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Comparative analysis of the performance of mixed terraces and level and graded terraces

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ABSTRACT. The terracing of agricultural land is the most widespread mechanical practice used among farmers in the control of water erosion. The objective of this paper was to carry out a comparative analysis between mixed terraces and level and graded terraces. The dimensioning of level terraces was carried out based on the surface runoff volume, while the graded terrace dimensions were based on the maximum runoff flow rate. For the mixed terraces, the dimensioning was carried by considering two surface runoff hydrographs, one for the determination of the terrace channel capacity and another to estimate the flow rate at the extremity of the terrace channel. Therefore, in order to contain and transport the excess volume, an additional value was calculated and added to the depth of the channel. A case study was performed for the Uberaba, Minas Gerais State (Brazil) rainfall conditions, considering events with return periods of 10, 30, and 50 years. The obtained results provided quantitative evidence that mixed terraces have a lower height than level terraces and a higher level than the graded terraces, resulting in direct consequences for the soil movement for the terrace construction.

Keywords: terraces, soil and water conservation, control of water erosion.

Análise comparativa do desempenho de terraços mistos com terraços em nível e com gradiente

RESUMO. O terraceamento de terras agrícolas consiste na prática mecânica mais difundida entre os agricultores no controle da erosão hídrica. O objetivo deste trabalho foi proceder a análise comparativa do desempenho de terraços mistos com terraços em nível e com gradiente. O dimensionamento de terraços em nível foi feito com base no volume de escoamento superficial, enquanto o de terraços com gradiente foi baseado na vazão máxima de escoamento superficial. Para o dimensionamento de terraços mistos são utilizados dois hidrogramas de escoamento superficial, sendo um para a determinação da capacidade de armazenamento do terraço e o outro para a estimativa da vazão que escoa na extremidade do canal do terraço. Assim, de maneira a conter e transportar o excesso de volume escoado, um valor adicional foi calculado e somado à altura do canal. Um estudo de caso foi realizado para condições de precipitação de Uberaba, Estado de Minas Gerais (Brasil), considerando eventos de precipitação com período de retorno de 10, 30 e 50 anos. Os resultados obtidos permitiram evidenciar, quantitativamente, que terraços mistos requerem menor altura do que os terraços em nível e maior que os com gradiente, o que traz consequências diretas na movimentação de terra para a construção dos terraços.

Palavras-chave: terraços, conservação de água e solo, controle da erosão hídrica.

Introduction

Water erosion is the most important form of soil degradation. Besides leading to a reduction of soil fertility and declines in crop yields in farmlands, it causes strong financial and environmental impacts (BERTOL et al., 2007; ZUAZO et al., 2011).

Soil conservation Beneficial Management Practices (BMPs) play an important role in the control of water erosion (YANG et al., 2009; ZHOU et al., 2009). These practices are divided into three groups: fertilizer and soil amendments, which adjust the cropping system to maintain or improve soil fertility and also maintain its surface with greater coverage; vegetative, related to the use of vegetation to protect the soil against the direct raindrop action; and mechanical, based on the use of artificial structures in order to intercept and conduct surface runoff at a nonerosive velocity to stable outlets (PRUSKI, 2009).

Terracing, an agricultural technique for collecting water and reducing soil erosion (LIU et al., 2011; ZUAZO et al., 2005), is one of the best known and most widely used mechanical practices

(GRIEBELER et al., 2005). Terracing consists of a set of channels adequately spaced and placed so as to divide the long slope into short slopes (FAO, 2000; ZHANG et al., 2008), whose objective is to retain and infiltrate or intercept and transport, with a controlled flow velocity, the surface runoff originating from rains that exceed the infiltration capacity (AL ALI et al., 2008). A typical terrace unit consists of a terrace riser, a compacted central drain and a terrace bed that slopes backwards toward the central drain (VAN DIJK; BRUIJNZEEL, 2004). Depending on their function, terraces are classified as either level or graded.

Level terraces are built so that the channel is leveled, and the extremities are blocked so that the water coming from the surface runoff will be retained and infiltrated in the channel (FAO, 2000). Although this type of terrace is the most beneficial with respect to soil and water conservation, there are some risks associated with it, such as overtopping or, in the worst cases, break through. These are risks that can lead to the destruction of the downstream terraces, causing damage to the cultivated area and to the surrounding rural communities.

An alternative to reduce these risks is the construction of graded terraces, which are terraces constructed with the channel on a slight slope, accumulating the excess water and directing it to waterways that will safely transport water down slopes. However, these terraces present little effect with regard to water conservation and present a higher likelihood for erosion to occur in the waterway. Ehigiator and Anyata (2011), who studied the effects of land-clearing techniques and tillage systems on runoff and soil erosion, observed a high rate of erosion, even when graded-channel terraces were constructed to minimize soil erosion.

With this in mind, the use of mixed terraces, constructed such that the transport of the water to external areas only starts at the moment in which the water reaches a determined level, allows the advantages related to level terracing without taking on any of the risks associated with it. Up to a certain volume of runoff, mixed terraces act as level terraces, ensuring the accumulation and infiltration of water into the soil. After this volume is reached, the terraces begin working as graded terraces, promoting the transport of surplus runoff to outside areas. For events with little surface runoff, the mixed terraces ensure the infiltration of the total volume flow, and only remove the flow coming from extreme events when the retention of the total volume could put the hydraulic structures at risk. However, there are some limitations associated with mixed terracing, such as the difficulty of their design and location. With the aim of spreading the use of this type of terrace, a method based on physical concepts and mathematical techniques was developed for the design of mixed terracing systems (PRUSKI, 2009). Thus, the objective of this paper was to carry out a comparative analysis of the performances of mixed terraces and level and graded terraces.

Material and methods

The dimensioning of mixed terracing systems was based on the design of a surface runoff hydrograph using the principle that the flow increases until the time in which the water coming from the most distant point reaches the considered section, and after that, the flow decreases with time (PRUSKI, 2009). Two hydrograph limbs are identified (Figure 1): rising limb, where there is a growth of the flow rate over time because of the increased area of contribution to the runoff up until the considered section, and falling limb, where the flow rate decreases with time, starting at the time that water originating from the most remote cell reaches the considered section.

The hydrograph shown in the Figure 1 is also essential for the level and graded terracing systems. The necessary surface runoff volume for the level terracing systems design corresponds to the area under the hydrograph, while the maximum surface runoff flow rate, necessary for the graded terracing systems design, is equal to the hydrograph peak.

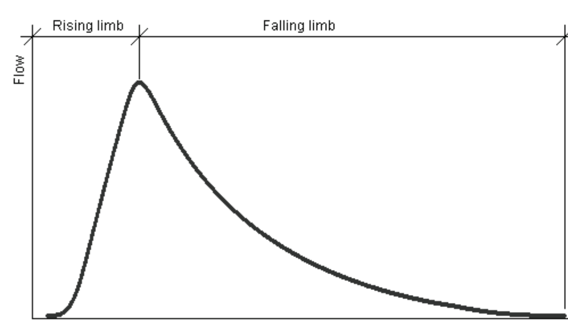
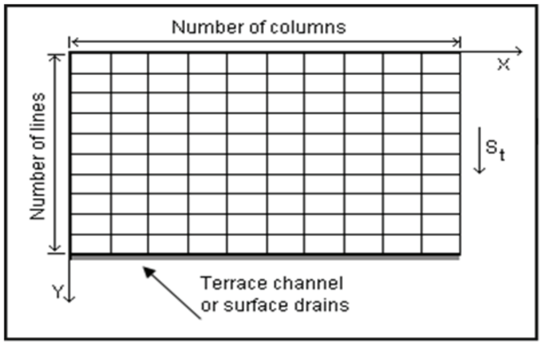
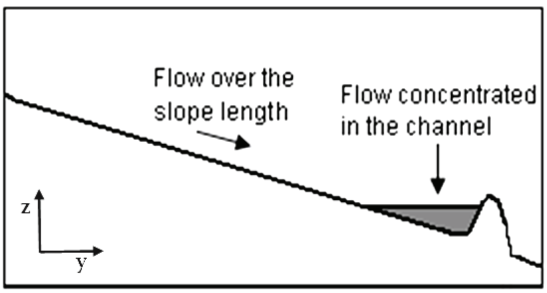


Figure 1. Graphic representation of a runoff hydrograph, showing the rising limb and the falling limb.

To obtain the hydrograph for any position of a slope field, terrace channels or surface drains, the slope field was divided using a matrix system that permits the analysis of the runoff at any position (Figure 2a). This is performed for two conditions: flow over the slope length and flow concentrated in the channel (Figure 2b).



a



b

Figure 2. Schematic representation of the division of the slope in a matrix system (a) and flow over the slope length and concentrated flow in the channel (b).

The equations of continuity and momentum for gradually varied unsteady flow are often referred to as the Saint-Venant equations (SINGH, 1996). The kinematic wave model is one of the ways to apply the Saint-Venant equations, and, according to Chua et al. (2008), Naik et al. (2009) and Chua and Wong (2011), the model is given by:

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = i_i - Tie \quad (1)$$

$$S_f = S_0 \quad (2)$$

where:

h is the runoff depth (L), t is time (T), q is the flow per unit of slope width in the hill slope ($L^2 T^{-1}$), x is the distance (L), i_i is the instantaneous rainfall intensity ($L T^{-1}$), Tie is the stable rate of infiltration ($L T^{-1}$), S_f is the slope of the energy line ($L L^{-1}$) and S_0 is the slope of the soil surface ($L L^{-1}$).

The kinetic wave model, considering $S_f = S_0$, was taken over the average cross-sectional area of the runoff on the hill. Using equations typically used for uniform conditions, the relationship between the flow and depth of the runoff was obtained, expressed by the following equation:

$$q = \alpha h^{\beta} \quad (3)$$

The α and β parameters were obtained using Manning's formula and expressed as:

$$\alpha = \frac{\sqrt{S_0}}{n} \text{ and } \beta = \frac{5}{3}, \quad (4)$$

where:

n is the roughness coefficient ($T L^{-1/3}$).

The value of the runoff depth was obtained by Equation 1 and solved using the method of finite differences according to the algorithm proposed by Bras (1990). This value was transformed into the flow value by Equation 3.

The instantaneous rainfall intensity is obtained from the rainfall intensity-duration-frequency equation, expressed by (PRUSKI et al., 1997):

$$i_i = i_m \left(1 - \frac{c\,t}{t+b}\right) \quad (5)$$

$$i_m = \frac{K\,T^a}{(t+b)^c} \quad (6)$$

where:

i_m is the average maximum rainfall intensity ($L T^{-1}$), t is the rainfall duration (T), T is the return period (T), and K, a, b and c are parameters for a given geographic location.

According to Silva el al. (2009), Rai et al. (2010) and Chua and Wong (2010), for open channel flow, the kinematic wave model is given by:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \quad (7)$$

$$S_f = S_c \quad (8)$$

where:

A is the cross-sectional area of the terrace (L^2), Q is the total flow in the channel ($L^3 T^{-1}$) and S_c is the slope of the canal bottom ($L L^{-1}$).

For the dimensioning of the mixed terracing system, it was assumed that until the full capacity of the channel was reached, all the water volume would be retained. After the capacity is surpassed, the flow in its extremity will then begin.

The channel capacity is calculated using an event with a given return period ($T_{storage}$) as a reference. In considering events with return periods greater than $T_{storage}$, two hydrographs are designed, one for $T_{storage}$ and another for the return period determined by the designer (T_{design}). The two hydrographs are superimposed (Figure 3), and the difference between the water volumes corresponds to the excess amount ($Q_{-Tstorage}$) that must be conducted to the extremities of the channel (PRUSKI, 2009). The vertical line

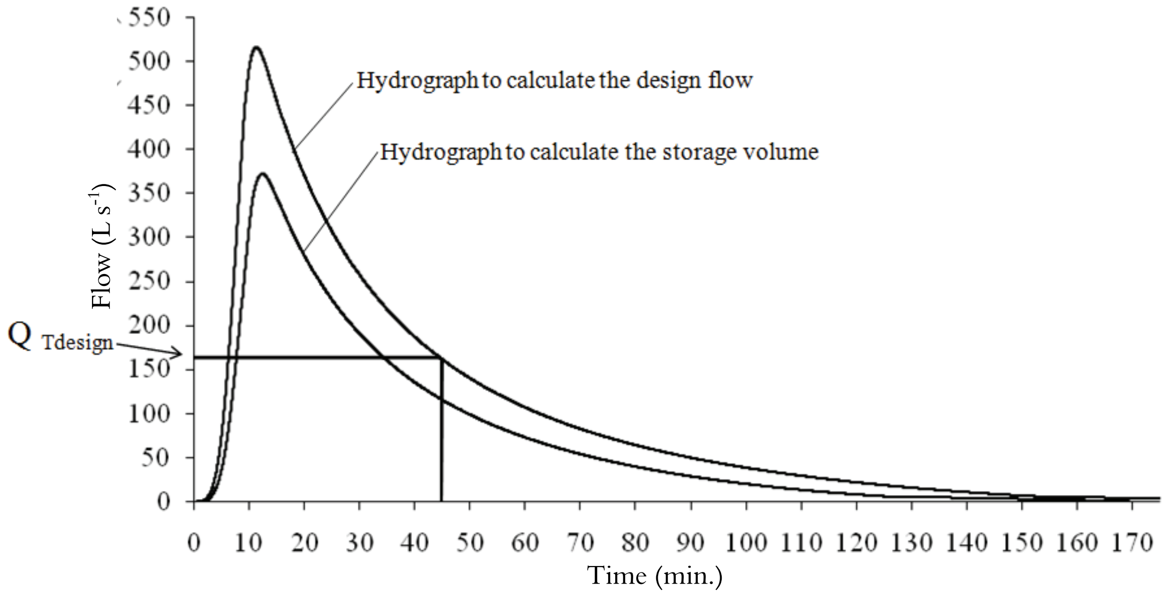


Figure 3. Graphic representation of runoff hydrographs for a return period equal to or greater than 10 years.

characterizes the time for which the flow volume, considering the hydrograph obtained with T_{design}, is equal to the total flow volume for the return period of $T_{storage}$ years.

To evacuate water, the mixed terraces have no gradient. They are built level with the lateral ends closed by a wall of height equal to the height (H) (Figure 4), determined according to the channel capacity to retain the amount corresponding to $T_{storage}$. When the runoff volume exceeds the channel storage capacity associated with the height H, the excess water volume should be drained to the outlets at one or both ends.

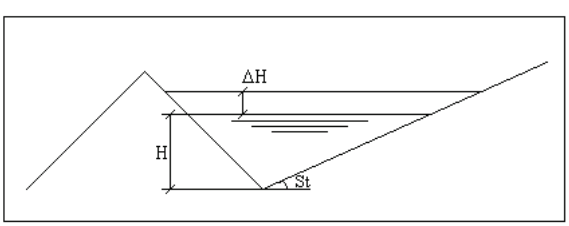


Figure 4. Representation of the cross-sectional area of a triangular terrace.

To contain and transport the excess water volume to the outlets, an increase in the depth of the channel (ΔH) is calculated using the Manning equation, which, for this condition, is solved using the Newton-Raphson method and expressed by:

$$\frac{Q_{max}\, n}{\sqrt{S_c}} = \frac{\Delta A^{5/3}}{\Delta P^{2/3}}, \qquad (9)$$

where:

Q_{max} is the maximum flow rate to be transported by the channel ($L^3\ T^{-1}$), ΔA is the increment of the area necessary to transport Q (L^2), and ΔP is the increment of the wetted perimeter when transporting Q (L).

The hydraulic gradient is calculated using the following equation:

$$S_c = \frac{\Delta H}{L}, \text{ to one outlet} \qquad (10)$$

$$S_c = \frac{\Delta H}{L/2}, \text{ to two outlets} \qquad (11)$$

where:

L is the length of the channel (L).

The design of the waterway can be performed using Manning's formula and the maximum flow rates to be transported at the terrace channel outlets, considering a segment obtained by the division of the waterway into sections according to each terrace outlet.

To compare the mixed terracing systems with the level and graded terracing systems, a case study was performed for the Uberaba (Minas Gerais State, Brazil) rainfall conditions considering $T_{storage}$ equal to 10 years and T_{design} equal to 30 and 50 years, a noncropped area with a 50 m slope length, 7% slope, no tillage and a roughness coefficient equal to 0.120. A channel with a triangular shape was assumed; this format is the most typical, with grass and some weeds added as a protective cover, with a roughness coefficient equal to 0.03, a gradient of the front slope of 66.7% and a 500 m length with two outlets.

The case study was performed considering a stable rate of infiltration in the soil equal to 15 and 30 mm h^{-1} and a slope of the canal bottom of 0.002 and 0.003 m m^{-1}.

The design of the surface runoff hydrographs was obtained using the software Hidrograma 2.1 (http://www.ufv.br/dea/gprh/softwares.htm), considering events with return periods of 10, 30 and 50 years.

Results and discussion

The surface runoff hydrographs obtained for return periods equal to 10, 30 and 50 years for one of the corresponding conditions of the case study (Tie = 15 mm h^{-1} and S_c= 0.002 m m^{-1}) are presented in Figure 5. The vertical lines represent the time for which the water volume, considering the return periods of 30 and 50 years, is equal to the total water volume corresponding to the 10-year return period.

For level terraces, an increase in the stored volume (up to 48%) and terrace depth (21.6%) occurred when the return period was increased from 10 to 50 years. For graded terraces, a reduction in water conservation efficiency is perceived because, whereas level terraces present a storage capacity for all the surface runoff, graded terraces are the ones that transport the runoff. In fact, the implementation, management and mechanization costs for graded terraces seem as though they would be minimized because of the shorter height in relation to level systems. However, with these systems, it is also necessary to consider the cost of the waterway for the runoff to be transported by the terraces.

Considering that a mixed system, as its name already implies, provides an intermediary solution between the two systems, Table 1 shows the effect of employing this system on storage capacity, terrace height, and on the volume and flow to be drained. With respect to the efficiency of water storage, which is zero for graded terraces, mixed terracing represents 84.2, 76.4 and 67.6% of that corresponding to level terraces for return periods of 20, 30, and 50 years, respectively. With respect to terrace depth, it was shown that with the mixed system, intermediate values between those observed for level and graded systems were obtained, as was expected, representing an alternative for the reduction of implementation and maintenance costs of the terraces.

For extreme events with return periods greater than 10 years and with greater magnitudes of surface runoff, the excess volume to be transported by the channel to the outlet was significantly less for mixed terracing, corresponding to 15.8, 23.6 and 32.4% of the maximum flows that would be transported in the waterways of the graded terraces for return periods of 20, 30, and 50 years, respectively.

With increasing Tie, a smaller amount of water will be transformed into runoff (volume or flow), reducing the required capacity for the terrace channel (level, graded and mixed).

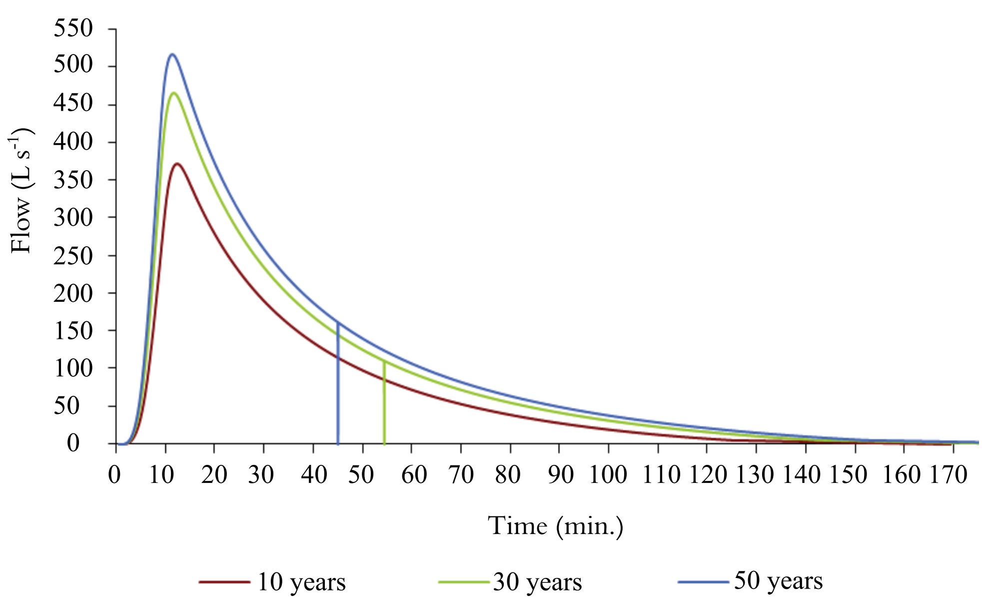


Figure 5. Surface runoff hydrographs for return periods equal to 10, 30, and 50 years for one condition (Tie = 15 mm h^{-1} and S_c = 0.002 mm^{-1}) of the conducted case study. The vertical lines represent the time for which the water volume, considering the return period of 30 and 50 years, is equal to the total water volume corresponding to the 10-year return period.

Comparing the results obtained for Tie values equal to 15 and 30 mm h^{-1}, it is evident that for level terraces, the channel height associated with 30 mm h^{-1} is approximately 67% of that corresponding to 15 mm h^{-1}, while for graded and mixed terraces, this ratio is 82 and 80%.

Regarding the slopes of the channel bottom, they only interfere with the behavior of graded terraces, and for these, the increase in slope from 0.002 to 0.003 mm h^{-1} is approximately 93%.

Similar behavior was observed for the other conditions of this case study—the values of the volume to be retained in the channel (V_s), the channel depth (H), the maximum flow (Q_{max}) and the volume to be transported in the channel (V_d) for each return period (T) and for each terracing system are presented in Table 1.

Table 1. Results of the hydrograph analysis.

S_c ($m\ m^{-1}$)	Tie ($mm\ h^{-1}$)	Terrace system	T (years)	V_s (m^3)	H (m)	Q_{max} ($m^3\ s^{-1}$)	V_d (m^3)
0.002	15	Level Terraces	10	730.8	0.75	-	-
			30	954.2	0.85	-	-
			50	1076.8	0.90	-	-
		Graded Terraces	10	-	0.40	0.372	730.8
			30	-	0.44	0.466	954.2
			50	-	0.45	0.516	1076.8
		Mixed Terraces	10	730.8	0.75	-	-
			30	730.8	0.78	0.111	223.4
			50	730.8	0.78	0.162	346.0
	30	Level Terraces	10	471.1	0.60	-	-
			30	649.4	0.70	-	-
			50	748.6	0.75	-	-
		Graded Terraces	10	-	0.38	0.319	471.1
			30	-	0.42	0.412	649.4
			50	-	0.44	0.463	748.6
		Mixed Terraces	10	471.1	0.60	-	-
			30	471.1	0.65	0.151	178.3
			50	471.1	0.66	0.213	277.5
0.003	15	Level Terraces	10	730.4	0.75	-	-
			30	953.8	0.85	-	-
			50	1076.4	0.90	-	-
		Graded Terraces	10	-	0.37	0.379	730.4
			30	-	0.41	0.474	953.8
			50	-	0.42	0.525	1076.4
		Mixed Terraces	10	730.4	0.75	-	-
			30	730.4	0.78	0.112	223.4
			50	730.4	0.78	0.163	346.0
	30	Level Terraces	10	471.4	0.60	-	-
			30	649.7	0.70	-	-
			50	748.8	0.75	-	-
		Graded Terraces	10	-	0.35	0.325	471.4
			30	-	0.39	0.420	649.7
			50	-	0.41	0.471	748.8
		Mixed Terraces	10	471.4	0.60	-	-
			30	471.4	0.65	0.152	178.3
			50	471.4	0.66	0.214	277.4

Conclusion

The comparison of the mixed terrace performance with level and graded terraces yielded quantitative evidence that led to the following observations:

- Mixed terraces exhibit a lower efficiency in surface water storage ability than level terraces and greater efficiency than gradient terraces, which has direct consequences on water loss; and

- Mixed terraces exhibit a lower height than level terraces and a higher height than gradient terraces, which has direct consequences on the volume of soil movement.

References

AL ALI, Y.; TOUMA, J.; ZANTE, P.; NASRI, S.; ALBERGEL, J. Water and sediment balances of a contour bench terracing system in a semi-arid cultivated zone (El Gouazine, central Tunisia). **Hydrological Sciences**, v. 53, n. 4, p. 883-892, 2008.

BERTOL, I.; COGO, N. P.; SCHICK, J.; GUDAGNIN, J. C.; AMARAL, A. J. Aspectos financeiros relacionados às perdas de nutrientes por erosão hídrica em diferentes sistemas de manejo do solo. **Revista Brasileira de Ciência do Solo**, v. 31, n. 1, p. 133-142, 2007.

BRAS, R. L. **Hydrology**: an introduction to hydrologic science. Massachusets: Addison - Wesley Publlishing Company, 1990.

CHUA, L. H. C.; WONG, T. S. W.; SRIRAMULA, L. K. Comparison between kinematic wave and artificial neural network models in event-based runoff simulation for an overland plane. **Journal of Hydrology**, v. 357, n. 3-4, p. 337-348, 2008.

CHUA, L. H. C.; WONG, T. S. W. Improving event-based rainfall–runoff modeling using a combined artificial neural network–kinematic wave approach. **Journal of Hydrology**, v. 390, n. 1-2, p. 92-107, 2010.

CHUA, L. H. C.; WONG, T. S. W. Runoff forecasting for an asphalt plane by Artificial Neural Networks and comparisons with kinematic wave and autoregressive moving average models. **Journal of Hydrology**, v. 397, n. 3-4, p. 191-201, 2011.

EHIGIATOR, O. A.; ANYATA, B. U. Effects of land clearing techniques and tillage systems on runoff and soil erosion in a tropical rain forest in Nigeria. **Journal of Environmental Management**, v. 92, n. 11, p. 2875-2880, 2011.

FAO-Food and Agriculture Organization. **Manual on integrated soil management and conservation practices**. Rome: FAO, 2000.

GRIEBELER, N. P.; PRUSKI, F. F.; TEIXEIRA, A. F.; SILVA, D. D. Modelo para o dimensionamento e a locação de sistemas de terraceamento em nível. **Engenharia Agrícola**, v. 25, n. 3, p. 696-704, 2005.

LIU, X.; HE, B.; LI, Z.; ZHANG, J.; WANG, L.; WANG, Z. Influence of land terracing on agricultural and ecological environment in the loess plateau regions of China. **Environmental Earth Sciences**, v. 62, n. 4, p. 797-807, 2011.

NAIK, M. G.; RAO, E. P.; ELDHO, T. I. A kinematic wave based watershed model for soil erosion and sediment yield. **Catena**, v. 77, n. 3, p. 256-265, 2009.

PRUSKI, F. F.; FERREIRA, P. A.; RAMOS, M. M.; CECON, P. R. Model to design level terraces. **Journal of Irrigation and Drainage Engineering**, v. 123, n. 1, p. 8-12, 1997.

PRUSKI, F. F. **Conservação de solo e água**: práticas mecânicas para o controle da erosão hídrica. 2. ed. Viçosa: UFV, 2009.

RAI, R. K.; UPADHYAY, A.; SINGH, V. P. Effect of variable roughness on runoff. **Journal of Hydrology**, v. 382, n. 1-2, p. 115-127, 2010.

SILVA, J. M. A.; PRUSKI, F. F.; RODRIGUES, L. N.; CECÍLIO, R. A. Modelo para a obtenção do hidrograma de escoamento superficial em bacias hidrográficas. 1. Desenvolvimento e análise de sensibilidade. **Revista Brasileira de Ciências Agrárias**, v. 4, n. 1, p. 78-84, 2009.

SINGH, V. P. **Kinematic wave modeling in water resources**: surface water hydrology. New York: Wiley, 1996.

VAN DIJK, A. I. J. M.; BRUIJNZEEL, L. A. Runoff and soil loss from bench terraces. 1. An event-based model of rainfall infiltration and surface runoff. **European Journal of Soil Science**, v. 55, n. 2, p. 299-316, 2004.

YANG, Q.; MENG, F.-R.; ZHAO, Z.; CHOW, T. L.; BENOY, G.; REES, H. W.; BOURQUE, C. P. A. Assessing the impacts of flow diversion terraces on stream water and sediment yields at a watershed level using SWAT model. **Agriculture, Ecosystems and Environment**, v. 132, n. 1-2, p. 23-31, 2009.

ZHANG, J. H.; SU, Z. A.; LIU, G. C. Effects of terracing and agroforestry on soil and water loss in hilly areas of the Sichuan basin, China. **Journal of Mountain Science**, v. 5, n. 3, p. 241-248, 2008.

ZHOU, X.; AL-KAISI, M.; HELMERS, M. J. Cost effectiveness of conservation practices in controlling water erosion in Iowa. **Soil and Tillage Research**, v. 106, n. 1, p. 71-78, 2009.

ZUAZO, V. H. D.; RUIZ, J. A.; RAYA, A. M.; TARIFA, D. F. Impact of erosion in the taluses of subtropical orchard terraces. **Agriculture, Ecosystems and Environment**, v. 107, n. 2-3, p. 199-210, 2005.

ZUAZO, V. H. D.; PLEGUEZUELO, C. R. R.; PEINADO, F. J. M.; GRAAFF, J.; MARTÍNEZ, J. R. F.; FLANAGAN, D. C. Environmental impact of introducing plant covers in the taluses of terraces: Implications for mitigating agricultural soil erosion and runoff. **Catena**, v. 84, n. 1-2, p. 79-88, 2011.

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