

Standardizing row spacing of vetiver for river bank stabilization of lower Ganges

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.

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 zizanioides* L.), as a bio-soil and water conservation method gained popularity and at present, almost 120 countries 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 P₂O₅ 45 kg/ha (0.5 M NaHCO₃ extract), available K₂O 243.3 kg/ha (Neutral N NH₄OAc 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°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 Rackzowski'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].

$$SCE (\%) = \frac{\text{Soil loss from control} - \text{Soil loss from conservation measures}}{\text{Soil loss from conservation measures}} \times 100$$

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

125 2.5 Statistical analysis

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

130 3. RESULTS AND DISCUSSION

131

132 3.1 Growth attributes of Vetiver

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

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

161 3.2 Physico-chemical changes of the soil

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

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

180 The water holding capacity of soil influences the availability of essential plant
181 nutrients and promotes the root activities [18]. The studies in this regard indicated that the
182 monthly water holding capacity of soil was increased by planting of Vetiver grass in barren
183 river bank (Fig. 1C). Amongst the different treatments, the maximum increment of the water
184 holding capacity was observed in plots where Vetiver was planted at 75 cm row spacing and
185 it was followed by 90 cm row spacing. A strong positive correlation ($R^2 = 0.61$) was found
186 between root length of Vetiver and water holding capacity of soil as clearly expressed in Fig.
187 2; where from it is evident that higher root length of Vetiver not only improves soil structure,
188 soil aeration as well as chemical and biological environment of soil but also water holding
189 capacity of it.

190 **3.3 Soil and Water Conservation potentiality**

191 To measure Soil and Water Conservation potentiality of Vetiver grass, monthly runoff and
192 Soil Conservation Efficiency (%) was worked out. A perusal of the results indicates that the
193 minimum surface runoff and maximum Soil Conservation Efficiency (%) were recorded in the
194 plots where Vetiver was planted at closer row spacing (30 cm) (Fig. 3A and 3B). It might be
195 due to higher planting density which effectively resists the surface flow of rainwater than
196 widely spaced Vetiver **rows**. Related observations regarding the effectiveness of Vetiver
197 grass over Bahia grass and Daylily in controlling the soil runoff were also reported by [22].
198 [23] also reported that vetiver plantation can conserve soil and water to an extent of 42.4%
199 and 53.7% respectively over without conservation measures. **A positive correlation ($R^2 =$**
200 **0.40) was found between Plant height of Vetiver and Soil conservation efficiency as clearly**
201 **expressed in Fig. 4; where from it is evident that higher plant height of Vetiver helps to**
202 **improve Soil conservation efficiency of river embankment.**

203 **3.4 Fertility status of soil**

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

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

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

227 The study revealed that different row spacing of Vetiver had significant impact on available
228 phosphorus (P) content of the river bank soil (Fig. 5C). The maximum depletion of available
229 soil P throughout the observation period was recorded from the soil of widely spaced (90 cm)
230 Vetiver plantation, whereas, that **soil P content** of barren river bank soil remained almost
231 constant. Widely spaced vetiver produced larger root system due to less intra-species
232 competitions which probably remove higher amount of soluble P from their root zone. [29]
233 confirmed that the low levels of available P might be due to the constant removal of soluble
234 P by the plants from the root zone. [27] also reported that vetiver crop could remove up to
235 110 kg P/ha within three months from a nutrient rich field. Amongst different row spacing
236 options, relatively higher amount of available soil P was recorded in the plots having 30 cm
237 Vetiver row spacing. It may probably be due to its high amount of organic carbon content as
238 discussed earlier. According to [30], organic anions of various sources can reduce P-fixation
239 by forming stable complexes with iron and aluminum ions of the soil.

240 Fig. 5D reveals that growing of vetiver in river bank with inherent nutrient supply is
241 disadvantageous-**for** the available potassium (K) contents of soil. A considerable depletion of
242 available soil K towards the maturity of the Vetiver was observed, whereas, available K
243 content at barren river bank soil remains comparatively at constant state. Such trend of
244 gradual depletion of soil available K from Vetiver planted plot is found due to high K
245 demanding nature of Poaceaeous plants. According to [31] cereals can remove upto 47%
246 exchangeable and solution K as compared to the shallow rooted vegetables.

247 **4. CONCLUSION**

248
249 The Ganges basin of West Bengal consists of a wide range of soil types; some are highly
250 erosion-prone and increase in river siltation leads to disastrous flood and pollution load.
251 Since the agro-climatic conditions of West Bengal are favourable for *Vetiver* cultivation,
252 Vetiver System Technology may be a potential innovative approach for conserving soil and
253 water as an alternative to hard engineering measures. From the present study it may be
254 concluded that Vetiver has significant role **to perform for stabilization** of erosion-prone river
255 bank of lower Ganges. **Initial study also suggested that growing of Vetiver with inherent**
256 **nutrient supply of soil may deplete soil fertility status, but as long run, soil fertility may be**
257 **increased owing to deposition of organic matter and recycling of nutrients.** Planting of Vetiver
258 with closer row spacing (30 cm) may initially be recommended for quick stabilization of river
259 bank, but as a long-term measure, wider row spacing (75 cm) is suitable for optimum
260 plant/root growth as well as bio-mass production of Vetiver. Considering all these findings
261 Government initiative may **be taken** to promote *Vetiver* cultivation along the embankment of
262 the river Ganges as a natural and cost-effective bio-engineering tool.

263 **COMPETING INTERESTS**

264

265 Authors have declared that no competing interests exist.

266

267

268 **CONSENT**

269 All authors declare that 'written informed consent was obtained from the patient (or other
270 approved parties) for publication of this case report and accompanying images. A copy of
271 the written consent is available for review by the Editorial office/Chief Editor/Editorial Board
272 members of this journal."
273

273

274 **REFERENCES**

275

276 1. Babalola O, Opara-Nadi OA. Tillage systems and soil properties in West Africa. Soil
277 and tillage research, 1993;27(1-4):149-174.

278 2. Liu GC, Tian GL, Shu DC, Lin SY, Liu SZ. Streamflow and soil moisture of
279 agroforestry and grass watersheds in hilly area. Pedosphere. 2004;14(2):263 -268.

280 3. Huang YL, Chen LD, Fu BJ, Zhang LP, Wang YL. Evapotranspiration and soil
281 moisture balance for vegetative restoration in a gully catchment on the Loess
282 Plateau, China. Pedosphere. 2005;15(4):509-17.

283 4. Saha SK. Water and Wind induced Soil Erosion Assessment and Monitoring Using
284 Remote Sensing and GIS. In: Satellite Remote Sensing and GIS Applications in
285 Agricultural Meteorology. 2003; pp. 315-330.

286 5. Shiferaw BA, Okello J, Reddy RV. Adoption and adaptation of natural resource
287 management innovations in smallholder agriculture: reflections on key lessons and
288 best practices. Environment, development and sustainability. 2009;11(3):601-19.

289 6. Truong T, Tan Van, Pinnars E. Vetiver Systems Application, Technical Reference
290 Manual. The Vetiver Network International. 2008; pp. 89.

291 7. Truong PN. Vetiver Grass Technology. In "Vetiveria", Chapter 6. p114-132. Ed.
292 Massimo Maffei. Taylor & Francis, London and New York, 2002.

293 8. Tan KH. Soil Sampling, Preparation, and Analysis. New York: Marcel Dekker, 1996.

294 9. Jackson ML. Soil chemical analysis. New Delhi, India: Prentice Hall India, 1967.

295 10. Subbiah BV, Asija GL. A rapid procedure for the determination of available nitrogen
296 in soils. Curr Sci. 1956;25:259-60.

297 11. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in
298 soils by extraction with sodium bicarbonate (USDA Circular 939). Washington, DC:
299 US Government Printing Office, 1954.

300 12. Brown AJ, Warncke D. Recommended cation tests and measures of cation
301 exchange capacity. In Recommended Chemical Soil Tests Procedures for the North
302 Central Region, ed. WC Dahnke, Bulletin No. 499 (Revised), 1988; North Dakota
303 Agricultural Experiment Station, Fargo, North Dakota. pp. 15–16.

- 304 13. Piper, Clarence Sherwood. Soil and plant analysis. Hans Publishers; Bombay, 1966.
- 305 14. Madhu M, Sikka AK, Tripathi KP, Ragupathy R, Singh DV. Contour staggered
306 trenching and cover crop for soil and water conservation in new tea plantation in
307 Nilgiris. Indian J. Soil Cons. 2001;29(1):1-6.
- 308 15. Soratto RP, Souza-Schlick GD, Fernandes AM, Zanotto MD, Crusciol CA. Narrow
309 row spacing and high plant population to short height castor genotypes in two
310 cropping seasons. Industrial Crops and Products. 2012;35(1):244-9.
- 311 16. Yellamanda Reddy T, Reddi S. Plant Population. In: Principles of Agronomy.
312 Kalyani, New Delhi, India. 182 p., 1995.
- 313 17. Jimba SC, Adediji AA. Effect of plant spacing in the nursery on the production of
314 planting materials for field establishment of Vetiver grass. Tropicultura.
315 2003;21(4):199-203.
- 316 18. Ghosh S, Sarkar S, Sau S, Karmakar S, Brahmachari K. Influence of Guava
317 (*Psidium guajava* L.) based Intercropping Systems on Soil Health and Productivity in
318 Alluvial Soil of West Bengal, India. Int. J. Curr. Microbiol. App. Sci. 2017;6(11):241-
319 51.
- 320 19. Maheswarappa HP, Hegde MR, Dhanapal R, Biddappa CC. Mixed farming in
321 coconut garden: Its impact on soil, physical and chemical properties, coconut
322 nutrition and yield. J. Plantation Crops. 1998;26:139-43.
- 323 20. Olu O. Long term effect of continuous cultivation of tropical ultisol in south western
324 Nigeria. In: Tilahun Tadios, Tesfa Bogale and D.C. Adjei-Twum (Eds.) The
325 influence of organic materials on the soil fertility of Melko/nitosol for grain maize.
326 *Proceeding of the Third conference of Ethiopia Society Soil Science (ESSS)*. pp.
327 207-215, 1996.
- 328 21. Agbenin JO, Goladi JT. Carbon, nitrogen and phosphorus dynamics under
329 continuous cultivation as influenced by farmyard manure and inorganic fertilizers in
330 the savanna of northern Nigeria. Agriculture, ecosystems & environment.
331 1997;63(1):17-24.
- 332 22. Cao L, Zhang Y, Lu H, Yuan J, Zhu Y, Liang Y. Grass hedge effects on controlling
333 soil loss from concentrated flow: a case study in the red soil region of China. Soil
334 and Tillage Research. 2015;148:97-105.
- 335 23. Donjadee S, Tingsanchali T. Soil and water conservation on steep slopes by
336 mulching using rice straw and vetiver grass clippings. Agriculture and Natural
337 Resources. 2016;50(1):75-79.
- 338 24. Quraishi S, Alam SM, Sinha AK. Study of the effect of different soil conservation
339 measures in the upland of Chotanagpur on physico-chemical properties of soil.
340 Journal of soil and water conservation in India. 1977;27:33-36.
- 341 25. Lal R. Soil erosion on alfisols in Western Nigeria. VI. Effects of erosion on
342 experimental plots. Geoderma 1981;25:215–230.

- 343 26. Danh LT, Truong P, Mammucari R, Tran T, Foster N. Vetiver grass, *Vetiveria*
344 *zizanioides*: a choice plant for phytoremediation of heavy metals and organic
345 wastes. *Int. J. Phytoremediation*. 2009;11(8):664-91.
- 346 27. Vieritz A, Truong P, Gardner T, Smeal C. Modelling Monto Vetiver Growth and
347 Nutrient for Effluent Irrigation Schemes. *Proc. Third Int. Vetiver Conf. (ICV-3)*
348 (October 6–9) Guangzhou, China, 2003.
- 349 28. Wagner S, Truong P, Vieritz A. Response of vetiver grass to extreme nitrogen and
350 phosphorus supply. *Proc. Third Int. Vetiver Conf. (ICV-3)* (October 6–9) Guangzhou,
351 China, 2003.
- 352 29. Smeck NE. Phosphorus: An indicator of pedogenetic weathering processes. *Soil*
353 *Science*. 1973;115(3):199-206.
- 354 30. Tisdale SL, Helson WL, Deaton JD. Soil fertility and fertilizer (4th ed). In: Bobe
355 Bedadi. Soil productivity evaluation under different soil conservation measures in the
356 Harerege highlands of Ethiopia. *Msc. Thesis*, 1990.
- 357 31. Baligar VC, Barber SA. Mechanism of K supply to plant roots characterized by K/Rb
358 rates. *Proceedings 11th International Soil Science Congress* 1978;1:309-315.

359 **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

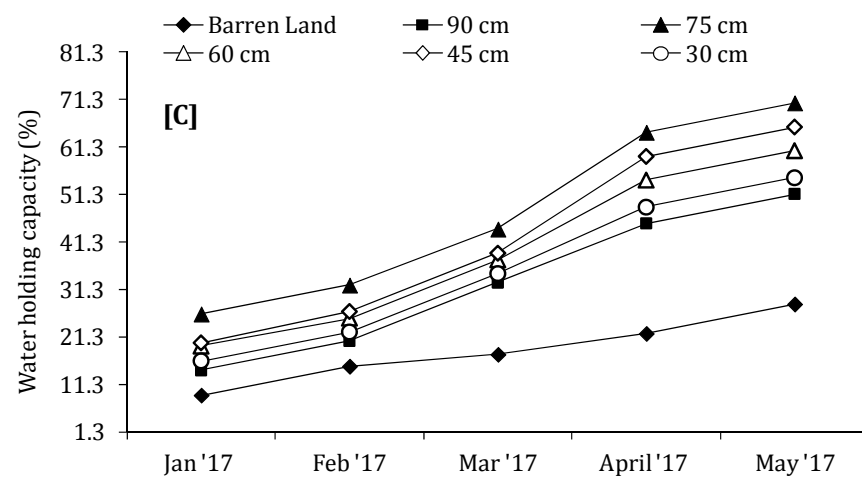
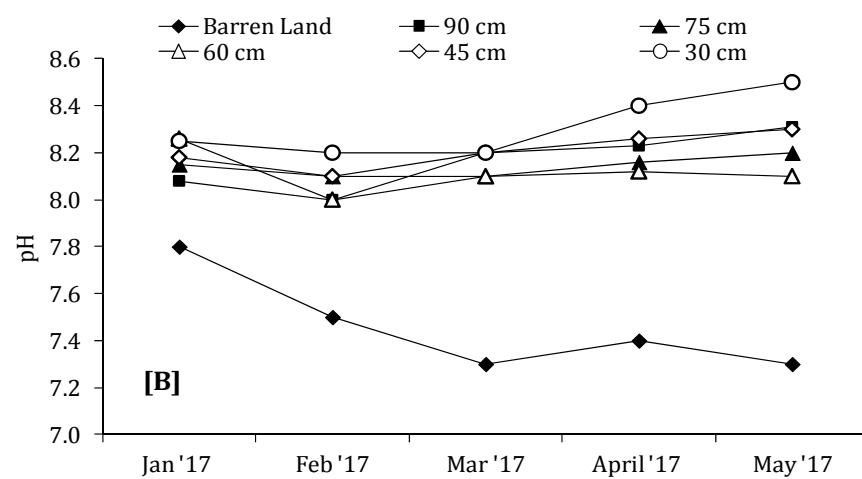
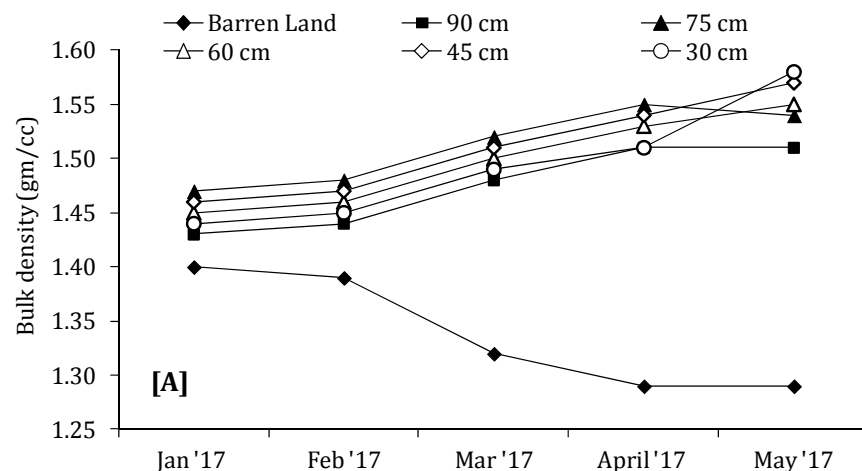


Fig. 1(A-C). Phyco-chemical properties of experimental soil as influenced by vetiver sown at different row spacing

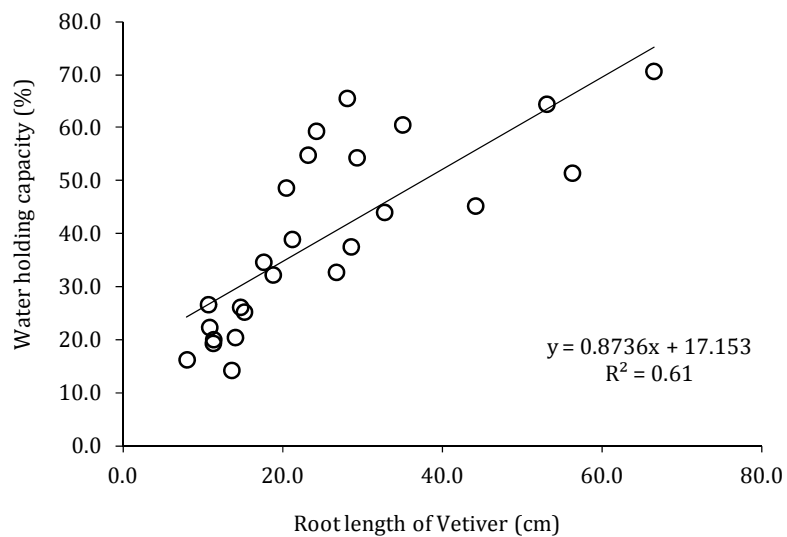


Fig. 2. Relationship between Root length of vetiver and water holding capacity of soil

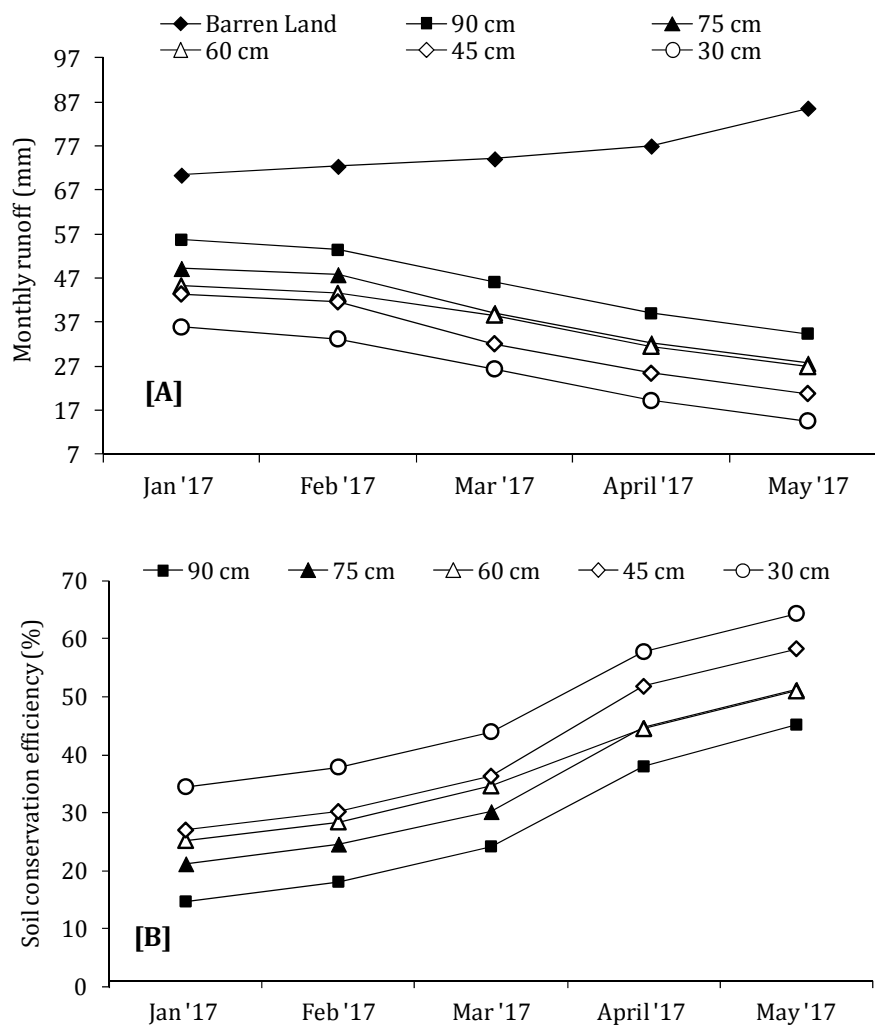


Fig. 3. Effect of row spacing of Vetiver on (a) Monthly runoff (mm) and (b) soil conservation efficiency (%)

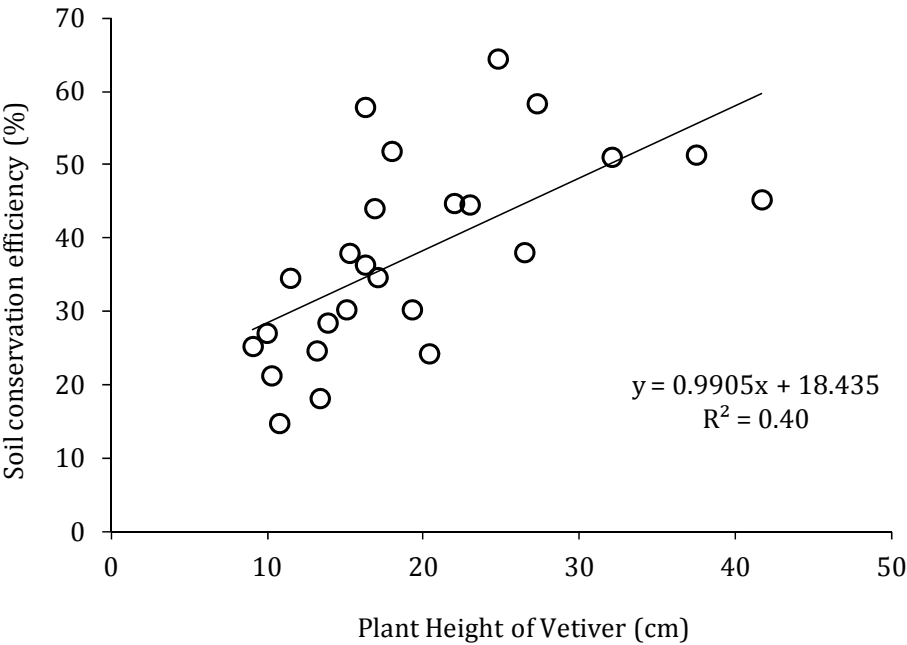


Fig. 4. Relationship between Plant height of vetiver and Soil conservation efficiency

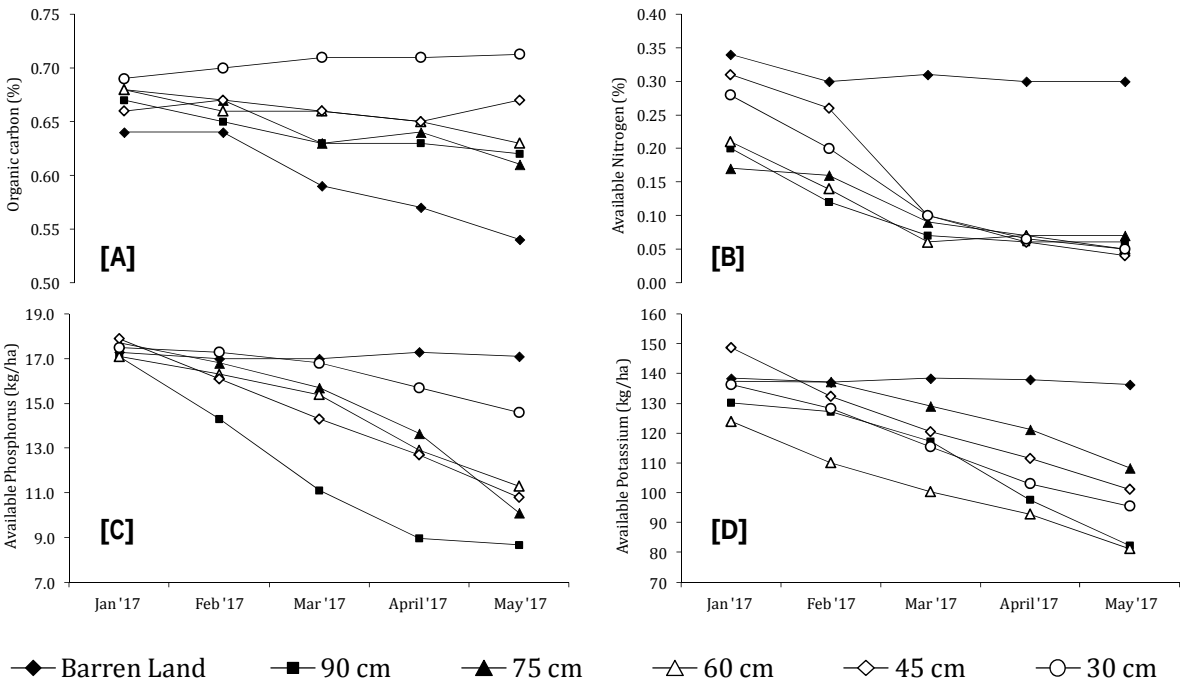
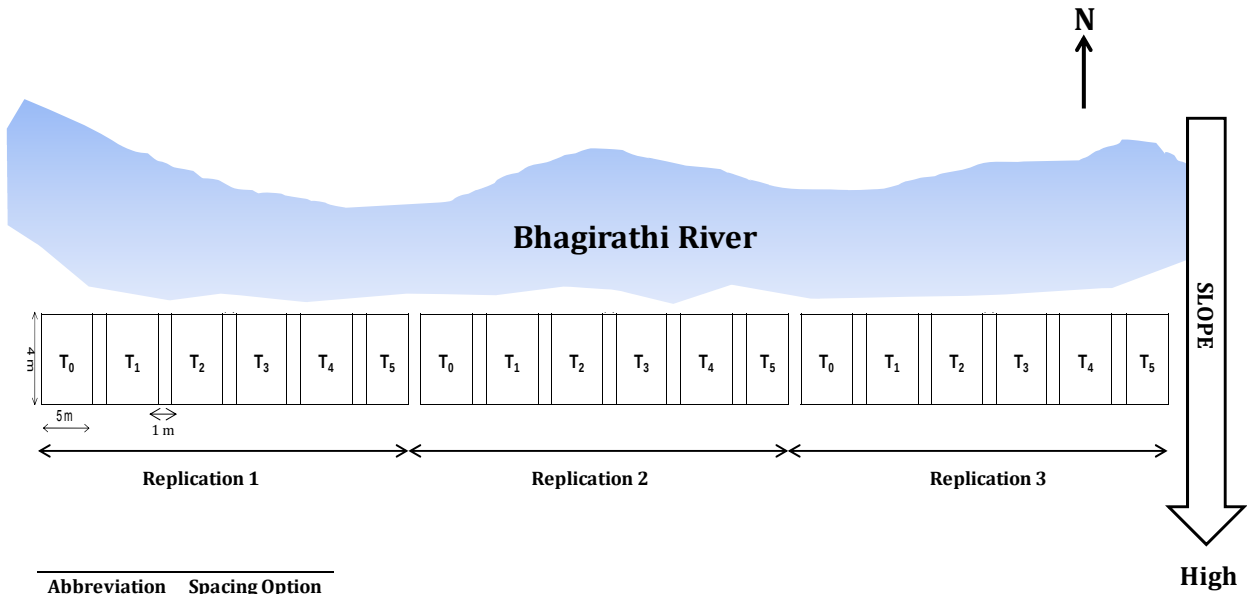


Fig. 5 [A-D]. Effect of row spacing of Vetiver on nutrient status of soil

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



Layout of the Experiment



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