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Vetiver system technology for river bank stabilisation

(Final Report of the project KFRI 619/2011)

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ABSTRACT OF THE PROJECT PROPOSAL

1. Project Number	:	KFRI 619/2011
2. Title of the Project	:	**Vetiver system technology for river bank stabilisation**
3. Objectives		1. To identify and characterize different ecotypes of vetiver. 2. To evaluate the efficiency of vetiver ecotypes in river bank stabilization 3. To organize training programmes for the benefit of end users
4. Date of commencement	:	July 2011
5. Duration	:	3 years
6. Funding agency	:	KFRI Plan Grants
7. Investigators	:	S. Sandeep R. Jayaraj T.K. Hrideek A.V. Raghu

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ABSTRACT

Stream bank erosion is a major problem in Kerala. Physical and vegetative methods are effectively used for stream bank stabilization. In vegetative methods, *Vetiveria zizanioides* is a widely accepted plant. The present project was undertaken to identify and characterize different ecotypes of vetiver, evaluate their efficiency in river bank stabilization and to impart training programmes for the benefit of end users.

A total of 15 vetiver accessions were collected from different research centers and private individuals. Correlation analysis and character associations of 12 morphometric characters of the collected vetiver accessions were done and their relationship derived. Plant height showed the highest factor loading followed by leaf breadth, root length, leaves per tiller and fresh root weight showing their higher contribution towards the variability of the population and their usability in breeding programmes as lead characters. In the collected accessions, phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) in all cases indicating polygenic background of characters and additive gene action.

Field experiments conducted at Field Research Centre of KFRI at Velupadam in Thrissur district showed that Periavura (vetiver accession) and ODV – 23 were the most promising in terms of growth parameters. Soil modifying parameters such as soil reaction, organic carbon content and mean weight diameter (MWD) did not differ between accessions. However, organic carbon (%) and water stable aggregates expressed as mean weight diameter were higher vetiver cropping.

Periavura accession had the lowest oil content in roots and ODV – 23 the highest. Thus, ODV – 23 though acceptable by growth standards its high oil content may tempt the planting community to harvest the crop thereby defeating the purpose of soil stabilization. Hence among the tested vetiver accessions, Periavura could be preferred for river bank stabilization.

1. INTRODUCTION

Vetiver (*Vetiveria zizanioides*) is a perennial grass species belonging to the family Gramineae. It has originated in India and Africa (Xia *et al*., 1998). This species has long been accepted worldwide for conserving soil and stabilizing slopes and stream banks. When planted in single rows, vetiver will form a hedge which, acts as a "flow-through" barrier against down slope sediment and water runoff, holding back most of the sediment (as much as 90%) to form natural terraces behind the hedge, reducing rainfall runoff (upto about 70%) and soil erosion, conserving soil moisture and trapping nutrients on site. The unique morphological and physiological characteristics make vetiver a preferred species for soil conservation. In addition, the extremely deep and massively thick root system of vetiver binds the soil and makes it very difficult for it to be dislodged by fat flowing water. The deep and fast growing root system also makes vetiver very drought tolerant and highly suitable for steep slope stabilization. The sediment retention by vetiver hedges also presents loss of nutrients and organic matter. Vetiver roots easily penetrate through hardpans facilitating ground water recharging. The efficiency of vetiver hedgerows improves with time as the plants grow denser. Hedgerows reduce sediment loss (and thus retain soil fertility) and reduce water velocity and prevent the lodging of crops (Rodriguez,1998; Singh. 2000; Shah *et al*. 2000; Welle *et al*. 2006; Donjadee *et al*. 2010).

Vetiver is an economically, pharmaceutically and ecologically important plant. Besides soil stabilization, roots of vetiver yield essential oil that is used as a basic material for perfumery and cosmetics (Maffei, 2002; Champagnet *et al*., 2006; Massardo *et al.,* 2006). It has strong ecological adaptability and resistance to drought, water logging, cold, heat, soil acidity and alkalinity. Apart from having a strong root system, vetiver is fast growing, easy to plant and high survival rate, and rarely turns into a weed, because of poor pollination and fertilization. Generally it propagates by producing new shoots at the joints above the soil surface and by branching at the joints below soil. The seeds are very thin and have a short dormancy period. As in the case of other crops, most of the agronomical characters are quantitative in nature in this species also. Such characters show interrelationship due to sharing of alleles. Polygeneic characters show association between them and factor analysis is a very efficient tool used to find out character association and to group the variables into different groups and also to effect data reduction by identifying the lead variables of each group (Raghu *et al.*, 2007; Nikhila *et al.,* 2008; Hrideek *et al.,* 2008; Umamaheswari and Mohanan, 2011).

Vetiver ecotypes differ in growth pattern especially rooting depth, root strength, oil content and morphology. In the past, the utilization of the vetiver grass was limited to the extraction of the fragrant oil from the root (Cheng, 1998; Cheng and Li, 1998). Recently, it is increasingly used worldwide in soil conservation and stream bank stabilization. Certain ecotypes of vetiver have roots that do not normally go beyond a meter depth while there are others that extend their roots to depth greater than two meters. The tensile strength of roots also varies between ecotypes and this is reflected in their stream bank stabilization capacity. This project intends to assist the local self-government institutions (LSGIs) and other implementing agencies in utilizing vetiver for stream bank stabilization by providing guidance and support from selection of ecotypes to technical aspects in implementation. The specific objectives of the project are given below.

Objectives:

1. To identify and characterize different ecotypes of vetiver

2. To evaluate the efficiency of vetiver ecotypes in river bank stabilization

3. To organize training programmes for the benefit of end users

REVIEW OF LITERATURE

Soil erosion by water is one of the major causes of land degradation in Kerala since most of the land is sloping and the rainfall is of highly erosive. But the interception of rain by natural vegetation helps reduce the flow of raindrops and velocity of flowing water facilitating infiltration of water into the soil. Disturbance to the natural multi-storeyed protective vegetation disrupts the balance and accelerates soil erosion necessitating adoption of conservation practices. Among the conservation practices, vegetative measures are preferred over mechanical ones. Among the vegetative practices, establishing grass strips along the contours is the often recommended practice (Rodriguez, 1998; Shah, 2000; Singh, 2000; Suyamto and Howler, 2004; Tscherning *et al.,* 1995).

Basics of erosion control are to reduce detachment of soil and transportation capacity of the eroding agents (water and wind) through different agronomic and vegetative measures generally known as conservative measures (Amatya and Shrestha, 2002). The functions of the root system are engineering (anchorage, armour, catch, reinforcement and drain) and physiological (storage, conduction, and absorption). The fibrous root system of the grasses, consisting of several main roots that branch to form a dense mass of intermeshed lateral roots has an armouring function apart from providing anchorage; catch, reinforcement and drain (if planted accordingly) are other engineering functions of grasses (Rost *et al.,* 1979).

Semipermeable vegetative barriers slowdown soil and water movement downslope and terraces may form naturally over time. The Sloping Agricultural Land Technology System (SALTS) is a complete conservation production system in which hedgerows act as the frame work, between which crops are grown (Critchley *et al.*, 2004). Grass hedges of *Pennisetum alopecuroide* and *Arundinella hirta* were tried on sloping croplands in Northern China. Pennisetum hedges reduced soil loss by 84% and overland flow by 68% while Arundinella hedges reduced soil loss and overland flow by 55% and 38% respectively (Xiao *et al.,* 2010). Effectiveness of grass strips on 9% cultivated slopes in northern part of Somali region of Ethiopia revealed significant reduction in runoff and soil loss compared to control. Lowest runoff and soil loss was recorded from vetiver grass (Welle *et al.,* 2006). Narrow strips of vetiver (*Vetiveria zizanioides*) and napier grass (*Pennisetum purpureum*) reduced runoff by an average of 54 and 12% respectively from a clay loam soil in Kenya (Owino *et al.,* 2006). Rodriguez (1998) compared the efficiency of vetiver, lily, fern and lemongrass with mulching in Venezuela by providing simulated rainfall of 55.6 mm/hr on 15 and 26% slopes and reported that hedge rows of vetiver and fern and mulch were good conservers of soil. Vegetative barriers of vetiver, gautemala grass, fern, african lily and lemon grass were compared for their efficiency in conserving soil on 15-20% slopes using erosion plots of 10m x 1m size on an Aquic Paleudult soil of Venezuela. Ten year old vetiver was found to be the most efficient species in reducing soil, nutrients, organic matter and water losses (Andrade and Rodriguez, 2002).

Experiments in the degraded hills of the Eastern Ghats of India by Susama (2008) with sambuta (Saccharum spp.) and vetiver (*Vetiveria zizanioides*) revealed that sambuta and vetiver barriers on 11% slope reduced runoff and soil loss by 63.4 and 68.6% respectively over control plots with runoff 25.9% and soil loss 14.0 t /ha. Sambuta barriers resulted in increased yield of finger millet (*Eleusine coracana*) and enhanced organic carbon accumulation and available potassium in the soil. Overall performance was highest in the case of sambuta. Vetiver barriers were found effective in conserving soil and water in many countries of the world (Susama *et al*., 2008; Madhu *et al.,* 2011; Xiao Bo *et al.*, 2010; Owino *et al.,* 2006; Critchley *et al.,* 2004; Mane *et al.*, 2009; Nwachokor and Bergsma, 2011; Poudel *et al.,* 2000; Suyatmo and Howeler, 2004; Tscherning *et al.,* 1995; Andrade and Rodriguez, 2002). *Vetiveria zizanioides* with strong roots and a rooting depth of upto 5m has been identified by the World Bank as the most promising green technology against erosion(Mengozzi, 2001).

The root dynamics is difficult to investigate due to continuous extension during the growing season (Etherington, 1976). The majority of roots, especially the small absorbing roots, are located in the upper soil horizons where favourable aeration, nutrients, and moisture conditions prevail (Spur and Barnes, 1980). The amount of soil erosion is influenced not only by the soil itself, but by the treatment or management it receives. Experience has shown that vegetation-based soil erosion control measures need to be adapted to the sites and to the needs of the people. No one recipe can be applied as blanket recommendation for all environments.

Vetiver has always been the choice species among different vegetative barriers and hence no alternative species were tried in its place for the purpose (Andrade and Rodriguez, 2002; Mane *et al*., 2009; Nwachokor, 2011; Poudel *et al.,* 2000). The present project was undertaken to identify and characterize different ecotypes of vetiver, evaluate their efficiency in river bank stabilization and to impart training programmes for the benefit of end users.

3. MATERIALS AND METHODS

Vetiver collection

Vetiver ecotypes were collected from different geographical locations and research centres in Kerala.

Variability among vetiver accessions

Selection of appropriate genotypes based on characters that show good heritability and genetic advance is a very important tool in crop improvement since selection could not be carried out based on all characters. Also study of interrelationship of characters is essential to identify the variables which show maximum relationship with others.

The growth analysis experiments for the variability among collected vetiver accessions and initial screening for field experiments were conducted at Kerala Forest Research Institute, Peechi, Thrissur during 2011- 2013. The study area was located at an altitude of 80 m above MSL at 10^{0} 31' 51.4" N latitude and 07^{0} 20' 47.58" E longitude and it enjoyed humid tropical climate. Vetiver accessions collected from different sources were raised and observed critically. The experiment was laid out in randomized block design with three replications and 12 plants per plot. Observations on twelve growth characters were recorded for three consecutive seasons and analyzed. Morphological characters like plant height (cm), number of tillers, tiller girth, leaves per tiller, leaf length (cm), leaf breadth (cm), root length (cm), number of roots per tiller, fresh weight of shoot (gm), fresh weight of root (gm), dry weight of shoot (gm) and dry weight of root (gm) were recorded.

Mean, standard deviation and critical difference (CD) were calculated in the case of the 12 characters studied. Analysis of variance (ANOVA) was carried out to test the significance of variations between the accessions. Test of significance was done with reference to standard F table (Fisher and Yates, 1963). Phenotypic and genotypic variance, coefficients of variation, heritability (broad sense) and genetic advance were also calculated to find out the variation among the cultivars. Phenotypic and genotypic variances for the different characters studied were estimated using the formula given below (Singh and Choudhary, 1985).

$$\text{Genotypic variance } (\sigma^2 g) = \frac{\text{MSS for treatment - MSS for error}}{\text{Number of replications}}$$

Phenotypic variance ($\sigma^2 p$) = $\sigma^2 g + \sigma^2 e$ where $\sigma^2 e$ is error variance.

Phenotypic and genotypic coefficients of variation were estimated following Burton and Devane (1953).

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\sigma g \times 100}{\dot{x}}$$

$$\text{Phenotypic coefficient of variation (PCV)} = \frac{\sigma p \times 100}{\dot{x}}$$

where σg = genotypic standard deviation, σp = the phenotypic standard deviation and = $\dot{x}$ grand mean for the character.

Heritability (broad sense) is the fraction of the total variance that is heritable and is estimated as the percentage of genotypic variance over phenotypic variance (Jain, 1982).

$$H^2 = \frac{\sigma^2 g \times 100}{\sigma^2 p}$$

Genetic advance under selection was calculated using the following formula proposed by Abraham (2000).

$$GA = \frac{KH^2 \sigma p}{\dot{x}}$$

where H^2 = heritability in the broad sense; σ p = phenotypic standard deviation; K = selection differential which is 2.06 at 5% intensity of selection in large samples (Allard, 1960); ẋ = grand mean of the character.

The fourteen genotypes studied above have been subjected to cluster analysis using the software STATISTICA, following UPGMA procedure (Unweighted Pair Group Mathematical Average procedure) (Sneath and Sokal, 1973) to find out the affinities between them, based on growth, yield and quality characters.

Biometric study of characters of the genotypes were used to analyze character association in the vetiver accessions. Correlation of the morphological characters were done using the procedures outlined by Rangaswamy (1995). Factor analysis by way of principal component analysis was carried out for the purpose with the help of the software STATISTICA (Sneath and Sokal, 1973).

Field experiments

The experiment was carried out in a stream bank at the Field Research Centre of the Institute situated at Velupadam in Thrissur district. The land is undulating with moderate to steep slopes. Vetiver species for the field experiment was selected based on the observations from growth trials for assessing variability among vetiver accessions (discussed above). Out of the 12 morphometric observations, only the accessions which had atleast 50 % of the observed morphometric characters above average were used for the field experiments. Accordingly, six promising varieties were selected for the field experiments:

Sl. No.	Accession name
1	ODV-4
2	ODV-20
3	ODV-26
4	ODV-23
5	Periavura
6	Madapalli

The slips of selected accessions were planted along the stream banks in strips extending upto the stream edge with 6 lines and a spacing of 30 cm x 30 cm. Three strips representing replications were randomly allocated for each accession. A 50 cm space was provided between two strips to avoid interferences. The growth characters such as shoot length, number of tillers and root length were recorded at the end of the experiment by destructive sampling. Soil samples were also collected and analyzed.

In the experimental strips, soil texture was determined by hydrometer method, bulk density by core sampling, particle density by standard flask method, water holding capacity by saturation and drainage of unsieved soil and porosity by calculation

Porosity = (1- Bulk density/Particle density) x100

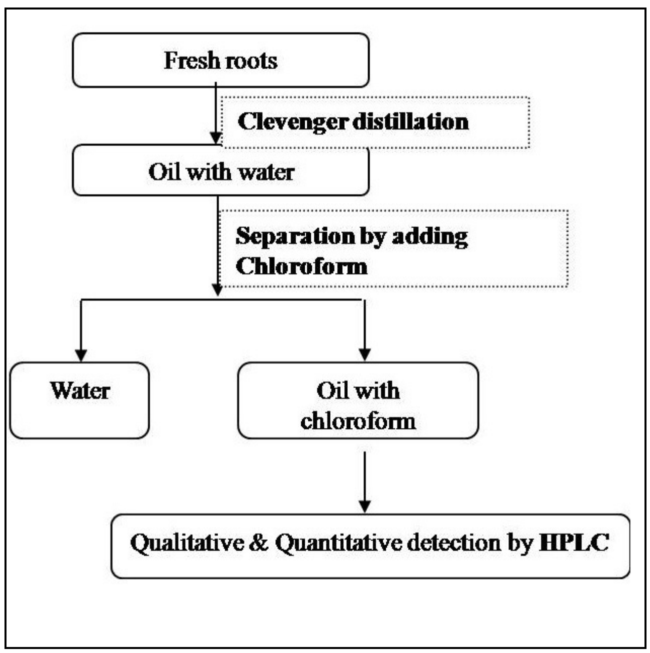
pH was measured in a 1:2.5 soil : water suspension, exchangeable bases by 0.1N HCl method and organic carbon by Walkley and Black(1934) method. Aggregate fractions were determined by wet sieving using a Yoder type sieve shaker with a set of sieves of size BSS 4, 9, 16 and 25. Mean weight diameter (MWD) an index of aggregate stability was calculated using the formula,

$$\mathbf{MWD} = \sum_{j=1}^{k} W_j \bar{X}_j$$

where, MWD = mean-weight diameter, (mm); $\bar{X}_j$ = arithmetic mean diameter of the j-1 and *j* sieve openings (mm); *Wj* = proportion of the total sample weight (uncorrected for sand and gravel) occurring in the fraction (dimensionless); and *k* = total number of size fractions.

Oil content in the roots of field planted vetiver accessions were analyzed at the end of the experiment using Clevenger distillation. As vetiver plants are harvested for their roots, accessions with high root growth and low oil content was used as a criterion to identify the best accession for soil stabilization. Clevenger distillation is a special type of separation process in which the material to be extracted is immersed in water, followed by boiling. Temperature sensitive materials like oils, resins, hydrocarbons, etc. which is insoluble in water will decompose at their boiling point. Steam distillation helps to overcome this and enables a compound or mixture of compounds to be distilled at a temperature substantially below that of the boiling point(s) of the individual constituent(s). Essential oil contains components with boiling points up to 200°C or higher. In the presence of steam or boiling water, however, these substances are volatilized at a temperature close to 100°C (at atmospheric pressure). In the Clevenger distillation vapours of the volatile components are carried by the steam to a condenser in which two layers - oil-rich and water-rich layers - are formed on condensation. The oil layer was separated from the water rich layer by decantation.

Flow chart for the production of Vetiver oil from roots



HPLC analysis

Oil with chloroform was analyzed in HPLC (shimadzu LC-8A) equipped with a PDA detector (shimadzu M10A VP). The C-18 column 250x4.6 mm dimension and 5 µm particle size was used for analysis. A mixture of methanol and water (7:3) at a flow rate 1 ml/min was used as the binary gradient mobile phase for the analysis. The separation was done at ambient temperature. A calibration graph of vetiver oil was plotted by injecting 10, 20, 40, 60 and 80 ppm of vetiver oil in chloroform at a detector wavelength of 215 nm. The samples were delivered via 20µl injection loop using a 25µl capacity Hamilton micro liter syringe. A run time of 30 minutes was given for each run. Shimadzu class =VP software (Chromatography Data system) on PC was used for integration and computation of signals. The HPLC was stabilized for half an hour before the injection.

4. RESULTS AND DISCUSSION

Vetiver collection

Vetiver accessions were collected from research stations as well as private individuals. However, only those accessions which had an established identity were used for the study. As such 15 accessions were collected as detailed in Table 1. Out of the 15 accessions, ODV -9 is a commercial vetiver variety with high essential oil content and was developed and popularized by Aromatic and Medicinal Plants Research Station, Kerala Agricultural University, Odakkali. Root being the economic part in vetiver, plant types with high root oil content will encourage their harvest thus defeating the purpose of soil protection. Hence this accession was not used for further studies.

Table 1: List of vetiver accessions collected from various sources

Sl.No.	Plant name	Collected from
1	ODV-4	AMPRS, Odakkali; KDHP, Munnar; Private individuals
2	ODV-5	KDHP, Munnar; KDHP, Munnar
3	ODV-8	AMPRS, Odakkali
4	ODV-9	AMPRS, Odakkali; KDHP, Munnar; Private individuals
5	ODV-16	AMPRS, Odakkali
6	ODV-18	AMPRS, Odakkali
7	ODV-20	KDHP, Munnar
8	ODV-23	KDHP, Munnar
9	ODV-24	AMPRS, Odakkali
10	ODV-26	AMPRS, Odakkali
11	ODV-27	AMPRS, Odakkali
12	ODV-30	AMPRS, Odakkali
13	Madapalli	KDHP, Munnar
14	Periavura	KDHP, Munnar
15	Pandimedu	KDHP, Munnar
AMPRS - Aromatic and Medicinal Plants Research Station, Kerala Agricultural University, Odakkali; KDHP - Kanan Devan Hills Plantations Company Private Limited, Munnar		

Growth analysis of vetiver accessions

All the 12 characters studied showed statistically significant variation indicating the genetic difference between accessions (Table 2). Among the 14 accessions plant height varied from 81cm to 121.33 cm; tillers varied from 6.7 to 22; tiller girth showed the range between 0.6 to 0.8; leaves per tiller ranged between 4.5 to 6.6, leaf length varied from 50.0 to 87.5; leaf breadth from 0.5 to 0.8 cm; root length from 38.3 to 124.7 cm; roots per tiller varied from 10- 51; fresh weight of shoot between 6.5 to 20.1 gm, fresh weight of root ranged between 4.0 to 21.8 gm; dry weight of shoot from 3.5 to 8.2 gm and dry weight of root varied from 3.1 to 7.4 gm.

Phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) in all cases indicating polygenic background of characters and additive gene action. All the characters under study showed high percentage of heritability (H^2). Genetic Advance (GA) was also comparatively high in most of the cases (Table 3). Among the characters, highest GCV (217.79) and PCV (225.12) were shown by number of roots per tiller. Differential variability of quantitative characters has been reported by earlier workers in cardamom (Radhakrishnan *et al.*, 2006), coffee (Nikhila *et al.,* 2002; Raghu *et al.*, 2003) and medicinal plants (Misra *et al.*, 1998; Jayasree *et al.,* 2006). Study of variability of the genetic resources of a crop is the first step towards understanding the genetic diversity of genetic stock so as to use them in crop improvement programmes. Highest heritability (broad sense) was shown by root length (96.24 cm). Most of the agronomic characters of plants are polygenic and vetiver is no exemption. Polygenic characters show different levels of heritability based on their response to environmental factors. Highest heritability of characters indicates the limited influence of environment on these characters. Genetic advance of characters in percentage of mean is a very effective indicator of the characters that could be utilized in selection programmes. It is a measure derived from heritability. Statistically significant characters analyzed for the present study showed genetic advance ranging from 14.31 % to 75.18%. Dry weight of root gave the highest genetic advance.

The statistically significant variability observed between different genotypes of a species can be grouped into different clusters of genetically closer accessions based on genetic divergence studies. Cluster analysis indicated the genetic identity of most of the accessions under study. ODV 4, ODV 16, ODV 20 and ODV 26 formed distinct cluster at linkage distance one were

analysed based on the 12 characters under study. Madapally and ODV 8 formed distinct cluster and ODV 5, ODV27, Periavura , ODV 30, ODV 18, ODV 23 and ODV 24 found another cluster. ODV 5 and ODV 27 ; ODV 18 and ODV 23 and Madapalli and ODV 8 were the closest genotypic pairs. Genotypes belonging to different clusters can be considered to be genetically divergent and such genotypes could be used for breeding programmes (Figure 1).

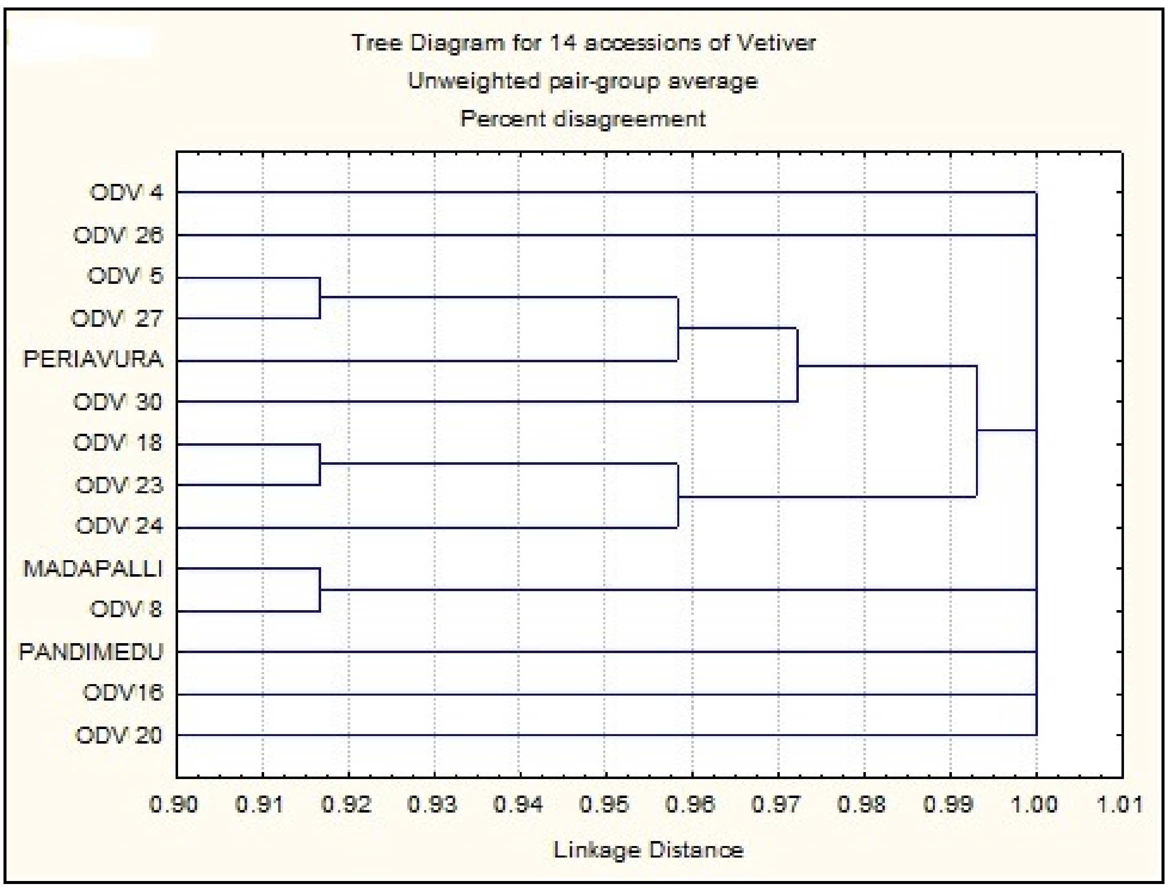


Fig. 1. Cluster diagram for the studied vetiver accessions

Table 2. Variability in vetiver accessions

Sl. No	Accession	Plant height (cm)	No. of tillers	Tiller girth	Leaves per tiller	Leaf length (cm)	Leaf breadth (cm)	Root Length (cm)	No. of Roots per Tiller	Fresh weight shoot (gm)	Fresh weight root (gm)	Dry weight shoot (gm)	Dry weight root (gm)
1	ODV-4	106.7	15.3	0.8	6.1	52.5	0.8	89.3	31.3	17.3	9.2	6.1	3.9
2	ODV-26	116.3	18.3	0.7	5.7	71.6	0.8	77.3	24.7	16.7	10.6	6.3	4.9
3	ODV-5	91.7	22.0	0.7	4.5	59.2	0.7	56.3	25.0	14.6	9.8	7.3	6.4
4	ODV-18	87.3	14.3	0.7	6.6	50.0	0.8	96.3	23.3	11.6	7.5	5.6	4.9
5	Periavura	109.7	11.0	0.7	5.7	78.9	0.8	117.0	45.0	13.4	21.8	4.6	7.4
6	Madapalli	99.7	13.7	0.6	4.8	59.5	0.8	124.7	25.3	9.7	11.7	3.5	3.9
7	Pandimed u	121.7	14.7	0.6	5.4	77.3	0.7	71.7	40.0	20.1	13.3	8.2	6.6
8	ODV-23	106.0	14.3	0.6	4.8	87.5	0.6	86.0	25.7	11.9	9.5	4.5	4.8
9	ODV-16	81.0	13.3	0.7	5.8	52.0	0.7	57.0	17.3	6.5	14.4	5.2	5.2
10	ODV-27	121.3	7.7	0.7	4.5	78.6	0.8	59.0	25.0	16.0	7.6	4.9	3.4
11	ODV-20	94.0	20.0	0.6	5.9	69.2	0.5	38.3	51.0	15.4	11.9	6.5	6.4
12	ODV-24	83.3	13.0	0.6	6.1	59.1	0.6	53.7	30.7	10.9	7.7	4.4	3.6
13	ODV-8	99.7	6.7	0.8	5.6	74.1	0.6	63.3	10.0	8.7	4.0	4.0	3.1
14	ODV-30	92.3	17.3	0.7	4.8	77.9	0.7	86.0	22.0	13.1	9.4	4.8	4.1
Mean		**100.8**	**14.4**	**0.7**	**5.5**	67.7	**0.7**	**76.9**	**28.3**	**13.3**	**10.6**	**5.4**	**4.9**
SD		**26.7**	**4.2**	**0.1**	**0.7**	12.1	**0.1**	**24.8**	**10.8**	**3.7**	**4.2**	**1.3**	**1.4**
CD		**4.8**	**2.6**	**0.5**	**0.6**	**6.7**	**0.5**	**14.1**	**4.7**	**1.5**	**1.5**	**1.4**	**0.9**

Table 3. Genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (broad sense) and genetic advance of the morphological characters studied in vetiver accessions

SI. No	Characters	GCV	PCV	Heritability (broad sense) (%)	Genetic advance (%)
1	Plant height	13.16	13.46	95.51	26.50
2	Leaf length	28.81	30.75	87.87	55.67
3	Leaf breadth	8.05	9.30	75.00	14.31
4	No of tillers	11.38	13.39	73.58	20.30
5	Leaves/ tiller	5.84	6.16	94.81	12.03
6	Tiller girth	12.09	12.81	87.5	23.08
7	Root length	31.62	32.64	96.24	64.67
8	No of roots/ tiller	217.79	225.12	93.59	75.18
9	Fresh weight - root	27.63	28.45	94.32	55.20
10	Fresh weight -shoot	38.98	40.21	93.99	77.84
11	Dry weight - root	22.78	27.39	68.78	38.88
12	Dry weight - shoot	4.90	29.06	84.34	50.32

Twelve morphometric characters that are important in the study of growth and yield behaviour of *Vetiveria zizanioides* were recorded and analysed presently so as to assess the interrelationship and association of the characters. Study of interrelationship of characters by correlation analysis is an important tool used to identify the variables which show maximum relationship with others in the case of polygenic characters. Correlation analysis was carried out presently in the case of 12 morphometric characters in vetiver so as to study the interrelationship between them (Tables 4 and 5). Among the characters plant height showed significant positive correlation with two characters (leaf length and fresh weight of shoot). Leaf breadth showed significant positive correlation with root length. Lal *et al.* (2013) and Srivastava and Lal (2012) also reported that the leaf photosynthetic rate showed significant positive association with root biomass in *Vetiveria zizanioides*.

Number of tillers showed significant positive correlation with dry shoot weight. Number of roots per tiller showed significant positive correlation with three characters (fresh root weight, fresh shoot weight and dry root weight). Fresh root weight showed significant positive correlation with two characters (number of roots per tiller and fresh root weight). Fresh shoot weight showed significant positive correlation with three characters (plant height, number of roots per tiller and dry shoot weight). Dry root weight showed significant positive correlation with three characters (number of roots per tiller, fresh root weight and dry shoot weight). Dry shoot weight showed significant positive correlation with fresh shoot weight and dry root weight. This type of interrelationship is due to sharing of common alleles among them since the characters are governed by polygenes. Characters that show significant positive correlation are considered to be interrelated and thus can be jointly considered in selection programmes. The inherent linkage between various traits has been reported by correlation analysis in other plants also (Sunil, 2014).

When subjected to factor analysis, four factors could be extracted in the case of the twelve morphometric characters of *Vetiveria zizanioides* in the present study (Tables 6 and 7). Among the characters tiller girth was grouped under factor I; plant height, leaf length, leaf breadth, root length and fresh weight-shoot grouped in factor II; number of tillers, leaves per tiller, number of roots per tiller and dry weight-root under factor III and fresh root weight under factor IV. Characters with the highest factor loadings can be considered as lead characters in each group based on which selection could be practiced.

Plant height showed the highest factor loading followed by leaf breadth, root length, leaves per tiller and fresh root weight showing their higher contribution towards the variability of the population. Such characters can be used as lead characters in further selection programmes in the case of *Vetiveria zizanioides*. Genetic variability and association analysis for yield and yield components in indigenous and exotic collections of vetiver was done by Lal (2000). He reported that plant height by itself may be a good direct selection criterion to obtain promising lines with longer roots in vetiver aiming at a better oil yielder and a good soil binder. Agronomic characters of plants show different levels of association since they are polygenic.

Table 4. Correlation analysis of morphometric characters of vetiver accessions- correlation coefficients

	Plant height	Leaf length	Leaf breadth	No. of tillers	Leaves per tiller	Tiller girth	Root length	Roots per tiller	Fresh weight root	Fresh weight shoot	Dry weight root	Dry weight shoot
Plant height	1											
Leaf length	**0.610594***	1										
Leaf breadth	0.378829	-0.21901	1									
No. of tillers	-0.23433	-0.22292	-0.21378	1								
Leaves/ tiller	-0.30691	-0.51685	-0.01593	-0.0474	1							
Tiller girth	0.10113	-0.10813	0.413227	-0.38293	0.325894	1						
Root Length	0.204255	0.025032	**0.644252***	-0.16665	-0.0278	0.150325	1					
Roots /tiller	0.249522	0.175314	-0.14386	0.324126	0.185488	-0.46798	-0.00344	1				
Fresh weight root	0.15638	0.132333	0.190961	0.131797	0.032481	-0.29409	0.363399	**0.601814***	1			
Fresh weight shoot	**0.701024***	0.289842	0.196928	0.34411	-0.09278	-0.07657	-0.08926	**0.560539***	0.108238	1		
Dry weight root	0.103052	0.115062	-0.1002	0.467781	0.039243	-0.32283	0.027968	**0.669791***	**0.77451***	0.338231	1	
Dry weight shoot	0.248389	-0.09309	-0.07202	0.598146*	0.080019	-0.14382	-0.38082	0.407062	0.134	**0.730278***	**0.587392***	1

Table 5. Correlation analysis of morphometric characters of vetiver accessions - characters correlated

Sl. No.	**Character**	**Characters correlated**	**Number of characters correlated**
1	Plant height	Leaf length, fresh weight - shoot	2
2	Leaf length	Plant height	1
3	Leaf breadth	Root length	1
4	No of tillers	Dry weight - shoot	1
5	Leaves/ tiller	Nil	0
6	Tiller girth	Nil	0
7	Root length	Leaf breadth	1
8	No of roots/ tiller	Fresh weight - root, fresh weight - shoot, dry weight - root	3
9	Fresh weight - root	No. of roots/ tiller, dry weight - root	2
10	Fresh weight -shoot	Plant height, No. of roots/ tiller, dry weight - shoot	3
11	Dry weight - root	No. of roots/ tiller, fresh weight - root, dry weight - shoot	3
12	Dry weight - shoot	fresh weight - shoot, dry weight - root	2

Similar analyses have been carried out by earlier workers so as to bring out the interrelationship of polygenic plant characters and their association with similar objectives. Hrideek *et al.* (2008) and Umamaheswari and Mohanan (2011) also highlighted the importance of such studies in understanding the relationship between characters and also in finding out lead characters which could be concentrated upon in future breeding programmes.

Table 6. Factor analysis in vetiver accessions- eigen values, percentage of total variance, cumulative eigen values and cumulative percentage of variance

Eigenvalue	% Total variance	Cumulative Eigen value	Cumulative % of variance
3.64	30.35	3.64	30.35
2.42	20.15	6.06	50.50
1.88	15.65	7.94	66.16
1.62	13.53	9.56	79.69

Table 7. Factor loadings of vetiver growth parameters

Characters	Factor 1	Factor 2	Factor 3	Factor 4
Plant height	-0.39	**0.80**	-0.29	-0.24
Leaf length	-0.26	**0.51**	-0.64	0.30
Leaf breadth	0.11	**0.69**	0.52	-0.26
No of tillers	-0.57	-0.49	**0.08**	-0.14
Leaves/ tiller	0.09	-0.32	**0.62**	-0.32
Tiller girth	**0.49**	0.33	0.24	-0.54
Root length	0.10	**0.63**	0.54	0.30
No of roots/ tiller	-0.83	-0.02	**0.16**	0.15
Fresh weight - root	-0.60	0.22	0.48	**0.50**
Fresh weight -shoot	-0.73	**0.32**	-0.18	-0.53
Dry weight - root	-0.83	-0.09	**0.29**	0.21
Dry weight - shoot	-0.74	-0.21	-0.02	-0.56

Field experiments

A total of 15 accessions were collected for the study. ODV - 9 being a commercial variety was not considered for the field experiments as it has an established high essential oil content and is prone to harvesting thereby destabilizing the stream banks. Among the remaining 14 accessions, ODV - 4, ODV - 20, ODV -23, ODV - 26, Periavura and Madapally were used in the field experiments (Table 8).

Growth pattern

Growth attributes such as number of tillers and roots, length of shoot and root production are presented in Table 9. The root length in the different accessions varied from 79 - 122 cm and shoot length from 91 - 168 cm in the stream banks. The loose soil and abundant soil moisture may have contributed to a much higher growth in these soils compared to experiments at KFRI, Peechi. There was not much difference between Periavura and ODV - 23 in the production of roots. Periavura produced 648 roots, ODV - 23 produced 562 roots and ODV - 4 produced the lowest numer of roots among the different accessions (412). Except ODV - 4 and ODV - 26, all the vetiver accessions were similar in shoot length. Periavura had the highest values with respect to root length (72 cm), shoot length (100 cm), no. of tillers (22) and no. of roots (248). Among the ODV accessions, ODV - 23 can be considered a promising one. Presence of large number of roots in the species facilitates greater penetration through smaller pores; any root can only enter pores that are equal to or bigger than its soft root tip. After entering the pores, roots can exert huge pressure through expansion of cells, pressing soil particles and encouraging adhesion and formation of aggregates. Thus, Periavura and ODV – 23 can stabilize more soil volume compared to other vetiver accessions used in the study especially in stream banks with gentle slope. Thomas *et al.* (2012) have also reported the capacity of vetiver plants in stabilizing soil in gentle slopes.

Site conditions markedly influence the form and pattern of root development. Lateral spread is related to the nature of the rooting medium, being more extreme in sandy soil than in clay (Spur and Barnes, 1980). Plants themselves show considerable variation of rooting depth within the soil profile (Etherington, 1976). A variety of exogenous factors are known to influence the branching pattern of roots (Torrey and Clarkson, 1975). However, the maximum effective depth of rooting of plants, and therefore the depth to which they can reinforce or anchor the soil, is a subject for debate in the world-wide bio-engineering literature.

There was no significant difference in the root: shoot ratio of different accessions and they varied from 0.21 to 0.25. This does not mean that root length or root biomass of all the accessions were equal. The ratio shows that approximately 20 - 25% of the total biomass is contributed by the root.

Table 8. Variability of morphometric characters in the vetiver accessions studied

Sl. No.	Accession	Plant height (cm)	Number of tillers	Tiller girth (cm)	Leaves per tiller	Leaf length (cm)	Leaf breadth (cm)	Root length (cm)	Number of roots per tiller	Fresh weight-shoot (g)	Fresh weight-root (g)	Dry weight-shoot (g)	Dry weight-root (g)
1	ODV-4	107	15	1	6	53	1	89	31	17	9	6	4
2	ODV-5	92	22	1	4	59	1	56	25	15	10	7	6
3	ODV-8	100	7	1	6	74	1	63	10	9	4	4	3
4	ODV-16	81	13	1	6	52	1	57	17	6	14	5	5
5	ODV-18	87	14	1	7	50	1	96	23	12	7	6	5
6	ODV-20	94	20	1	6	69	1	38	51	15	12	7	6
7	ODV-23	106	14	1	5	88	1	86	30	15	10	4	5
8	ODV-24	83	13	1	6	59	1	54	31	11	8	4	4
9	ODV-26	116	18	1	6	72	1	77	25	17	11	6	5
10	ODV-27	121	8	1	5	79	1	59	25	16	8	5	3
11	ODV-30	92	17	1	5	78	1	86	22	13	9	5	4
12	Madapalli	110	11	1	6	79	1	117	45	13	22	5	7
13	Pandimedu	100	14	1	5	59	1	125	25	10	12	4	4
14	Periavura	122	15	1	5	77	1	72	40	20	13	8	7
Mean		**98**	**15**	**1**	**5**	**67**	**1**	**69**	**26**	**13**	**9**	**5**	**5**

Table 9. Morphometric characters in the vetiver accessions used in field experiment

	Root length (cm)	**Shoot length (cm)**	**No. of tillers**	**No. of roots**	**Root: Shoot ratio**
ODV-4	79 ± 16	91 ± 31	51± 9	412 ± 92	0.24 ± 0.09
ODV-20	90 ± 36	132 ± 26	59 ± 7	432 ± 87	0.21 ± 0.10
ODV-23	114 ±23	158 ± 24	69 ± 12	562 ± 115	0.25 ± 0.09
ODV-26	80 ± 18	93 ± 29	52 ± 10	415 ± 86	0.23 ± 0.09
Madapalli	100 ± 24	133 ± 18	67 ± 11	458 ± 51	0.23 ± 0.14
Periavura	122 ± 40	168 ± 21	74 ± 14	648 ± 122	0.24 ± 0.12

Root and shoot biomass are maintained by plants within a certain balance that is characteristic of each species under normal conditions. This pattern is affected under stress, when roots proliferate more to support and maintain the above ground growth (Thomas *etal.*, 2012). Thus species that respond better under stress will have greater root: shoot ratio. ODV - 4, ODV - 23 and Periavura were slightly more efficient in this respect compared to ODV - 20, ODV - 26 and Madapally.

Influence of vetiver growth on soil and its properties

Soil parameters such as soil texture, particle density, bulk density and posrosity were unaffected by the cropping of vetiver in these soils. There was no definite trend for the soil parameters at the end of the experiment and all the studied accessions equally modified the soil reaction, organic carbon content and MWD. There was a decrease of 0.1 – 0.2 units in the soil pH for all the accessions (Table 10 and 11). The high root growth and subsequent organic acid releases by vetiver plants may have played a role in reducing the soil pH. Also the utilization of basic cations for crop growth will reduce the soil reaction. However, vetiver with its deep roots will be able to recycle the leached cations from deeper layers and improve soil pH on continuous retention of the plant without harvest.

Table 10. Initial physico – chemical characters of the experimental soil

Sand (%)	83
Silt (%)	10
Clay (%)	7
Particle density (gcm^{-3})	2.2
Bulk density (gcm^{-3})	1.3
Porosity (%)	41
pH	5.1
Organic carbon (%)	1.2
Mean weight diameter	1.1

Table 11. Soil physico – chemical characters in the vetiver planted plots at the end of the experiment

Accessions	**pH**	**Organic carbon (%)**	**MWD**
ODV-4	4.9	1.3	1.29
ODV-20	5.0	1.3	1.35
ODV-23	4.9	1.4	1.34
ODV-26	4.9	1.3	1.32
Madapalli	5.0	1.3	1.30
Periavura	4.9	1.4	1.36
CD (p = 0.05)	NS	NS	NS
MWD = Mean weight diameter; NS = Non significant			

The organic carbon and mean weight diameters were found to be improved at the end of the experiment. Soil structure can be envisaged as the arrangement of soil particles in aggregates, which leaves voids spaces (*i.e.* pores) in the free spaces intra- and inter-aggregates. The stability of soil structure is defined as the capacity of soil to maintain a given arrangement of solids and pores, against the effect of external disturbances. Soil aggregates can be formed by both aggregation and fragmentation processes and stability of wet aggregates can be related to surface-seal development and field infiltration, as water-stable fractions may restrict water entry and form surface seals (Sandeep and Manjaiah, 2014). Hence vetiver planting can be considered to be an effective system for improving the water stable aggregates and soil stability in streams

The higher mean weight diameter of vetiver systems compared to the initial conditions can also be attributed to the higher amount of organic carbon in these soils. Earlier studies have reported that free primary particles and silt-sized aggregates (<20 µm) are bound together into microaggregates (20-250 µm) and macroaggregates (> 250 µm) by persistent binding agents (i.e. humified organic matter and polyvalent metal cation complexes), oxides and highly disordered aluminosilicates (Dexter, 1988 ; Six *et al.*, 2004).

Oil content in selected accessions

The vetiver oil concentration ranged from 50 ppm to 152.7 ppm in different accessions (Table – 12 and Figures 2- 7). In general, ODV accessions had higher oil concentration and oil volume than Madapally and Periavura. The concentration was lowest in Periavura and highest in ODV - 23. The volume of oil (per gram of root) was lowest in Madapally. ODV – 23 had good root and shoot growth but its high oil contents may make it prone to harvest thereby defeating the purpose of soil stabilization.

Table 12: Oil content in vetiver accessions

Accession	**Vetiver oil**	
	Concentration (ppm)	**Volume of oil in 1 gm of root (µl)**
ODV-4	83.9	26.2
ODV-20	147.5	61.4
ODV-23	152.7	54.5
ODV-26	62.8	15.7
Madappally	76.6	19.1
Periavura	50.0	38.8

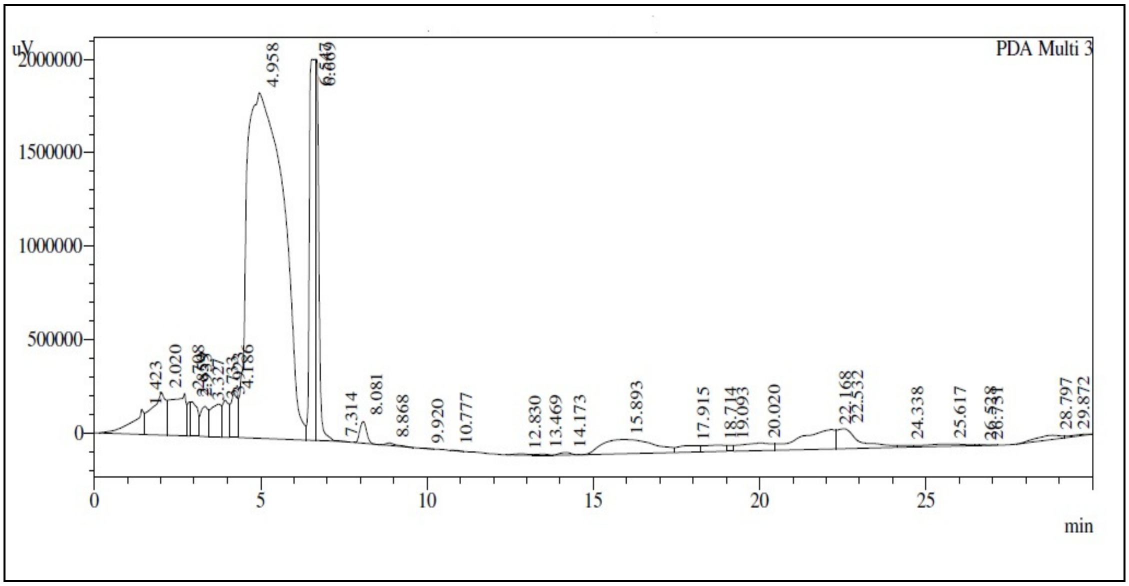


Fig. 2. Chromatogram of vetiver oil extract of ODV -4

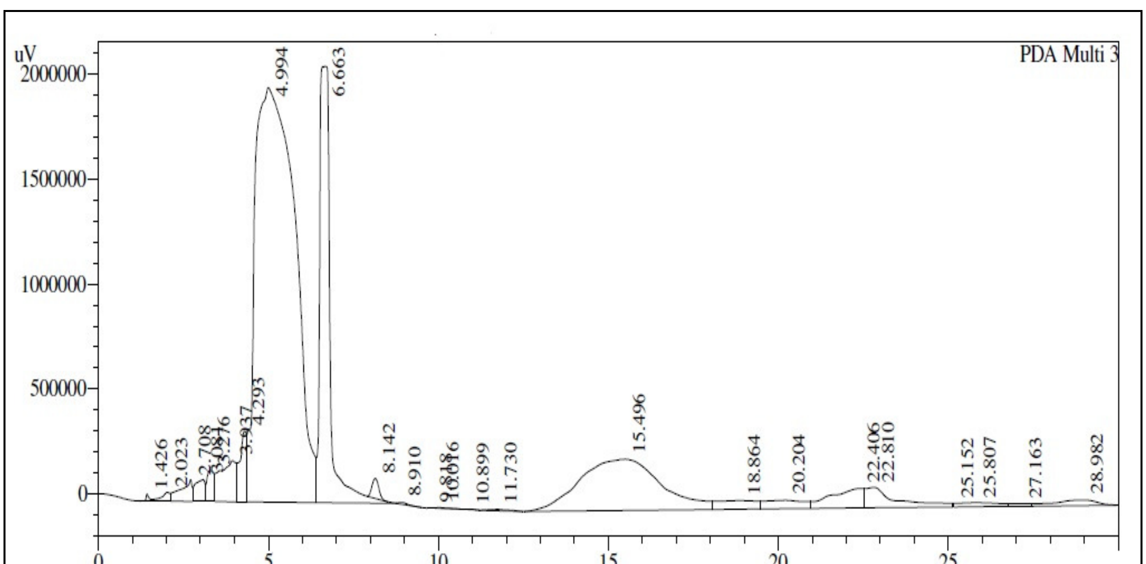


Fig. 3. Chromatogram of vetiver oil extract of ODV -20

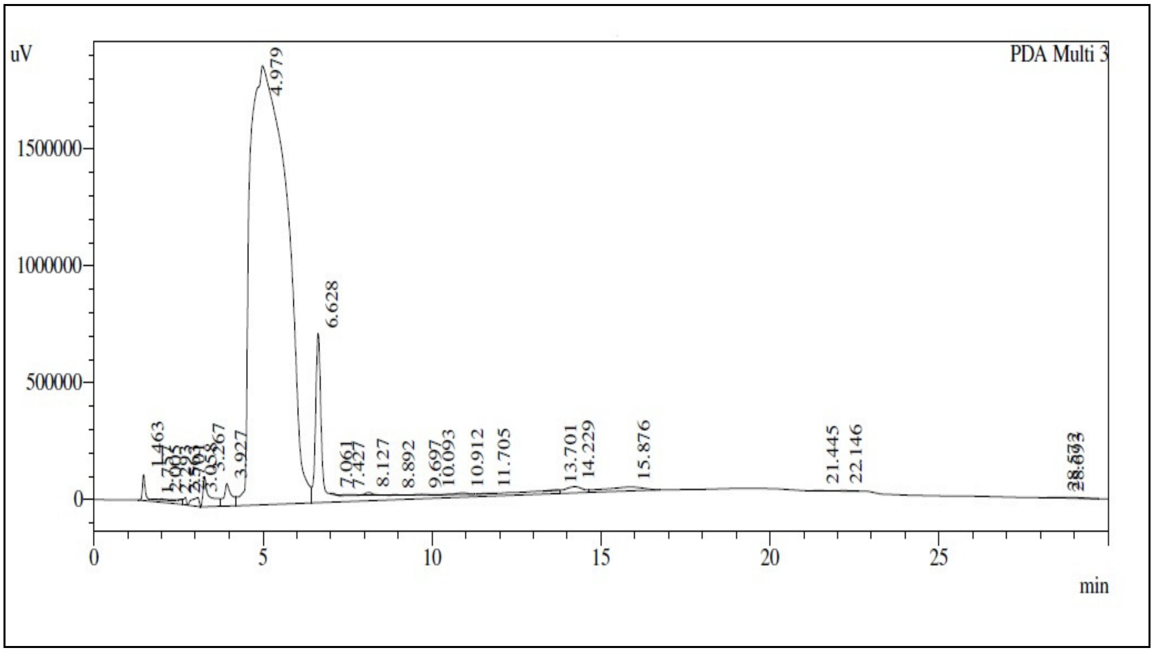


Fig. 4. Chromatogram of vetiver oil extract of ODV -23

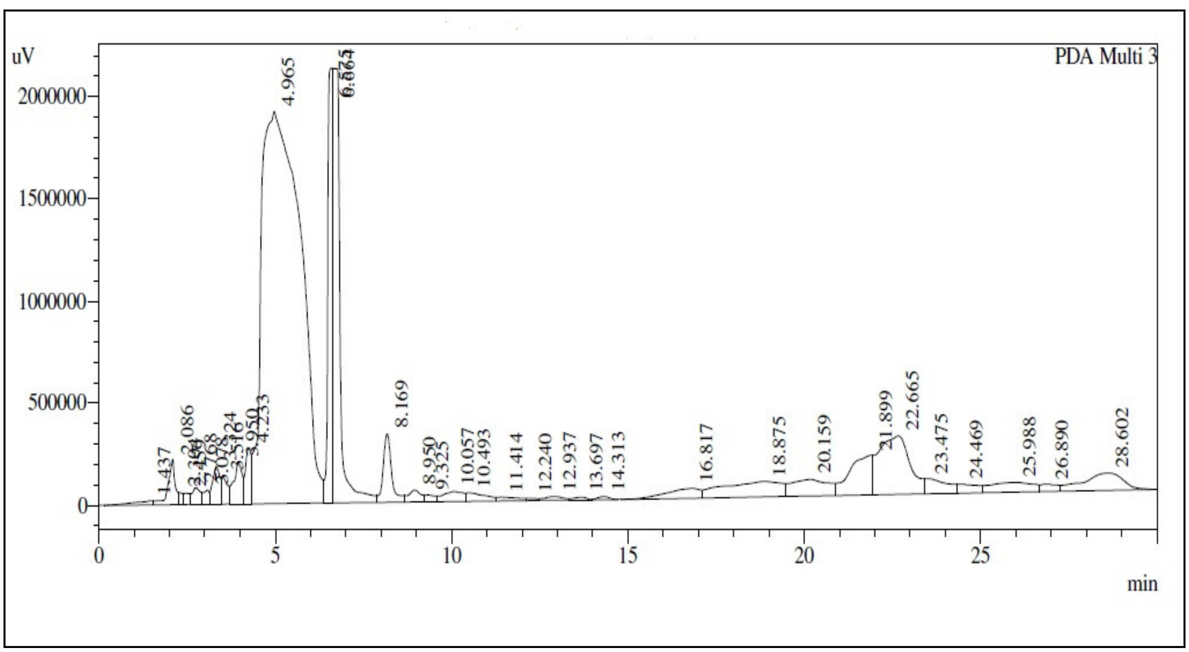


Fig. 5. Chromatogram of vetiver oil extract of ODV -26

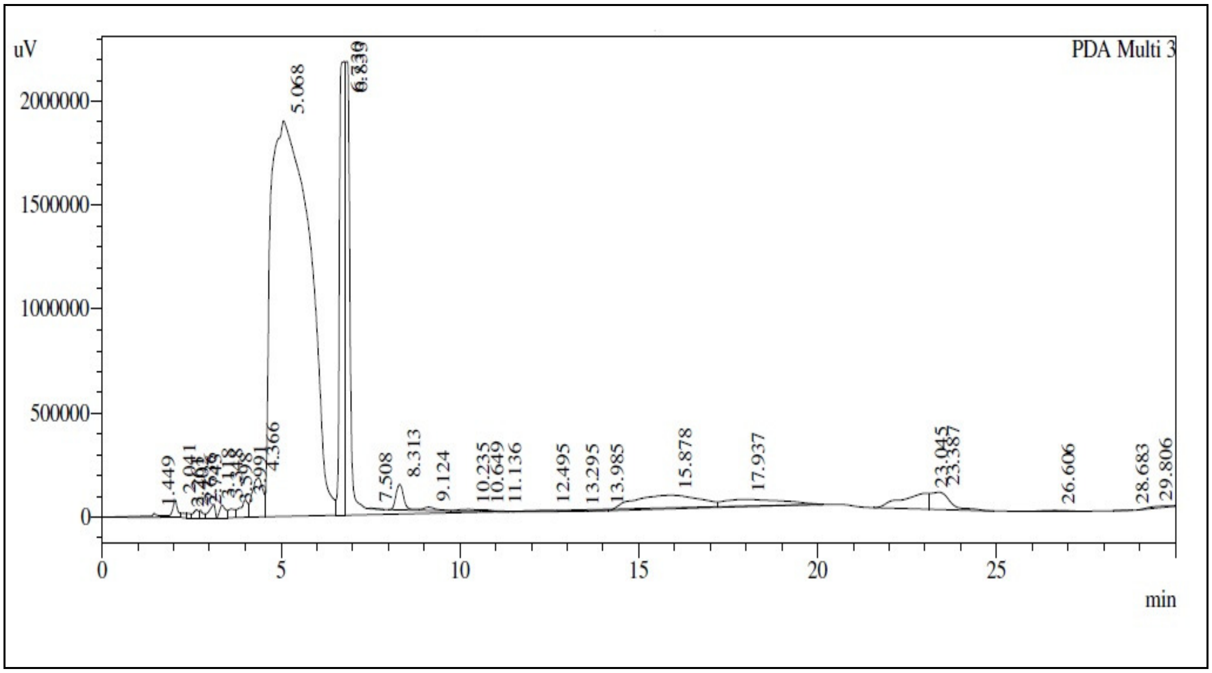


Fig. 6. Chromatogram of vetiver oil extract of Madapally

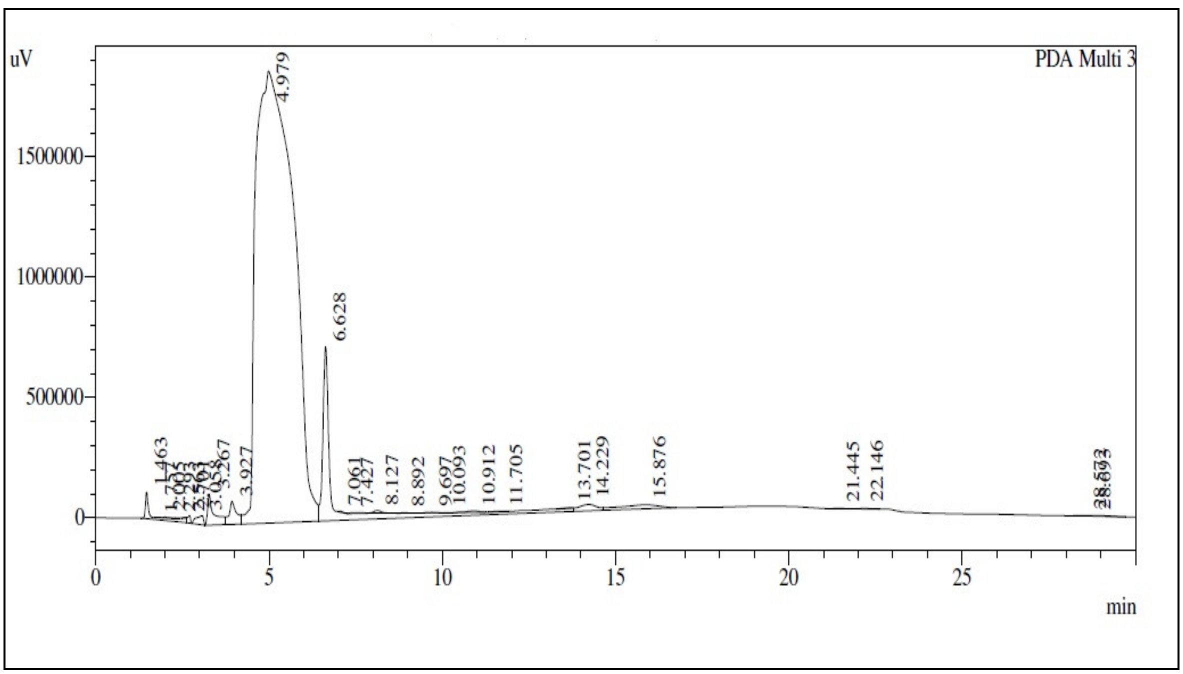


Fig. 7. Chromatogram of vetiver oil extract of Periavura

Training activities

As part of the project a training programme was conducted for selected farmers of Pananchery and Nadathara at KFRI, Peechi on use of vetiver systems for river bank stabilization. The training programme dealt on the advantages of vetiver over mechanical structures in protecting river banks, vetiver propagation, planting and maintenance for stabilizing stream banks. A malayalam booklet titled ‘Ramacham’ with the intention of popularizing the use of vetiver was also released on the occassion.

SUMMARY AND CONCLUSIONS

Suitability of 15 different accessions of vetiver (*Vetiveria zizanioides)* for planting on river banks to control erosion was assessed through a field trial. Variability in root and shoot growth in terms of eight root and four shoot parameters, variability in terms of heritability and genetic advance, changes in the physico – chemical chararcters of the vetiver accession planted soil and oil content in roots were studied. Among the collected accessions, ODV - 9 being a commercial variety was not considered for the field experiments as it has an established high essential oil content and is prone to harvesting thereby destabilizing the stream banks.

Analysis of interrelationship between the collected accessions showed that there is a sharing of common alleles among them since the characters are governed by polygenes. Cluster analysis indicated the genetic identity of most of the accessions under study. ODV 4, ODV 16, ODV 20 and ODV 26 formed distinct clusters. Madapally and ODV 8 formed a distinct second cluster and ODV 5, ODV27, Periavura, ODV 30, ODV 18, ODV 23 and ODV 24 formed the third cluster. ODV 5 and ODV 27; ODV 18 and ODV 23 and Madapalli and ODV 8 were the closest genotypic pairs. When subjected to factor analysis, four factors could be extracted in the case of the twelve morphometric characters. Among the characters tiller girth was grouped under factor I; plant height, leaf length, leaf breadth, root length and fresh weight-shoot grouped in factor II; number of tillers, leaves per tiller, number of roots per tiller and dry weight-root under factor III and fresh root weight under factor IV.

The results suggest that there is no definite trend of vetiver accessions on the soil parameters at the end of the experiment and all the studied accessions equally modified the soil reaction, organic carbon content and mean weight diameter. There was a decrease of 0.1 – 0.2 units in the soil pH for all the accessions. In all the cases, organic carbon and mean weight diameters were found to be improved at the end of the experiment. However there was significant variation in the morphometric parameters of the vetiver accessions. Among the accessions, the highest number of roots were produced by Periavura (648 roots) followed by ODV - 23 (562 roots). Though ODV – 23 had good root and shoot growth, its high oil contents (3 times

higher than the lowest oil content accession Periavura) may make it prone to harvest thereby defeating the purpose of soil stabilization. Thus among the studied vetiver accessions, Periavura can be considered the most promising one and can be recommended for stream bank stabilization.

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