A Comparison of the R-factor in the Universal Soil Loss Equation and Revised Universal Soil Loss Equation

B. Yu

Abstract. *The R-factor in the Universal Soil Loss Equation /Revised Universal Soil Loss Equation (USLE/RUSLE) characterizes the climatic influence on the average rate of soil loss. The way in which the R-factor was calculated for RUSLE differs from that for the USLE. Rainfall intensity data at 6-min intervals from 41 long-term sites in the tropical region of Australia were analyzed to determine the discrepancy in the calculated R-factor as a result of using different unit energy equations and different rainfall thresholds. The mean annual rainfall varies from 261 to 4030 mm for the 41 sites. The calculated R-factor using the unit energy equation for the USLE is greater than that using the unit energy equation recommended for RUSLE. The typical difference is about 10% for the tropical region of Australia. The difference tends to increase as peak rainfall intensity decreases. The percentage difference in the R-factor due to different unit energy equations was found to be significantly correlated with the ratio of the R-factor to mean annual rainfall. The discrepancy in the calculated R-factor due to different rainfall thresholds increases as mean annual rainfall decreases because the relative contribution to the R-factor from small storm events increases in low rainfall areas. Lowering the rainfall threshold from 12.7 mm to 0.0 mm would on average increase the calculated R-factor by 5% for the same region. Relationships based on mean annual rainfall and the R-factor were developed so that the magnitude of the discrepancy in the calculated R-factor due to different unit energy equations and different rainfall thresholds can be readily assessed.*
Keywords. *USLE, RUSLE, R-factor, tropics, Australia.*

At present the most commonly used method of predicting the average rate of soil loss due to water erosion, especially from agricultural lands, is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and its successor the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). In the USLE/RUSLE, the climatic influence on water-related soil erosion is characterized by a rainfall-runoff erosivity factor, known as the R-factor. By definition, the R-factor is the mean annual sum of individual storm erosivity values, EI_{30}, where E is the total storm kinetic energy and I_{30} is the maximum 30-min rainfall intensity. When factors other than rainfall are held constant, soil losses due to water erosion are directly proportional to the level of rainfall erosivity (Wischmeier and Smith, 1958, 1978).

Although the procedure to calculate the storm erosivity, hence the R-factor, is well defined (Renard et al., 1997), there are discrepancies in the way in which the R-factor is determined for individual regions. For example, for the eastern United States, the isoerodent map was prepared using the original unit energy equation (Wischmeier and Smith, 1978); while for the western United States, a different unit energy equation suggested by Brown and Foster (1987) was used (Renard et al., 1997), and this new unit energy equation was recommended for all future use in relation to RUSLE (Renard et al., 1997). Furthermore, a rainfall threshold of 12.7 mm was used to select erosive storms for the eastern United States, while all storms were used in calculating the R-factor for the western United States unless the precipitation occurred as snowfall (Renard et al., 1997). Although no systematic examination of the effects of using different unit energy equations and rainfall thresholds was undertaken, Agriculture Handbook 703 (Renard et al., 1997) seems to suggest that any difference in the calculated R-factor would be small since less than 1% difference in the total kinetic energy of some sample storms was cited (Renard et al., 1997). However, as shown later in this article, considerable difference in the calculated R-factor can occur as a result of using a different unit energy equation or a different rainfall threshold.

For convenience of discussion, the difference in the R-factor that results from using a different unit energy equation for computing storm energy is called the Type-I difference. The difference that arises from using a different rainfall threshold is called the Type-II difference. In particular, we are interested in the magnitude of the two percentage differences δ_1 and $\delta_2(R)$, and they are defined as follows:

$$\delta_1 = 100\frac{R_U - R_R}{R_R} \quad (1)$$

where R_U is the R-factor calculated using the unit energy equation of Wischmeier and Smith (1978) for the USLE and R_R is the R-factor calculated using the unit energy equation of Brown and Foster (1987) for RUSLE. A threshold of 12.7 mm is used for both R_U and R_R. $\delta_2(R)$ is similarly defined:

Article was submitted for publication in December 1998; reviewed and approved for publication by the Soil & Water Division of ASAE in August 1999.

The author is **Dr. Bofu Yu**, Faculty of Environmental Sciences, CRC-Sustainable Production Forestry, Griffith University, Nathan, Qld 4111, Australia, voice: 617-3875-5258, fax: 617-3875-7459, e-mail: b.yu@mailbox.gu.edu.au.

$$\delta_2(R) = 100\frac{R_o - R_R}{R_R} \qquad (2)$$

where R_o is the R-factor calculated using a threshold of 0.0 mm and the unit energy equation of Brown and Foster (1987). Hence, the R-factor based on a threshold of 12.7 mm and the unit energy equation of Brown and Foster (1987) can be seen as a reference R-factor against which the effects of using different unit energy equations and different rainfall thresholds will be evaluated. For completeness, the Type-I difference using a threshold of 0.0 mm and the Type-II difference using the unit energy equation for the USLE are also considered.

In this article, an analytical relationship for the difference in storm energy is derived first for a simple storm pattern. Rainfall intensity data at 6-min intervals for 41 sites from the tropical region of Australia are then used to determine the differences in the calculated R-factor as a result of using different unit energy equations and rainfall thresholds. Finally, the differences are related to the R-factor and mean annual rainfall so that an assessment of the magnitude of the these differences can easily be made.

Data and Method of Analysis

All the pluviograph sites in Australia's tropics were screened to select those in operation for at least 20 years. Data used in this article include all the available 6-min pluviograph data from Bureau of Meteorology for 41 sites in the tropics of Australia. Table 1 shows the location, mean annual rainfall and the R-factor for the 41 sites. The R-factor was calculated in an identical manner as for the western United States, i.e., using the unit energy equation of Brown and Foster (1987) and all storm events. The mean annual rainfall for these sites ranges from 261 to 4030 mm/yr (10-159 in./yr), and the R-factor from 623 to 25,600 MJ·mm/(ha·h·yr). With a conversion factor of 17.02 (Foster et al., 1981), the range of the R-factor in U.S. customary units is 36.6 to 1,500. Calculated R-factors were then compiled for the 41 sites in order to evaluate the Type-I and Type-II differences. The mean annual rainfall and the R-factor were determined using the pluviograph data alone. More reliable estimates of the mean annual rainfall and the R-factor based on the long-term daily rainfall data in addition to pluviograph data for the 41 sites have been produced and are available elsewhere (Yu, 1998). Rainfall data from the tropical region were thought to be particularly suitable for evaluating the Type-I and Type-II differences in the R-factor because the range in rainfall intensity experienced in this region is greater than that in temperate regions.

Table 1. Location, mean annual rainfall, and R-factor for 41 sites in the Australian tropics

Station No. and Name	Location	Elevation (m)	Rain (mm/yr)	R-factor [MJ·mm/(ha·h·yr)]
02012 Halls Creek	18°14'S 127°40'E	410	575	2588
03003 Broome	17°57'S 122°14'E	17	605	3684
04032 Port Headland	20°22'S 118°37'E	9	364	1323
06011 Carnarvon	24°53'S 113°40'E	4	261	623
13017 Giles	25°02'S 128°18'E	580	302	787
14015 Darwin Airport	12°25'S 130°52'E	31	1688	13279
14400 Maningrida	12°03'S 134°13'E	11	1175	6997
14508 Gove Airport	12°17'S 136°49'E	54	1349	8148
14618 Daly Waters	16°16'S 133°23'E	212	896	4699
14626 Daly Waters AMO	16°16'S 133°23'E	220	628	2557
15085 Brunette Downs	18°39'S 135°57'E	218	547	2651
15135 Tennant Creek	19°38'S 134°11'E	375	445	2025
15548 Rabbit Flat	20°13'S 130°01'E	340	502	1995
15590 Alice Springs	23°49'S 133°54'E	537	323	917
15602 Jervois	22°57'S 136°09'E	325	352	1105
27006 Coen	13°46'S 143°07'E	162	1190	5839
27022 Thursday Island	10°35'S 142°13'E	60	1795	12985
28004 Palmerville	16°00'S 144°04'E	207	1027	6646
29041 Normanton	17°40'S 141°04'E	8	946	6447
29127 Mount Isa	20°40'S 139°29'E	343	448	2061
30045 Richmond	20°42'S 143°08'E	211	569	2483
31011 Cairns	16°53'S 145°45'E	3	1993	11589
31034 Kairi	17°12'S 145°34'E	715	1282	4735
31055 Mossman South	16°19'S 145°23'E	0	2120	11579
31066 Mareeba	17°00'S 145°25'E	406	870	3403
31083 Koombooloomba	17°50'S 145°36'E	732	2627	8908
32021 Goondi Mill	17°31'S 146°01'E	27	3220	15026
32040 Townsville	19°15'S 146°46'E	4	1101	5931
32042 Tully	17°56'S 146°56'E	24	4027	25578
32064 Paluma	19°00'S 146°12'E	892	2649	18369
33002 Ayr	19°37'S 147°22'E	12	998	5610
33119 Mackay	21°07'S 149°13'E	6	1665	10001
34002 Charters Towers	20°05'S 146°16'E	310	670	3217
35069 Tambo	24°53'S 146°15'E	395	516	1682
35098 Emerald	23°30'S 148°09'E	180	648	3299
36031 Longreach	23°26'S 144°17'E	192	455	1706
37051 Winton	22°24'S 143°02'E	185	465	1625
38003 Boulia	22°55'S 139°54'E	157	295	668
38024 Windorah	25°26'S 142°39'E	126	307	838
39083 Rockhampton	23°23'S 150°29'E	10	843	3116
39090 Theodore	24°57'S 150°04'E	142	699	2845

As part of a project to determine rainfall erosivity for Australia's tropics, a program, known as RECS, was written to compute EI_{30} for individual storms and ultimately the R-factor (Yu, 1998; Yu and Rosewell, 1998). Although the program strictly conforms to the recommendations from Agriculture Handbook 703 (Renard et al., 1997), users are allowed to choose, among other things, the unit energy equation to be used, and to specify the rainfall threshold to define erosive storm events. Users can select one of three unit energy equations. They are the original set of equations for the USLE (Wischmeier and Smith, 1978), that of Brown and Foster (1987) which was recommended for RUSLE (Renard et al., 1997) and that of Rosewell (1986) which is more appropriate for southeastern Australia. A rainfall threshold of 12.7 mm (0.5 in.) was commonly used to eliminate small storm events in the calculation of the R-factor. It was thought that storms with total rain less than 12.7 mm did not contribute significantly to the R-factor and soil erosion, and removal of these small events with a threshold of 12.7 mm greatly reduced the cost of analyzing rainfall data (Renard et al., 1997).

For each of the 41 tropical sites, the program RECS was run four times using the same pluviograph data but with a different unit energy equation or a different rainfall threshold. Only the unit energy equations for the USLE and RULSE and thresholds of 0.0 and 12.7 mm were considered in this article.

Results

An Analytical Relationship for the Difference in Storm Energy and Storm Erosivity

The R-factor is the mean annual sum of individual storm erosivity values. It follows that the Type-I difference in the R-factor should be related to the difference in storm erosivity for individual events. Since the unit energy equation has no effect on the peak 30-min intensity, the difference in storm erosivity, hence in the R-factor, is only related to the difference in storm energy. We derived an analytical relationship between peak rainfall intensity and storm energy for a simple storm pattern to gain insight into