Reprinted from

Agricultural water management

Agricultural Water Management 31 (1996) 91 - 104

Vetiver grass hedges for erosion control on a cropped flood plain: hedge hydraulics

P.A. Dalton [a,*], R.J. Smith [a], and P.N.V. Truong [b]

[a] *Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Qld. 4350, Australia*

[b] *Natural Resource Management, Queensland Department of Primary Industries, Indooroopilly, Qld. 4068, Australia*

Received 26 June 1995; accepted 27 October 1995

Vetiver grass hedges for erosion control on a cropped flood plain: hedge hydraulics

P.A. Dalton [a,*], R.J. Smith [a], and P.N.V. Truong [b]

[a] *Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Qld. 4350, Australia*
[b] *Natural Resource Management, Queensland Department of Primary Industries, Indooroopilly, Qld. 4068, Australia*

Received 26 June 1995; accepted 27 October 1995

Abstract

Vetiver grass is a tall perennial tussock grass from Asia which has been used in a variety of soil conservation applications in that region. Interest in this grass outside Asia is increasing but its application is handicapped by a lack of quantitative knowledge of its flow-retarding and sediment-trapping capability. In this paper, trials aimed at a quantitative description of the hydraulic characteristics of stiff vetiver grass hedges are described. Three hedges were planted across a large outdoor flume, perpendicular to the flow. Trials were conducted at various discharges and depths. The discharge and the depths upstream and downstream of each hedge were recorded. From these data a hydraulic relationship was developed between the depths and the discharge. Finally, this relationship was used to calculate the maximum vetiver grass hedge spacing required to control soil erosion on a cultivated flood plain of low slope subject to overland flow.

Keywords: Vetiver grass hedges; Erosion control; Flood plain

1. Introduction

1.1. Vetiver grass

Vetiver grass *(Vetiveria zizanioides*, L. Nash) is a tail (1-2 m), fast-growing, perennial grass which form a dense hedge when planted closely in rows. Vetiver grass is native to south and south-east Asia where it has been grown for centuries for its aromatic oil (from the roots), roof thatching and fodder for livestock. Vetiver grass was first used for soil conservation and land stabilisation purposes in Fiji in the early 1950s (Truong and Scattini, 1990). Vetiver grass is now being used world-wide as a low-cost, low-technology and effective means of soil and water conservation and land stabilisation (Truong, 1993a).

Vetiver grass hedges have the morphological and physiological characteristics that are ideal for the purposes of soil and water conservation. The plant has stiff erect stems and a fast growing extensive root system (up to 3 m deep in 12 months). New shoots and roots will grow readily from its base when buried in sediment. Vetiver is tolerant to extremes in temperature (- 10° 48° C in Australia), soil moisture and soil acidity and alkalinity (pH from 3.3 to 10.5). The plant also adapts to adverse soil conditions such as AI and Mn toxicities and high soil salinity and sodicity.

Recognising this potential in combating land degradation, the World Bank in the last 10 years has promoted the vetiver grass system as a simple, practical, low-technology and low-cost system for soil and water conservation in developing countries. The vetiver system is known as the 'flow-through' system in contrast to the conventional diversion system used in contour banks. The flow through system allows erosive flood flows to be spread laterally reducing the velocity but allowing the water to remain flowing over and thus irrigating the land being protected (World Bank, 1990).

A recent review conducted by the US Board of Science and Technology for International Development (National Research Council, 1993) concluded that the vetiver grass system has provided an effective and simple means of soil erosion and sediment control, citing successful applications in numerous countries throughout the tropical and subtropical regions of the world in Asia, Oceania, America and Africa. Applications include stabilisation of slopes, terraces and channel banks; gully and washout control; reclamation of wind eroded scalds; and as a replacement for the traditional structural soil conservation measures such as contour banks.

Field trials have been performed in Queensland since 1988 to evaluate vetiver in a number of situations, including: contour bank replacement on steep cane lands; for the stabilisation of eroded gullies and mine spoil; stabilisation of steep and unstable embankments and filter strips on waterways to prevent the ingress of non-point source pollutants. In addition, glasshouse trials have been conducted to establish the tolerance level of vetiver grass under extreme levels of soil pH, salinity, sodicity, AI and Mn (Truong, 1993b; Truong, 1994; Truong et al., 1995).

Vetiver grass is normally established vegetatively by slips because establishment from seeds is extremely difficult and slow. A sterile cultivar of vetiver grass, registered as Monto Vetiver in Queensland, is recommended to reduce its potential to spread as a weed (Truong and Creighton, 1994). Fig. 1 shows an example of a hedge of Monto Vetiver.

Despite the extensive use of vetiver grass to control erosive water flows and anecdotal research, few studies are known which describe the hydraulic characteristics of vetiver hedges in a quantitative sense. Rodriguez (1993) used simulated rainfall to determine empirical relationships between soil loss and slope length for hedges planted on steeply sloping land. However the results he obtained are only applicable to the uppermost of a sequence of hedges.

A more useful result was provided by Rao et al. (1992) and Rao et al. (1993). They demonstrated the reduction in runoff and soil loss resulting from hedges planted along the contour on slopes of 2.8% and 0.6%. Of particular interest to the present project are the results for the lower slope. Here the vetiver hedges reduced the peak rate of runoff by approximately 64%.

1.2. Strip cropping

Strip cropping was first practised in the United States in the 1930s to control water and wind erosion on slopes up to 16% (Hays and Clarke, 1941: Borst et al., 1945). In Australia, strip cropping has been practised in a unique manner since 1956 (Macnish, 1980) to control water erosion on low gradient lands (up to 0.5% slope) subject to relatively deep, major overland flooding. Practised mainly on the Darling Downs of Queensland and the north-western slopes of New South Wales, this form of strip cropping consists of a sequence of crop, stubble and fallow strips of uniform width arranged perpendicular to the flood flow (Smith et al., 2991).

The aim is to spread the flood waters laterally thus reducing the depth and velocity of flow. Further, the flow-retarding effect of the vegetative strips may provide an additional control on the velocity of flow across the fallow strips.

Smith et al. (1991) presented an analysis of flood flow through strip cropping for the purpose of determining optimum strip spacing guidelines in strip farming systems on the flood plain. The guidelines developed considered particular soil types, land slopes, flood discharges and crop rotations. Successful implementation of strip cropping requires care in the selection of crops, rotations, strip widths and cultural practices. However, with certain crops, or in drought years when little or no stubble remains from previous crops, the soil is unprotected. Perhaps more importantly, at any time, more than 30% of the land available for cropping is not producing, being under stubble or fallow.

If vetiver hedges, planted at appropriate spacings at right angles to the flow direction, could provide sufficient retardance to the flood flow, the management of strip cropped areas would become much simpler and more flexible. The hedge could provide a more effective means of spreading flood flows in drought years and with low stubble-producing crops.

In the present paper controlled flume trials aimed at a quantitative description of the hydraulic characteristics of vetiver grass hedges are described. The role of vetiver hedges in erosion prevention on lands of low slope subject to overland flow is discussed and a method for calculating the appropriate hedge design spacing is illustrated.

2. Discharge depth equation

There is little precedent in the literature on which to base a hydraulic description of the flow through a dense hedge. The only study known to the authors (Klaassen and van der Zwaard, 1974) simply derived effective values of the Chezy C for a flood plain transected by hawthorn hedgerows. A possible direction is provided by the literature on flow through more extensive vegetation, much of which was reviewed by Smith et al. (1990). The flow of water through a continuous stand of tail vegetation described by Turner et al. (1978), Turner and Chanmeesri (1984) and Smith (1982) can be quantified by an empirical discharge depth equation. For a grass hedge the stand of tail vegetation is discrete in nature and hence the form of equation described in this literature is not directly applicable. However, developing this theory for a discrete grass hedge produces a similar useful equation. The equation development is reviewed below.

The flow of water in natural channels, including overland flow on flood plains, is most commonly described by the empirical Manning equation which when expressed m' a form that describes the discharge per unit width of overland flow, q is

$$q= (1/n)S_f^{1/2}Y^{5/3} \qquad (1)$$

where n is the Manning roughness coefficient, S_f is the slope of the energy line and y is the depth of flow.

The inability of the Manning equation to describe flow over or through flexible vegetation led to the use of discharge-depth equations (Turner et al, 1978) of similar form to the Manning equation:

$$q=ky^m \qquad (2)$$

where the coefficient k describes the geometry of the land surface and is a function of the surface roughness and land slope. Turner et al. (1978) suggested that the exponent m would vary between 1.7 and 3 depending on the flow conditions.

Turner et al. (1978) and later Turner and Chanmeesri (1984) showed that the discharge-depth equation could describe shallow flows through tail vegetation for

Fig. 2. System of flow through a vetiver grass hedge and definition of terms in the discharge-depth equation.

depths up to 0.1 m and at discharges up to 0.01 $m^3 s^{-1}$ per unit width. For deeper flows Smith (1982) was able to quantify the effect of the land surface slope and hence the energy slope. He determined the parameters for a more general form of the equation

$$q=AS_f^b y^c \quad (3)$$

where A, b and c are constants for the particular vegetation. This form of equation was subsequently used by Smith et al. (1990) to describe relatively deep flows through the broadacre crops typically used in strip cropping.

The flow system in the vicinity of a vetiver grass hedge is defined in Fig. 2. The application being considered is on a flood plain of low slope (< 0.5%) hence upstream and downstream of the hedge the flows will be subcritical. Across the hedge the change in bed elevation will be negligible and an energy loss δE will be assumed to occur over the thickness δx of the hedge.

An equation similar in form to Eq. (3) might be assumed to apply. In this case the energy slope S_f be replaced by $\delta E/\delta x$ and the depth y by the depth upstream of the hedge y_1 giving

$$q = a\delta E^b y_1^c \qquad (4)$$

where the coefficient a is equal to $A/\delta x^b$. Finally, if the difference between the velocity heads upstream and downstream of the hedge is small, the energy loss δE might be approximated by the depth difference δy, then

$$q = \alpha\delta y^\beta y_1^\chi \qquad (5)$$

An equation of similar form can be developed assuming that the hedge behaves like a submerged orifice. While neither approach could be described as rigorous the equations provide a vehicle for the analysis of experimental data.

3. Experimental

3.1. The flume facility

The outdoor flume facility at the University of Southern Queensland was originally built for the purpose of making hydraulic retardance measurements on the crops commonly used in the soil conservation technique of strip cropping. It is described in detail in Smith et al. (1990). The particular channel used in the vetiver experiments is 20 m long, 2 m wide and has a bed slope of 0.25%. Discharges of up to 300 1 s^{-1} are supplied by a 350 mm diameter axial flow pump and measured using a 300 mm diameter McCrometer in-line propeller flow meter. A drop board weir at the downstream end of the channel allows control over the depth and velocity of flow for any given discharge. Depths up to 0.6 m can be obtained in this manner.

Longitudinal depth profiles can be monitored by a series of manometers located at 1 m intervals along the centre line of the channel. These manometers protrude 30 mm above the channel bed and are connected to a manometer board in the nearby instrument shed. The depths can be measured with a discrimination of 1 mm.

3.2. Experimental method

The vetiver grass hedges were planted across the flume in October 1992. The planting material was provided by the Queensland Department of Primary Industries in the form of pot-raised plants. Each hedge comprised 15 plants spaced about 125 mm apart. The hedges were irrigated as required over the summer of 1992/1993 and quickly grew to a height of about 1.5 m. Since planting the vetiver has continually produced new shoots, with adjacent plants meshing together to form a strong, dense hedge (Fig. 1).

Three hedges were planted 5 m apart to speed up the rate of data collection. The upstream hedges were under the influence of the backwater from the hedge downstream. Hence for any discharge and downstream drop board setting each hedge would have a different combination of upstream and downstream depth and thus three data points would be obtained.

Trials were performed in March, July, September and December 1993 and July 1994. Each trial consisted of measurements of the depths upstream and downstream of each hedge for a range of discharges up to 125 1 s^{-1} and for various drop board settings (that is, depths at the downstream end of the flume). A detailed description of the experimental procedure is to be found in Dalton (1993).

The vetiver grass remained unsubmerged in all trials, the maximum depth of flow being 0.6 m. Even though there was a substantial difference in the water levels either side of a hedge, the plants showed little tendency to flex and remained upright throughout the tests. Fig. 3 shows one hedge during a trial.

4. Evaluating the constants in the discharge-depth equation

Eq. (5) suggests a form for a discharge-depth equation to describe the hydraulic characteristics of a vetiver grass hedge. Multivariate non-linear regressions were attempted using the measured values from the first trial of the variables q, y_1, Y_2, δy and δE in various combinations, with that described by Eq. (5) giving the best fit. or the subsequent trials only that form of equation was used. The regression results for the combined data measured at the three hedges for the five trials are presented in Table 1.

From these results it appears that Eq. (5) provides an adequate description of the hydraulic characteristics of the vetiver hedge. As the hedges developed the fit improved, as evidenced by greater r^2 , suggesting that minor differences in initial hedge geometry become insignificant with age. The remainder of the variability in the discharge, q, not predicted by the regression equation, must be due to differences between the hedges. As an illustration, Fig. 4 compares the discharges measured in the final trial with those predicted using Eq. (5) and the corresponding parameter values for the July 1994 flume trial.

For a given discharge, the flow depths for each hedge were different. At hedge l, the furthest upstream, the flow was deepest and at hedge 3 shallowest. From Fig. 4, it can be seen that the hydraulic behaviour of the three hedges differs slightly because of the difference in flow depths and/or velocity through each hedge.

Table 1

Parameters a, b and c in the discharge-depth equation for each flume trial and the regression coefficients. r^2

Trial	a	b	c.	r^2
March 1993	1.65	0.57	2.16	0.900
July 1993	0.96	0.54	1.85	0.957
September 1993	0.74	0.48	1.81	0.968
December 1993	0.66	0.62	1.78	0.969
July 1994	0.51	0.46	2.44	0.963

There was a trend in the values of the coefficient a and the exponents b and c for the first three trials. However, the cessation of this trend for the final trials makes prediction of the parameter values for a mature hedge difficult. There is also a trend in the discharges predicted for any given flow depths. For example, Fig. 5 shows the relationship between discharge and upstream depth for a given downstream depth for each set of parameter values. The effect of hedge maturity or thickness is clearly evident.

The hedges tested in July 1994 (which were then 20 months old) appeared to have sufficient retardance at least for effective use on the flood plains. To date no attempt has been made to measure or describe the thickness or density of a vetiver hedge and relate this to the retardance of the hedges or to its age. The results indicate that the vetiver hedges may continue to thicken and become more resistant to flow, perpetually. The authors have no indication of what may constitute an optimum or desirable hedge thickness. However such a maximum may need to be nominated. The hedges could be maintained at that optimum hedge thickness by ploughing out any vetiver which tillers beyond that thickness.

It should be noted that the data and regressions described above are limited in their applicability, namely:

1. the maximum depth of flow was 0.6 m and the regression coefficients would not be valid at greater depths;
2. the flow downstream of each hedge was not normal for the discharge but was subject to a backwater from a downstream control.

5. Application of vetiver hedges on a cropped flood plain

The cropped flood plains of the Darling Downs are subject to regular deep overland flood flows that originate from rainfall occurring in upland catchments which discharge on to the plain. Strip cropping is currently being used successfully to spread and reduce the velocity of these flows on the plains when seasons provide adequate crop cover.

According to Smith et al. (1991) strip cropping widths in this application are a function of the anticipated discharge, the soil erodibility, the land surface slope and the land surface roughness. The discharge is estimated using an appropriate design storm and hydrologic procedure for the catchment. The flood discharges on the plains are significantly large compared with the spatially and temporally variable parameters of local infiltration and rainfall. Hence these parameters are insignificant and are ignored in the flow model. Soil erodibility is commonly described by soil conservationists for the design of soil conservation structures in terms of the maximum permissible velocity of flow (Vmax) for a particular soil type and condition. Appropriate values for the soil erodibility, land slope and roughness are site specific.

The water surface profile through a strip cropping sequence is a series of drawdown or M2 curves (Chow, 1959) in the cropped or high retardance strips and backwater (M I) curves (Chow, 1959) in the fallow or low-retardance strips. The backwater curve is defined by the gradually varied flow equation

$$\frac{dy}{dx} = \frac{S_O - S_f}{1-N_f^2} \qquad (6)$$

where S_0 the land surface slope, S_f is the energy slope and N_F the Froude number of the flow. The energy slope is determined from either the Manning equation (Eq. 1) or the discharge-depth equation (Eq. 3).

The strip cropping widths developed by Smith et al. (1991) have been proven successful in their application for soil conservation on the flood plains of the Darling Downs. Hence in the case of cropping between vetiver hedges on the flood plain a similar model could be used to calculate the appropriate hedge spacing. The drawdown profile would be replaced by the change in depth (or energy difference) across the hedge (as defined by Eq. (5)), with a backwater curve occurring over the bare strip between the hedges. The worst (or least protected) case will be that of bare soil between the hedges for which an appropriate value of the Manning *n* would be selected. The physical flow model is illustrated in Fig. 6.

For given values of q, n, S_o V_{max}, the hedge spacing required can be calculated from Eqs. (5) and (6) if it is assumed that the maximum velocity of flow occurs at the downstream side of the hedge. This point coincides with the upstream edge of the bare soil strip between the hedges.

The form of the hedge spacing relationships are shown in Figs. 7 and 8. The hedge spacings indicated in these figures are comparable to the strip widths in conventional strip cropping, suggested by Smith et al. (1991). For any combination of the variables q, S_o, Vmax and n, the hedge spacings are greater than the conventional strip cropping widths.

It appears that vetiver grass hedges could be successfully applied beyond slopes of 0.5%, for which strip cropping is successful, up to approximately 2% if relatively narrow hedge spacings were tolerated by farmers. There is a minimum discharge below which hedges are not required for erosion control and above which the hedge spacings are essentially independent of the discharge. The presence of crops between the hedges will serve as greater protection to the soil although the design does not take their retardance into account.

From Fig. 7 the application of vetiver to lands steeper than 2% in slope does not seem valid. However, on these steeper upland slopes the flow model used in the above design would not apply. Unlike the flood plains case the flow would be unsteady, influenced significantly by local rainfall and infiltration. Overland flow from rainfall further upstream in the catchment would be less significant. The application of an unsteady flow model to vetiver spacing design on the steeper upland slopes may provide hedge spacings that are practical in that situation.

The model used by Smith et al. (1991) to develop the strip cropping widths uses the parameters of discharge and soil erodibility based on a good knowledge of the hydrologic and agronomic properties of the flood plains of the Darling Downs. The strip cropping designs based on this model have been proven successful in their application on the flood plain. The hedge spacings calculated above have been developed from a similar model of the flood plain flows and catchment characteristics. The topographical, hydrological and soil parameters remain the same in the application of vetiver. The only difference is the 'hydraulics' of flow through the vegetation as quantified in the flume trials. It is therefore suggested that vetiver hedges used at these hedge spacings are a feasible option for erosion control on cropped flood plains.

In accordance with the above model of flow through vetiver hedges on a flood plain design spacings were selected for a field trial site near Jondaryan, on the Darling Downs of Queensland to validate the model. The various catchment and farm characteristics critical to the selection of the vetiver hedge spacing were considered before a hedge spacing of 91.5 m (that is five existing 18.3 m strip widths) was selected for the site. In December 1993, the site was planted to vetiver on the contour at these hedge spacings.

In the event of a flood, discharges and depths of flow and sediment movement will be monitored at this site to validate the hedge spacing model and monitor the effectiveness of the hedges.

6. Conclusions

The work presented in this paper is an attempt to quantify the hydraulic characteristics of vetiver grass hedges and to develop guidelines for hedge spacings on a cropped flood plain. It is possible to draw certain conclusions.

First, the flow through the hedge can be described by a simple equation relating discharge to the depths upstream and downstream of the hedge, with upwards of 90% of the variation in discharge described by the equation.

Secondly, it appears hydraulically feasible to use vetiver hedges to control flood flow and erosion on cropped flood plains. The hedge spacings required are comparable to and slightly greater than the strip spacings required for conventional strip cropping but are far less sensitive to the magnitude of the discharge. The validation of the strip cropping model in field conditions would suggest that the hedge spacings derived from a similar model are feasible to control erosion.

Finally, it also appears that vetiver grass hedges may be feasible at land slopes between 0.5 and 2%. This range of land slopes is not successfully protected from soil erosion by strip cropping or contour banks. If a narrow design spacing between vetiver hedges could be tolerated by farmers then vetiver grass would successfully protect these land slopes.

Although the equation has only been applied to design spacings on a flood plain it might be assumed that the hydraulic equation could be applied to vetiver hedge spacing design for soil conservation on various topographical situations provided the hedge remains unsubmerged in the flow. The design would also involve using an appropriate model of the flow between the hedges. Further work to evaluate the performance of hedges in field trials on the flood plain has commenced and will continue for several years.

Acknowledgements

The authors wish to thank Clive Knowles-Jackson and David Wildermuth of the Queensland Department of Primary Industries for their assistance in the planning and establishment of field trials, Mark Henseli of the Jondaryan Landcare group for the use of his property for the field trial site and Trevor Glasby of the University of Southern Queensland for his assistance in the flume trials. This project is funded by the National Landcare Program.

References

Borst, H.C., McCall, A.G. and Bell, F.G., 1945. Investigations in erosion control and reclamation of eroded land at the north-west Appalachian conservation experiment station, Zanesville, OH 1934-1942. US Dep. Agric., Tech. Bull. No. 888, pp. 1-95.

Chow, V.T. 1959. Open Channel Hydraulics, International Student Edition.
McGraw-Hill, Auckl,md.

Dalton, P.A.. 1993. The hydraulics of vetiver grass. B.Eng. (Agric) Honours Thesis, University of Southern Queensland, Toowoomba.

Hays, O.E. and Clarke, N., 1941. Cropping systems that help control erosion. Univ. Wis., Agric. Exp. Stn, Bull. No. 452.

Klaassen, G.J. and van der Zwaard, J.J., 1974. Roughness coefficients of vegetated flood plains. J. Hydraul. Res., 12:43-63.

Macnish, S., 1980. A review of strip cropping practices on the eastern Darling Downs. Rcp. No. 80/11, Queensland Department of Primary Industries, Division of Land Utilization.

National Research Council, 1993. Vetiver Grass, A Thin Green Line Against Erosion. National Academy, Washington, DC.

Rao, K.P.C. Cogle, A.L. and Srivastava, K.L.. 1992. Conservation effects of porous and vegetative barriers. In: A.P. Patancheru (Editor), Resource Management Program, ICRISAT 1992, Annual Report 1991. India: Resource Management Program, International Crops Research Institute for Semi-arid Tropics (semiformal publication).

Rao, K.P.C., Cogle, A.L. and Srivastava, K.L., 1993. Conservation effects of porous and vegetative barriers. In: A.P. Patancheru (Editor), Resource Management Program, ICRISAT 1993, Annual Report 1992. India:

Resource Management Program, International Crops Research Institute for Semi-arid Tropics (semi formal publication).

Rodriguez, O.S., 1993. Hedgerows and mulch as soil conservation measures evaluated under field simulated rainfall. In: Int. Workshop on Soil Erosion Processes on Steep Lands, Merida, Venezuela, 16-20 May 1993.

Smith, R.J., 1982. Design of grassed waterways -- a new approach. In: Proc. Syrup on Rural Drainage in Northern Australia, Darling Downs Institute of Advanced Education, Toowoomba.

Smith, R.J., Hancock, N.H. and Ruffini, J.L., 1990. Flood flow through tall vegetation. Agric. Water Manage., 18: 317-332.

Smith, R.J., Hancock, N.H. and Ruffini, J.L., 1991. Strip cropping -- development of guidelines lbr the selection of strip spacing. Agric. Water Manage., 20: 1-16.

Truong, P.N.V., 1993a. Report on the International Vetiver Grass Field Workshop. Kuala Lumpur. Aust. J. Soil Water Conserv., 6: 23-26.

Truong, P.N.V., 1993b. The effects of extreme soil pH on vctivcr growth. Vctivcr Ncwsl. No. 10, Asia Technical Department, The World Bank, Washington, DC.

Truong, P.N.V., 1994. Vetiver grass, its potential in the stabilisation and rehabilitation of degraded saline limd. In: V.R. Squires and A.T. Ayoub (Editors), Halophytes as a Resource for Livestock and for Rehabilitation of Degraded Lands. Kluwer Academic, Dordrccht. pp. 293-296.

Truong, P.N.V. and Creighton, C., 1994. Report on the Potential Weed Problem of Vetiver Grass and its Effectiveness on Soil Erosion Control in Fiji. Division of Land Management, Land Use and Group, Queensland Department of Primary Industries, Brisbane. Fisheries

Truong, P.N.V. and Scattini, W., 1990. Vetiver - The Hedge Against Erosion?.
3:16-18. Aust. J. Soil Water Conserv.,

Truong, P.N.V., Balker, D.E. and Christiansen, I.H., 1995. Effects of high soil acidity and high extractable Mn on vetiver grass growth, in press.

Turner, A.K. and Chanmeesri, N., 1984. Shallow flow of water through non-submerged vegetation. Agric. Water Manage., 8: 375-385

Turner, A.K., Langford, K.J., Wyn, M. and Clift, T.R., 1978. Discharge-depth equation for shallow flow. Proc. ASCE, 104(IRR 1): 95-110.

World Bank, 1990. Vetiver grass - The Hedge Against Erosion, 3rd edn. The World Bank, Washington, DC.