Plant and Soil (2005) 278:33–41
DOI 10.1007/s11104-005-2379-0

Uprooting of vetiver uprooting resistance of vetiver grass (*Vetiveria zizanioides*)

S.B. Mickovski[1,3,4], L.P.H van Beek[2] & F. Salin[1]
[1]*LRBB, Domaine de l'Hermitage, 69, rte d'Arcachon, 33612, Cestas cedex, France.* [2]*IBED–Physical Geography, University of Amsterdam, Nieuwe Achtergracht 166, NL 1018, WV Amsterdam, The Netherlands.* [3]*Current address: Civil Engineering Department, University of Dundee, Dundee DD1 4HR, Scotland, UK.* [4]*Corresponding author**

Received 7 October 2004. Accepted in revised form 15 February 2005

Key words: pullout resistance, root system morphology, roots, uprooting, vetiver, *Vetiveria zizanioides*

Abstract

Vetiver grass (*Vetiveria zizanioides*), also known as *Chrysopogon zizanioides*, is a graminaceous plant native to tropical and subtropical India. The southern cultivar is sterile; it flowers but sets no seeds. It is a densely tufted, perennial grass that is considered sterile outside its natural habitat. It grows 0.5–1.5 m high, stiff stems in large clumps from a much branched root stock. The roots of vetiver grass are fibrous and reported to reach depths up to 3 m thus being able to stabilize the soil and its use for this purpose is promoted by the World Bank. Uprooting tests were carried out on vetiver grass in Spain in order to ascertain the resistance the root system can provide when torrential runoffs and sediments are trying to uproot the plant. Uprooting resistance of each plant was correlated to the shoot and root morphological characteristics. In order to investigate any differences between root morphology of vetiver grass in its native habitat reported in the literature, and the one planted in a sub-humid environment in Spain, excavation techniques were used to show root distribution in the soil. Results show that vetiver grass possesses the root strength to withstand torrential runoff. Planted in rows along the contours, it may act as a barrier to the movement of both water and soil. However, the establishment of the vetiver lags behind the reported rates in its native tropical environment due to adverse climatic conditions in the Mediterranean. This arrested development is the main limitation to the use of vetiver in these environments although its root strength is more than sufficient.

Introduction

Vetiver grass (*Vetiveria zizanioides*), also known as *Chrysopogon zizanioides*, is a graminaceous plant native to tropical and subtropical India. The southern cultivar is sterile; it flowers but sets no seeds. It is a densely tufted, perennial grass that is considered sterile outside its natural habitat. It is reported that vetiver grows 0.5–1.5 m high, stiff stems in large clumps from a much branched root stock (Erskine, 1992; Truong, 1999). The use of vetiver grass hedges against soil erosion increased following several key papers promoting vetiver grass planting as an effective and inexpensive erosion protection measure and the publication of World Bank's manual in 1990 (for a review see Grimshaw, 1989). Vetiver grass has wider applications due

*E-mail: s.b.mickovski @dundee.ac.uk

to its unique morphological, physiological and ecological characteristics that highlight its adaptability to a wide range of environmental and soil conditions. Currently used in more than 120 countries, vetiver grass applications include soil and water conservation systems in agricultural environment, slope stabilization, rehabilitation of mines, contaminated soil and saline land, as well as wastewater treatment (Truong and Loch, 2004). In addition, vetiver has added commercial value as its roots yield aromatic compounds that are applied for domestic and cosmetic use. However, there is an argument that when the plant is harvested for this purpose it may actually increase erodibility because the process loosens the soil (Smith 2000).

The most impressive characteristic of the vetiver grass is its root system that consists of fibrous roots reported to reach depths up to 3 m (Erskine 1992; Hellin and Haigh 2002). Such roots extend deep enough in the soil to provide the grip and anchorage needed to prevent surficial slip in the event of heavy prolonged rainstorm (Hengchaovanich, 1999). This is the major reason why the use of vetiver grass for slope protection is promoted by the World Bank (1990) and The Vetiver Network (Paul Truong personal communication, www.vetiver.org).

Planted in rows along slope contours, vetiver is able to quickly form a narrow but very dense hedge. Reported to tolerate adverse growing conditions (e.g. winters with ground temperatures as low as −14 °C) (Truong, 1999), its stiff foliage is able to block the passage of soil and debris in cases of torrential rains (Dalton et al., 1996; Hengchaovanich 1999), in the same time allowing the trapped sediment to form a terrace upslope the hedge. Vetiver hedge is also able to slow down any surface runoff which, in turn, gives the rainfall a better chance of percolating into the soil instead of running off downslope and potentially creating rills and gullies, in the same time contributing to the increased yield of crops planted on the slope (Truong and Loch, 2004). If the sediment is not removed vetiver will continue to grow up and adjust itself in tandem with it on the newly formed terrace (Truong, 1999; Hengchaovanich, 1999) which, rises as the soil accumulates behind the hedges, thus converting highly erodible slopes into relatively more stable terraces able to support sustainable agriculture or even forestry (Meyer et al., 1995). Being a low cost, natural and environmentally friendly method for erosion control (Truong, 1999), the efficiency of such contour hedges for soil and water conservation have been studied *inter alia* by Mishra et al. (1997), and Hellin and Haig (2002).

not true according to Nat'l Research Council who say Vetiver will not survive frost and dies when soil temps reach −15 C (damaged at soil temps of −10 C)

The versatility of vetiver has led to its application outside its original zones of provenance. Currently it is successfully used in Africa, Asia, Central and South America, southern Europe and Australia for stabilisation of steep batters of roads and railway embankments. For example, in China in the last 5 years it has been used for erosion and sediment control on more than 150 000 km of embankments (Truong and Loch, 2004). In principle it would be possible to apply it also in the European Mediterranean basin although the soil and climatic conditions are harsh. Therefore, a modest field trial was set up in the Alcoy region (Spain) to evaluate its performance within the framework of the EcoSlopes project. Two plots on the riser of a cultivated bench terrace were planted with vetiver and compared to similar plots under different treatments: Spanish cane (*Arrundo donax*), natural cover and regrowth after complete stripping. In the area bench terrace risers are left unarmored and are subject to erosion and failure despite their cover with natural vegetation (mainly *Brachypodium* sp.)

Previous studies have reported on the growth and the use of vetiver grass in its natural environment (Salam et al., 1993; Erskine, 1992; Hengchaovanich, 1999, Hellin and Haigh, 2002, Truong and Loch, 2004) but the properties of vetiver root systems have not been investigated in European context. In this study the mechanical properties of vetiver roots and their architecture are studied in order to evaluate its capacity to withstand torrential rain, ponding and sediment pressure (Hengchaovanich, 1999; Cheng et al., 2003), as well as its potential for application in eco-engineering.

Materials and methods

Site characteristics

Experimental plots of vetiver grass were planted on a site near Almudaina, Spain (X = 729275; Y = 4293850 and Z = 480 m on UTM 30s) in the spring of 2002. The vetiver was planted on the riser of a bench terrace (Figure 1) which parts are potentially endangered by runoff and soil slippage after intense rainfall events. The local gradients on the riser ranged between 35 and 60° while a nursery was established on the bench terrace. Cuttings of vetiver were planted in rows on the riser with a spacing of 10–15 cm. Rows were placed at the crest, bottom and middle of the riser that was between 1.75 and 2.25 m high (Figure 1). The vertical interval of the vetiver rows was approximately 40 cm and their length 3 m each.

The soil on the site derives from Miocene marl. The marl have a high clay content, predominantly smectites, but, due to a carbonate content of 60 per cent or more, most of the particles fall in the silt fraction. The dry bulk of the topsoil 14.6 kN m^{-3} and the porosity 0.413 m^3 m^{-3}. The soil shear strength was determined in the laboratory by means of strain-controlled, consolidated-drained direct shear tests on saturated samples (BS 1377). Sample size was 60 × 60 × 20 mm and the applied strain rate 0.2 mm h^{-1}. Because of the dominance of the silt fraction, the soil has a high angle of internal friction of 34° and a cohesion of a mere 4.8 kPa (N = 30). These strengths have been confirmed by two *in situ* consolidated-drained direct shear tests on pristine soil with field capacity of saturation with dimensions of 32 × 32 cm in plan and 20 cm high, for which no substantial root reinforcement was found. In comparison, four tests on soil rooted with vetiver

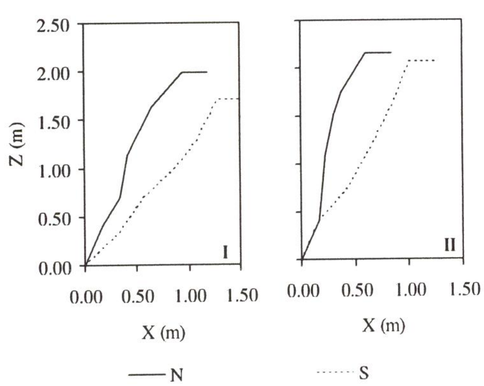

Figure 1. Profiles of the bench terrace risers along the north and south margins of the vetiver plots I and II. The toe is located on the abandoned terrace, the horizontal crest on the cultivated terrace.

yielded a significant root reinforcement in the order of 2.7 kPa (ranging between 2.1 and 3.7 kPa) when the shearing resistance derived from the laboratory tests was subtracted.

The climate at the site is continental and Mediterranean. It shows a strong seasonality in rainfall and temperature. Most rainfall occurs in the late autumn and winter and to a lesser extent in early spring. The total annual rainfall amounts to 700 mm per year but the rainfall has a strong inter-annual variability with annual totals varying between 350 and 1050 mm. Moreover, rainfall is erratic and exceptional events occur throughout the wet season: a 24 h total of 284 mm and an event total of 553 mm have been recorded at Almudaina (van Beek, 2002).

The mean annual temperature is 16 °C ranging between a mean monthly temperature of 24 °C in summer and 7 °C in winter. In winter, the variability in the temperature and its diurnal course are the largest with night frost occurring regularly between end December and April (van Beek, 2002). The climatic conditions at the site fall within the tolerances of vetiver (World Bank 1990) and the conditions over the growing period of the vetiver did not, on average, deviate from them. However, the summer of 2001 was characterised by a prolonged drought that was terminated by a 90 mm storm in August. Drip irrigation was applied over this period to enable the plants to establish themselves. February 2003 experienced exceptional snowfall which cover persisted for several days. In April 2003, a 146 mm event in 24 h occurred which induced some small slips on slopes and risers. At the test site damage was restricted to one plot planted with vetiver through which the overland flow of the overlying bench terrace was routed.

Since most erosion and slippage occur in the late autumn, the investigation of the uprooting resistance of vetiver grass was carried out in November 2003 when the ambient moisture conditions were close to field capacity (observed volumetric moisture content ranged between 0.25 and 0.35 m^3 m^{-3}). At that time, the plants were well established and have proliferated multiple stems from the cuttings planted in 2002.

Preliminary tests

In order to investigate the morphological characteristics of vetiver roots, four plants were completely excavated using the block excavation method (van

Noordwijk et al., 2000) (Figure 2). These plants were randomly selected from the plot, the soil surface in a radius 30 cm around each plant was carefully cleared from the litter, and the soil block with dimensions 0.3 m × 0.3 m and 0.5 m deep, containing their roots was manually excavated using a spade. Excavated plants were then transferred to the *in situ* root washing facilities where, to minimise root loss or damage, the plants together with their root systems were hand washed gently from the remains of the soil. Root systems were then sprinkled under a low water flow from a sprinkler. For separating the last remnants of soil on the roots, it was necessary to soak the root systems in water basins and remove the soil by gently agitating the sample after what the soil particles settled on the bottom of the basin, and the broken roots, if any, floated on the surface. After the root systems were thoroughly cleaned from the soil, they were placed on a paper mat and left to dry in the open air for half an hour and the maximum lateral spread, and maximum rooting depth was measured for each plant. All the primary lateral roots (Figure 2) were then carefully cut off from the plant base with scissors and the number of roots recorded; root diameter at its base and near its tip (d_i) was noted together with the length of the primary lateral root. The root cross sectional area (CSA) was calculated as an area of a circle with radius d_i. Observing the strong geotropical tendency in the rooting pattern of vetiver, it was assumed that all of the roots grow more or less vertically downwards and the length of each root was assumed to represent the maximum rooting depth reached by the root itself.

Pullout resistance of vetiver grass

In order to investigate the pullout resistance of vetiver grass, 22 plants were randomly chosen from the plantation and were used as a test sample. Before each pullout test the soil surface in a radius 30 cm around the plant was carefully cleared from the litter, exposing the stem base. A strong PVC rope (3 mm diameter) padded with soft tissue in order not to destroy the plant material was then tied around the stem base of the plant. The other end of the rope was connected to a hand-held portable force gauge (Alluris FMI-100) for accurate measurement of uprooting force. In order to mimic the forces applied to the plant during runoff and sediment impoundment, the pullout force was applied parallel to the slope in downslope direction. The force was applied manually with a rate of 10 mm min^{-1}, recording the change in resistance along the way. The test was terminated once the resisting force dropped sharply and the plant was uprooted. Each plant was then carefully excavated, its roots washed from the soil remnants, and left on a paper mat to air dry for an hour.

Plant morphological analysis

Aboveground characteristics such as the plant height and the average diameter at the base (Fig-

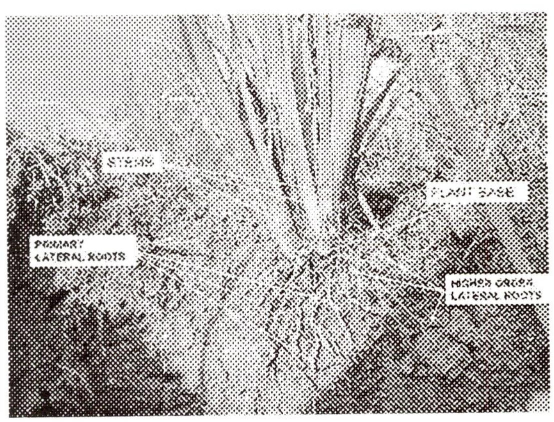

Figure 2. Morphological characteristics of a semi-excavated vetiver plant. Stiff stems grow upwards from the plant base, while primary lateral roots grow vertically down the soil. Primary lateral roots often branch into second/third, etc. order lateral roots.

ure 2) were measured with measuring tape and callipers for each of the 22 uprooted plants. The number of stems growing from each stem base was also recorded.

Similarly as in the preliminary tests, the number of roots was recorded for each tested plant and root system characteristics including the root length, root system lateral spread and depth were measured with measuring tape (Böhm, 1979). The diameter of each root close to the stem base was measured with callipers.

Root systems were then separated from the stems using scalpel and sharp blade and placed in an oven to dry over 24 h at 70 °C, after which the root:shoot ratio of each uprooted plant was calculated as the weight of dry root mass over the dry weight of shoots (Böhm 1979).

Statistical analysis

The results of the pullout tests were analysed using the statistical package SPSS 10.0 (SPSS Inc, Chichago). A bivariate correlation analysis with Pearson's coefficient was performed in order to investigate any underlying relation between the uprooting force for each plant and the stem and root parameters measured during the investigation. A two-tailed test of significance was used to identify the statistically significant correlations.

Results

Preliminary tests

The tests to describe the overall morphological characteristics of vetiver grass worked well in this specific plantation. Vetiver roots were shown to originate from the base of the plant that had between 8 and 10 stems on average (Figure 2). The roots were numerous, pale yellow in colour and strongly geotropic. Having diameters at the base of the plant in the range between 0.3 and 1.2 mm, the roots did not visibly taper and branched to second and third order laterals of decreasing diameters. None of the roots of the test plants had a lateral spread larger than 0.25 m from the base of the plant, nor did the depth of the excavated plants reach more than 0.3 m. These parameters justified the chosen size of the excavation block that provided that no mechanical damage is incurred to the root systems.

Plant morphology

Morphological characteristics of investigated vetiver plants are given in Table 1.

Pullout resistance

The plant pullout method described in the Materials and methods section was suited to the objectives of the investigation, and 19 out of 22 plants could be uprooted using this method. The other three plants were not uprooted because of the rope failure or a snap through the plant stem.

The investigated vetiver plants did not show any movement in the first several force/displacement increments. With the increase of the force applied, the plants started to rotate around a point close to the downslope end of the stem base but under the soil surface, while the upslope lateral roots were activated in tension and provided most of the resistance for the plant. In the

Table 1. Morphological characteristics of 22 investigated vetiver plants

Morphological characteristic	Range	Mean	Standard error
Plant height [m]	0.74–1.08	0.925	0.035
Number of stems per plant	4–23	12.5	1.25
Plant diameter at base [m]	0.030–0.092	0.062	0.005
Maximum rooting depth [m]	0.110–0.275	0.219	0.018
Lateral root spread [m]	0.151–0.292	0.229	0.015
Root diameter at base[mm]	0.30–1.45	1.02	0.04
Dry root mass [g]	4.40–37.8	22.96	3.33
Dry shoot mass [g]	36.40–114.20	70.05	8.04
Root : shoot ratio	0.121–0.636	0.353	0.059

later stages, sporadic sounds of root snapping were heard just before the plant was uprooted.

The plant pullout data showed that the plant resisting force increased with displacement until it reached the peak and then gradually started to decrease as the roots started to break or slip from the soil. A typical pullout force–displacement curve is shown on Figure 3. The slopes of the increase in the force–displacement curve to the maximum load ranged from 0.29 to 9.33, or on average 2.50 ± 0.36 (throughout this paper: mean ± SE). The maximum uprooting force ranged from 190 to 620 N, or on average 466.97 ± 31.25 N for the investigated plants.

The summary of the correlation analysis between the pullout resistance of the investigated plants and the other morphological characteristics measured during the investigation is shown in Table 2. Positive correlations were found between the uprooting force and all other measured parameters. However, only the correlation between the uprooting force and the plant height, and between the uprooting force and lateral root spread was statistically significant ($P < 0.05$).

Figure 4 shows the dependency of the uprooting force on the plant height for the investigated plants. Taller plants show higher uprooting resistance and require higher pullout forces. Figure 5 shows the relationship between the maximum uprooting force and the maximum lateral root spread. Vetiver plants with root system that spread wider are able to resist uprooting better than the plants with root systems that do not reach far from the stem base.

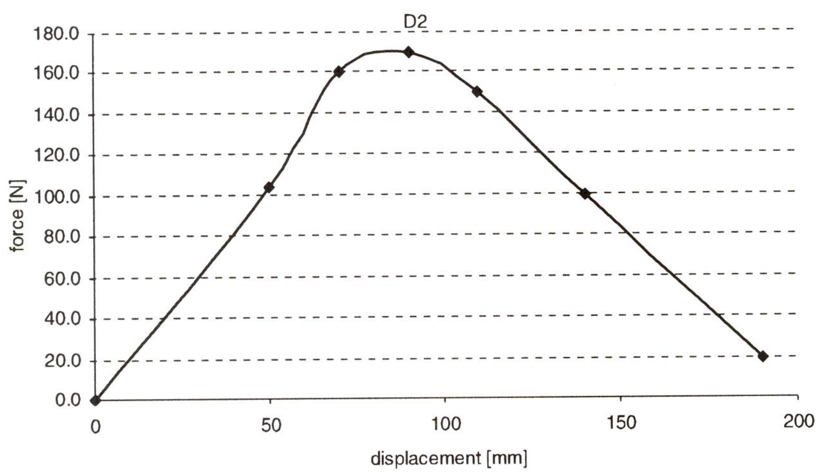

Figure 3. Typical force–displacement curve for a pullout test on vetiver grass (sample D2). The uprooting force increased with displacement to its peak value and then started to decrease due to root slippage or breakage.

Table 2. Correlation between the force necessary to uproot the plant and other morphological factors. Analysis based on $n = 22$ plants

Factor	Correlation coefficient R^2	Significance	Factor	Correlation coefficient R^2	Significance
Plant height	0.598	0.019*	Lateral root spread	0.517	0.048*
Number of stems	0.218	0.435	Root:shoot ratio	0.013	0.768
Plant diameter at base	0.130	0.644	Total CSA	0.236	0.397
Maximum rooting depth	0.201	0.472	Number of primary lateral roots	0.246	0.377
Average root length	0.378	0.165	Average root diameter	0.07	0.804

* significant at a 0.05 level.

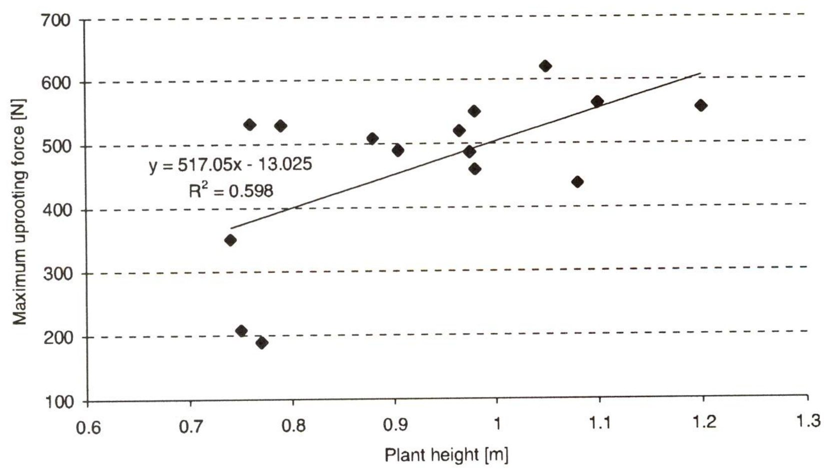

Figure 4. The relation between the maximum uprooting force and the plant height in the investigated vetiver grass (*Vetiveria zizanioides*) plants. Taller plants resist uprooting forces better than shorter plants.

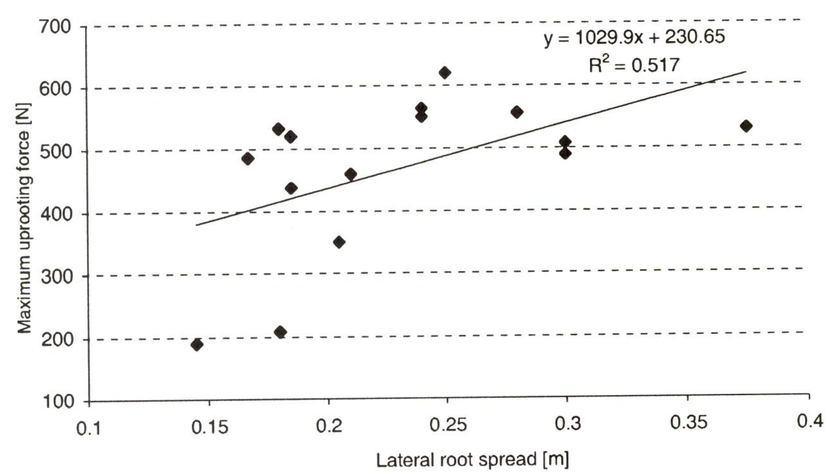

Figure 5. The relation between the maximum uprooting force and the maximum lateral spread of root systems in investigated vetiver grass (*Vetiveria zizanioides*) plants. Plants with wider-spreading roots resist uprooting forces better than the plants with roots systems that do not reach far from the stem base.

Discussion

The morphology of the investigated plants did not confirm findings on the plant morphology of vetiver grass in earlier studies. While the plant height reached almost the average reported for the vetiver in its natural environment (Erskine, 1992; Mishra et al., 1997; Hengchaovanich, 1999), neither the number nor the length of the roots reached the values reported in earlier studies (Salam et al., 1993, Mishra et al., 1997, Truong, 1999). Possible causes for the 'underdevelopment' of the root system might be the soil type and the severity of climatic conditions over the growth period (Paul Truong, personal communication). The topsoil is more structured and stores most water and nutrients available to the plant as the underlying marl has a dense structure. Moreover, during the short growth season under the Mediterranean climate the soil dries out and becomes more hard. While the local availability of water due to drip irrigation also prevents root expansion. Hence, the full root development, particularly in length and abundance observed in deeper, drainable soils such as present in the Tropics have not been achieved at the time of testing.

In Mediterranean environments therefore, where soils are shallow and water is scarce over the growing season, it would be more economical for plants to have the roots closer to the soil surface. This would explain the biased investment in aboveground biomass of vetiver observed at this site when water is available. This leads to successful growth as long as irrigation is applied over the growing season but when dependent on natural rainfall that often falls outside the growing season of vetiver, it loses the competition to endemic species that are better adapted.

Despite the poor root development, correlation and regression analysis showed that taller plants will resist uprooting better than the shorter ones, which was to be expected given the relatively constant root:shoot ratio. Plants that invest more in their above ground parts would also invest more in the proliferation of their root systems. Furthermore, the increase in uprooting resistance of plants that have root systems with extensive lateral spread can be explained by the fact that larger lateral spread also means larger anchoring length of the lateral roots. Bearing in mind that the lateral roots, especially the upslope ones (opposite of the side where the uprooting force was applied) provided most of the resistance for the plant resisting in tension, it is clear that larger anchorage length will provide better friction on the root–soil contact thus increasing the overall resistance of the root to pullout (Cheng et al., 2003). The differences in lateral root spread can be explained in terms of local differences in water and nutrient availability.

Even the limited root systems of the investigated vetiver grass proved able to withstand relatively high uprooting forces acting downslope. This high resistance shows that in a case of torrential rains and suspended runoff it can block the runoff and trap sediment behind the hedge. This function was tested during the extreme rainfall event that occurred in April 2004. One vetiver plot withstood the rain and hardly any sediment was collected. The other vetiver plot, however, received most of the overland flow generated on the overlying terrace and the riser failed as a slump with the slip plane at 30–40 cm, below the roots of the established vetiver.

The investigation of *Vetiver zizanioides* planted for soil and water conservation on a bench terrace riser in Spain showed that soil depth, water availability and to a lesser extent temperature, adversely influence root development in Mediterranean environments. Competition between native vegetation and vetiver highlights the poor adaptation of the vetiver, and shows that the dense, deep and columnar root systems can not develop to the same extent as under its native tropical and subtropical environment (Figure 6). Rooting depth is therefore the crucial factor for the performance of vetiver on steep slopes in Mediterranean environments as the event in April 2004 showed. Still, the uprooting force of the vetiver is high and sufficient to withstand the water and sediment loads that would apply during torrential runoff for which it may remain of interest for soil and water conservation in Mediterranean environments. However, because of its dependence on irrigation and advantageous soil conditions, vetiver seems more suitable for use in engineering solutions when sites are carefully prepared and maintained rather than as a species amenable to low cost vegetative solutions.

Acknowledgements

The work on this paper was funded under the framework of the ECOSLOPES project (EU, QLK5-2001-00289). Planting material was kindly provided by Mike Pease, the European and Mediterranean Vetiver Network Coordinator.

References

van Beek L P H 2002 Assessment of the Influence of Changes in Land Use and Climate on Landslide Activity in a Mediterranean Environment Netherlands Geographical Studies 294. KNAG, Utrecht. 363 pp.

Böhm W 1979 Methods of Studying Root Systems. Springer Verlag, Berlin.

British Standard 1377 1990 Methods of Test for Soils for Civil Engineering Purposes. British Standards Institution, London.

Cheng H, Yang X, Liu A, Fu H and Wan M 2003 A study on the performance and mechanism of soil reinforcement by herb root system. In Proc. of 3rd Int. Vetiver Conf., Guangzhou, China, 6–9 October 2003. China Agriculture Press, Beijing, China pp. 403–410.

Dalton P A, Smith R J and Truong P N V 1996 Vetiver grass hedges for erosion control on a cropped flood plain: hedge hydraulics. Agr. Water Manage 31(1996), 91–104.

Erskine J M 1992 Vetiver grass: its potential use in soil and moisture conservation in Southern Africa. S. Afr. J. Sci. 88(6), 298–299.

Grimshaw R G 1989 A review of existing soil conservation technologies, and a proposed method of soil conservation using contour farming practices backed by vetiver grass hedge barriers. In Proc. vetiver Grass Seminar at the Int. Agric. Centre in Wageningen, The Netherlands, January, 1989.

Hellin J and Haigh M J 2002 Better land husbandry in Honduras: towards the new paradigm in conserving soil, water and productivity. Land Deg. Dev. 13(3), 233–250.

Hengchaovanich D 1999 Fifteen years of bioengineering in the wet tropics: from A (*Acacia auriculiformis*) to V (*Vetiveria zizanioides*). In Proc. First Asia Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilisation, Manila, Philippines, April 1999. pp 54–63. International Erosion Control Association, Steamboat Springs, USA.

Meyer L D, Dabney S M and Harmon W C 1995 Sediment-trapping effectiveness of stiff-grass hedges. Trans. ASAE 38(3), 809–815.

Mishra V K, Ranade D H, Joshi R C and Sharma R A 1997 Vetiver: A miracle grass. Review of an international conference (Chiang Rai, Thailand, February 4–8, 1996). Crop Res. (Hisar) 13(2), 507–509.

van Noordwijk M, Brouwer G, Meijbroom F, Oliveira M R G and Bengough A G 2000 Trench profile techniques and core break methods. *In* Root methods: a handbook. Ed. A L Smit. pp. 211–233. Springer, Berlin.

Salam M, Abdul Shehana R S, Mammen M K and Kunjamma P M 1993 Rooting pattern of vetiver (*Vetiveria zizanioides* (L.) Nash) in an oxisol. Tropical Agriculture 70(3), 274–275.

Truong P N, 1999 Vetiver grass technology for land stabilisation, erosion and sediment control in the Asia Pacific region. In Proceedings of First Asia Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilisation, Manila, Philippines, April 1999. pp 72–84. International Erosion Control Association, Steamboat Springs, USA.

Truong P and Loch R, 2004 Vetiver System for erosion and sediment control. In Proc. 13th International Soil Conservation Organisation Conference, Brisbane, Australia, July 2004. pp. 1–6.

World Bank 1990 Vetiver Grass – The Hedge Against Arosion, 3rd ed. Washington D.C.

Zar J H 1998 Biostatistical Analysis. 4th ed. Prentice Hall, New York, USA. 929 pp.