of Poaceaeous plants. According to [31] cereals can remove upto 47% exchangeable and solution K as compared to the shallow rooted vegetables.

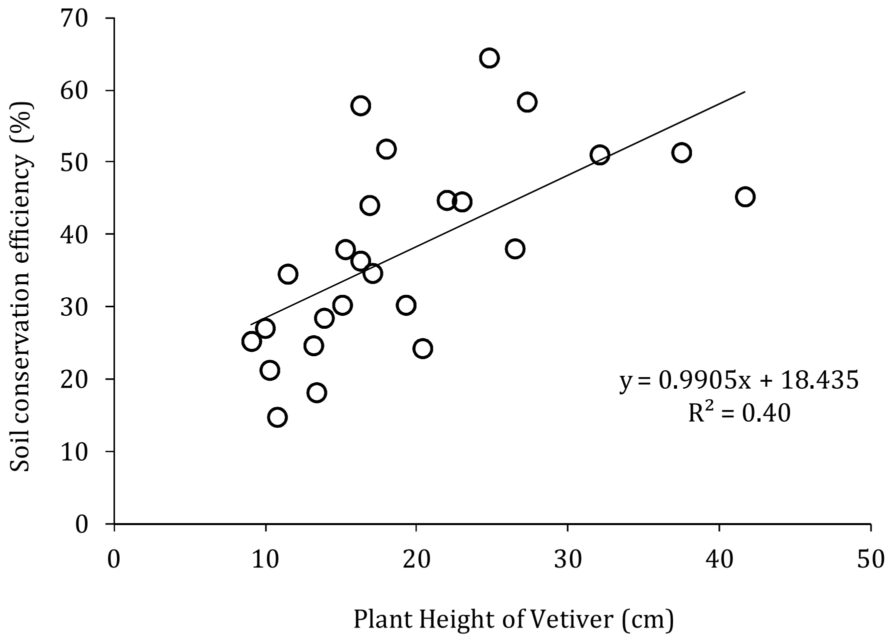


Fig. 4. Relationship between plant height of vetiver and soil conservation efficiency

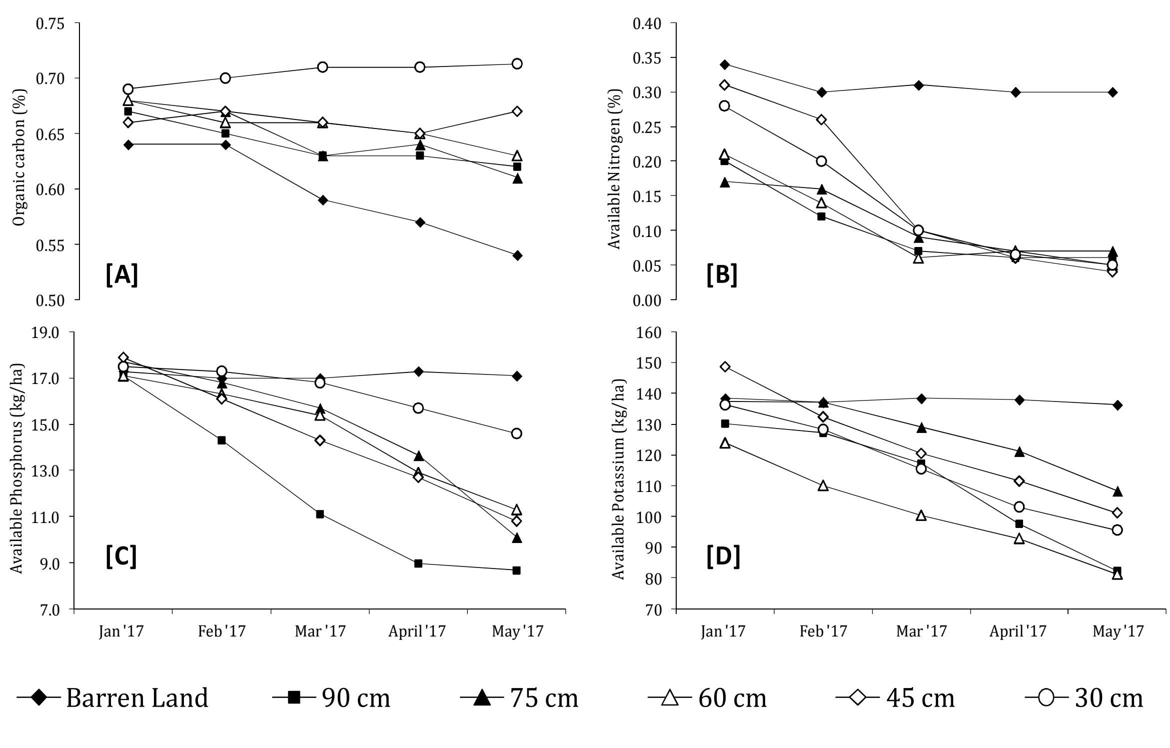
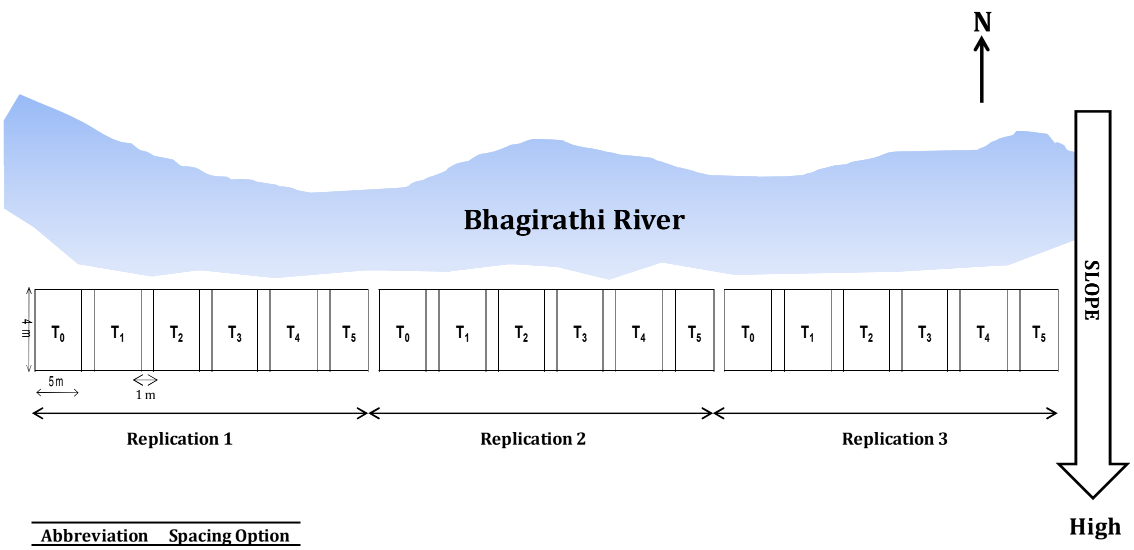


Fig. 5 [A-D]. Effect of row spacing of Vetiver on nutrient status of soil

Planting of vetiver in the river bank of the Ganges in different row spacing



Abbreviation	Spacing Option
T_0	Barren Land
T_1	90 cm
T_2	75 cm
T_3	60 cm
T_4	45 cm
T_5	30 cm

Layout of the experiment

4. CONCLUSION

The Ganges basin of West Bengal consists of a wide range of soil types; some are highly erosion-prone and increase in river siltation leads to disastrous flood and pollution load. Since the agro-climatic conditions of West Bengal are favourable for *Vetiver* cultivation, Vetiver System

Technology may be a potential innovative approach for conserving soil and water as an alternative to hard engineering measures. From the present study it may be concluded that Vetiver has significant role to perform for stabilization of erosion-prone river bank of lower Ganges. Initial study also suggested that growing of Vetiver with inherent nutrient supply of soil may deplete soil fertility status, but as long run, soil fertility may be increased owing to deposition of organic matter and recycling of nutrients. Planting of Vetiver with closer row spacing (30 cm) may initially be recommended for quick stabilization of river bank, but as a long-term measure, wider row spacing (75 cm) is suitable for optimum plant/root growth as well as bio-mass production of Vetiver. Considering all these findings Government initiative may be taken to promote *Vetiver* cultivation along the embankment of the river Ganges as a natural and cost-effective bio-engineering tool.

CONSENT

All authors declare that 'written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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