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Soil loss and erosivity index of Padang Besar soil series *(Petroferric Tropudult)* I: Possible application of Cate-Nelson methods, Anderson-Nelson method and simplified ANOVM for the determination of critical value

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Key words: Soil loss; erosivity index; critical value.

RINGKASAN

Pengetahuan tentang nilai kritikal bagi data hakisan tanah boleh digunakan dalam pemeliharaan dan pengurusan tanah. Satu percubaan keatas tanah siri Padang Besar (Petroferric Tropudult) *telah dijalankan di Universiti Pertanian Malaysia. Kehilangan tanah dari pada petak tanah terdedah dan ciri-ciri hujan ditentukan selepas setiap kali hujan dalam masa setahun. Kehilangan tanah dan indeks erosiviti (K.E. > 10) dipadankan dengan beberapa model. Kesesuaian beberapa cara pendekatan kemudiannya dikaji untuk mendapatkan nilai-nilai kritikal data hakisan tanah. Kertas ini menunjukkan satu contoh penggunaan teknik dan prinsip pendekatan-pendekatan tersebut. Keputusan percubaan menunjukkan bahawa keempat-empat prosedur memberikan nilai kritikal yang sama walaupun mempunyai prinsip yang berlainan. Seterusnya ditunjukkan bahawa teknik baru CateNelson dan ANOVM yang mudah (α= 0.001) menghasilkan nilai R^2 yang lebih tinggi (0.84**) daripada model kuadrat yang terbaik (R^2 = 0.54**). Walau bagaimanpun, penggunaan prosedur ANOVM mudah (α = 0.001) mungkin mencukupi memandangkan kepada prinsip mendapatkan nilai kritikal data hakisan tanah.*

SUMMARY

Knowledge of the critical value for soil erosion data is useful in terms of soil conservation and management. An experiment was carried out in Universiti Pertanian Malaysia on Padang Besar soil series (Petroferric tropudult). *The bare plot soil loss and rainfall characteristics were determined after every storm for a year. Soil loss and erosivity index (K.E. > 10) were fitted with different models. Various approaches were then adapted to study their suitability in obtaining critical values for soil erosion data. In this paper, an example showing the application of techniques and their principles is given. Results indicate that all the four procedures provide similar critical values despite their different principles. It is further showns that new Cate-Nelson technique and simplified ANOVM (α = 0.001) result in higher R^2 (0.84**) than the best quadratic model (R^2 = 0.54**). However, due to the principle of obtaining critical values for soil erosion data, it may suffice to use simplified ANOVM (α = 0.001).*

INTRODUCTION

In relating soil loss data and rainfall characteristics, it is commonly observed that quadratic models give better approximation of response patterns. At lower values of erosivity indices, the change of soil loss tends to be minimal. This phenomenon was generally attributed to the intensity of rainfall. Thus, it was suggested that K.E. > 25 and EI_{30} would provide better relationship with soil loss (Hudson, 1971). In Serdang, Selangor, the critical intensity was 10 mm.h^{-1} and the erosivity index of KE > 10 was suggested in favour of other recognized

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indices, namely EI_{30}, KE > 25 and Σai (Mustafa Kamal, 1977). The rainfall in Serdang was found to be more erosive, due to larger raindrop size than that in Rhodesia, in which the critical intensity was shown by Hudson, (1965) to be 25 $mm.h^{-1}$. It was also shown that K.E. > 10 gave better prediction of soil loss than total K.E. based on the quadratic model (Jamal, *et al.*, unpublished). However, such data do not identify the level where the values of erosivity indices become important in terms of expected drastic soil erosion. Hence, its practical importance in soil conservation and management is diminished.

As stated earlier, the scattering of data when soil loss was plotted against erosivity indices showed a characteristic sharp increase after a certain point. This presented a unique situation where two separate classes of data might be obtained; a) low soil loss per unit change of erosivity index and b) high soil loss per unit change of erosivity index. The dividing point of these two classes will be considered as the "critical value". Determination of the critical value soil was widely used by soil scientists in partitioning soil test values based on crop response probability. However, no similar attempt is known to be carried out to obtain the critical value for soil erosion data.

Various methods, both arbitrary and statistical, are used in soil fertility to evaluate the critical values. The most common techniques are Cate-Nelson graphical method (1965), new Cate-Nelson method (1971) and the Anderson-Nelson method (1975) as described by Nelson and Anderson (1977). The former is used due to its ease in computation and the latter is used because of its economic implication. However, all these techniques assume a sharp yield response to added nutrients followed by a plateau at higher nutrient levels. Their inverse are similar to the quadratic response of soil loss and erosivity indices. Hence, the purpose of this study was to investigate the possibility of adapting the above techniques and a proposed simplified ANOVM to obtain a critical value for soil loss and erosivity index. An actual example based on a year of soil erosion data is given.

METHODS AND MATERIALS

The experiment was carried out in Field 10 at the Universiti Pertanian Malaysia. The soil was classified as Padang Besar series which was a clayey, over clayey skeletal, kaolinitic, isohyperthermic, *Petroferric Tropudult*. The texture of the surface horizon is sandy loam going into sandy clay to clay for the deeper horizons.

The trial consisted of three runoff plots of bare soil of size 22.1 m x 1.8 m. The plots were under continuous fallow with tillage operations up and down the slope. At the bottom end of each plot was placed the collection system which collected runoff samples after each rainy day (Mokhtaruddin and Maene, 1979). Erosion losses were analyzed and calculated from these runoff samples. Rainfall was measured by means of a rainfall recorder. Erosivity index as K.E. > 10 (Jm^{-2}) was then calculated from the Casella raincharts obtained from the recorder. The various approaches, Cate-Nelson graphical method (1965), New Cate-Nelson Method (1971), Anderson-Nelson Method (1975, 1977) and simplified ANOVM were used to calculate the critical value of the erosivity index based on a year of soil erosion data.

Background Principles Of Techniques

A detailed presentation on the techniques can be found in papers written by Cate and Nelson (1965, 1971) Anderson and Nelson (1975) and Nelson and Anderson (1977). However, some basic concepts and assumptions necessary for the adaptation of the above methods and a proposed simplified ANOVM to obtain the critical value and R^2 will be discussed here. It shall be noted here that the new Cate-Nelson procedure is also known as Analysis of Variance Method (ANOVM).

The basic principle for the proposed simplified ANOVM is in estimating the point where soil loss (Y') is statistically insignificant from the "real" minimum soil loss (Y_o). In soil erosion studies (precipitation erosion), values where erosivity index (X) is less than zero, do not exist since rainfall is required before any soil loss can occur. On the other hand, for erosivity indices such as K.E. > 10, the variation in soil losses when kinetic energy is equivalent to 0 Jm^{-2} is averaged and assumed to be negligible. Thus, values when $x < 0$ are assumed to be unreal and the minimum soil loss (Y_o) is then at the point where $x = 0$.

As mentioned in the previous section, soil loss and erosivity indices data followed quadratic models, that is, in general,

$$Y = B_o + B_1X + B_2X^2 \qquad (1)$$

where Y = soil loss

X = erosivity index

B_o = constant

B_1 = coefficient of X

B2 = coefficient of X^2

The above equation will have a minimum value, if B_2 is positive. This condition holds true for the quadratic relationship between soil loss and erosivity index (Jamal *et al.*, umpublished). Hence, the minimum soil loss value (Y_o) for the above equation is when,

$$\frac{dY}{dX} = 0 = B_1 + 2B_2X \qquad (2)$$

and rearranging (2) gives $X = -\frac{B_1}{2B_2}$ (3)

However, due to the above assumption of unreal value, the minimum soil loss can also be at X = 0 or $Y_o = B_o$

Since the samples are assumed to be a random and normal population, the Y′ value can be obtained by using t-test (Duncan, 1975) as shown :

$$Y' = Y_o + t_\alpha \sqrt{\frac{2S_T^2}{N_T}} \qquad (4)$$

S_T = standard deviation of total samples

N_T = total number of samples

t = value of t-test tables

α = probability used for t-test

Here, a one-tailed t-test is used since Y′ is hypothesized to be greater than Y_o. Y′ so obtained is then used to compute the critical X-value where below it, the probability of soil loss is statistically insignificant from that obtained when X = 0.

To compute the R^2 of the relationship, the data are arranged in ascending order of X values. The average values are calculated and the data are separated into the two classes: those less than or equal to the critical value and those which are significantly higher. The sum of squares of the two classes are then pooled and subtracted from the sum of squares of deviation of the observation as shown:

$$\text{Pooled sum squares} = \frac{\sum\limits_{j=1}^{n_1} \sum\limits_{j=1} Yij^2}{n_1} + \frac{\sum\limits_{i=2}^{n_2} \sum\limits_{j=1} Yij^2}{n_2} - \frac{(\sum\limits_{i=1}^{2} \sum\limits_{j=1}^{n} Yij)^2}{n} \qquad (5)$$

where i = indication of classes (1 or 2),
j = observations in each class,
n_1 = number of observations in Class 1,
n_2 = number of observations in Class 2 and
n = total number of observations.

$$\text{Total sum of squares} = \sum_{n=1}^{2} \sum_{j=1}^{n} Yij^2 - \frac{(\sum\limits_{i=1}^{2} \sum\limits_{j-1}^{n} Yij)^2}{n} \qquad (6)$$

Since the difference of the total sum of squares and the pooled sum of squares represents the additional explanation obtained by fitting two means rather than one, then,

$$R^2 = \frac{\text{Equation (6)} - \text{Equation (5)}}{\text{Equation (6)}}$$

This method is aimed at simplifying the procedure of the new Cate-Nelson method without any loss of statistical information.

RESULTS AND DISCUSSION

Figure 1 shows the format of plastic overlay used in the Cate-Nelson graphical method and the determination of critical values. Results indicate that the various techniques used give different critical levels and corresponding soil losses (Table 1). However, they are statistically insignificant based on comparison of mean soil loss values by t-tests. Table 1 also illustrates that simplified ANOVM, as expected, provides the lowest value if α is high while the Cate-Nelson graphical method results in the highest critical value.

The Cate-Nelson graphical method presents a simple definite decision where individual extreme points have little influence. This advantage is explicitly illustrated in Figure 1 where soil erosion data are generally characterized by considerable scatter. However, this technique as mentioned earlier, has little statistical basis and biased interpretation of data might result.

Using the new Cate-Nelson procedure would result in similar critical values as shown in Table 1. It is generally superior to the above approach provided the number or suspected aberrant observations are low. It is also interesting to note that this method gives the highest R^2 when the data are fitted with various models, as

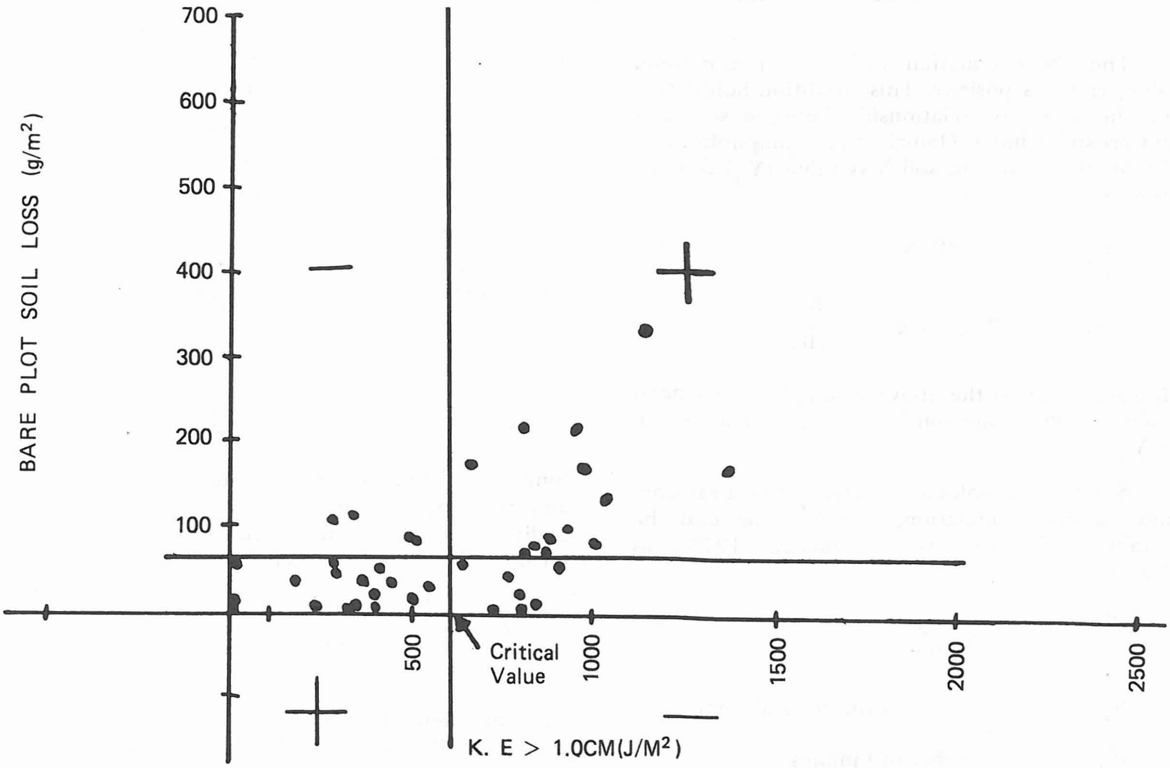

Fig.1. Format of overlay used in the Cate. Nelson graphical method and determination of the critical value

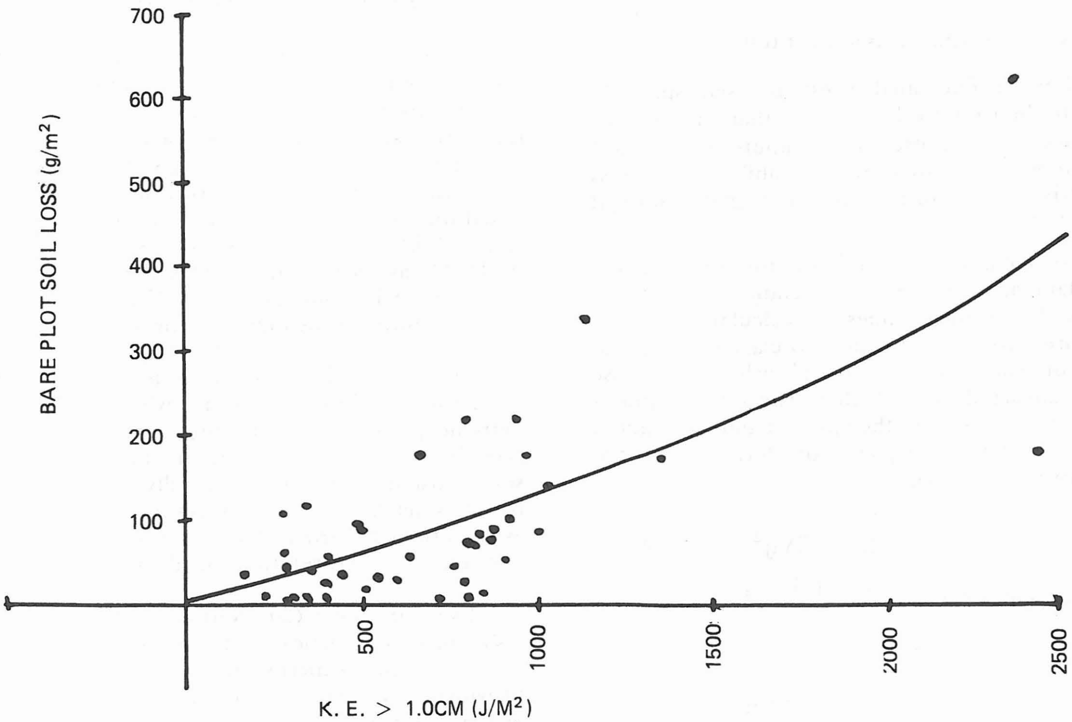

Fig. 2. Relationship of soil loss and K.E. > 1.0 based on the quadratic model.

TABLE 1
Comparison of critical value (J/m^2) and soil loss (g/m^2) obtained by various methods

Methods	Critical values of K.E. > 10 (J/m^2)	Corresponding soil loss (g/m^2)
Cate-Nelson graphical	685	66.67
New Cate-Nelson	563	62.07
Anderson-Nelson	537	59.07
simplified ANOVM		
a (α = 0.05)	344	38.07
b (α = 0.001)	437	49.79
c (α = 0.001)	563	62.08

TABLE 2
Comparison of R^2 values obtained by fitting various models

Model	R^2	Equation for model
Quadratic	0.54	$\overline{Y} = b_o + b_1 x + b_2 x^2$
Linear	0.52	$\overline{Y} = b_o + b_1 x$
Square root	0.37	$\overline{Y} = b_o + b_1 \sqrt{x}$
New-Cate Nelson	0.84	$\overline{Y} = b_o + b_1 x_1$ where $\begin{cases} x_1 = o \text{ if below critical level} \\ x_1 = 1 \text{ if above critical level} \end{cases}$
Simplified ANOVM		
a (α = 0.05)	0.15	$\overline{Y} = b_o + b_1 x_1$ where $\begin{cases} x_1 = o \text{ if below critical value} \\ x_1 = 1 \text{ if above critical value} \end{cases}$
b (α = 0.01)	0.23	
c (α = 0.001)	0.84	

TABLE 3
Some representative calculations used in new Cate-Nelson procedure

Order of K.E. >10 values (number)	Last value of K.E. >10 included in population 1 (J/m^2)	Corresponding bare plot soil loss (g/m^2)	Corrected sum square of population 1	Corrected sum square of population 2	R^2 for postulated critical value	Postulated critical level for each stage (J/m^2)
24	594.74	27.65	2403.01	385355.82	0.1352	323.36
31	794.93	6.46	62918.18	376965.30	0.2331	415.57
38	899.89	50.63	88333.26	453543.88	0.4247	494.43
42	996.31	82.98	137537.43	419943.38	0.4540	538.25
43	1027.85	136.32	150010.64	430847.83	0.4979	549.63
44	1129.65	336.07	187957.06	574463.78	0.8389	562.81
45	1348.42	169.97	206146.51	325414.71	0.4052	580.27

Total N = 47; Total corrected sum of squares = 532402.36.

demonstrated in Table 2 except for simplified ANOVM ($\alpha = 0.001$). This can be attributed to the sharp rise in soil loss after the plateau stage as discussed in the preceding section. The new Cate-Nelson procedure also has the advantage of giving the R^2 as compared to the other techniques except for the simplified ANOVM. This allows for the method to be compared with other available models. However, the disadvantage of this technique is that the error variance cannot be estimated or the number of optimum classes cannot be tested. It also requires tedious calculations as illustrated by Table 3 although it could be calculated using the Statistical Analysis System (SAS) as adapted by Barr *et al.* (1976).

The Anderson-Nelson method does not posses the above disadvantages. However, the definite critical values might be arrived at arbitrarily. Apart from this, it has the disadvantage of not being able to calculate the R-square value. On the other hand, it has the advantage of testing the variance heterogeneity and providing a first step towards selecting the best division points. Furthermore, the critical value obtained through this method is similar to the other procedures as shown in Table 1.

In view of the above advantages and disadvantages of the various methods, it is proposed that the critical values may be obtained using simplified ANOVM based on a one-tailed t-test. This procedure allows for a fast and nonarbitrary means of obtaining a definite critical value. It also provides a statistical basis for assuming data below the critical value to be similar to K.E. $> 10 = 0$ Jm^{-2}. The procedure is also suitable if the square root or reciprocal models are used in fitting the data.

Table 1 shows that simplified ANOVM gives slightly lower critical values compared to the other techniques when $\alpha \geqslant 0.01$. This might be attributed to the "linear-plateau" scattering of data which is not as sharp as defined by the other approaches. Thus, by decreasing α to 0.001, we were able to increase our critical value which then became similar to that of the new Cate-Nelson procedure (Table 1). At this value, the R^2 also improved dramatically to 0.84 the same figure obtained by the new Cate-Nelson Approach. However, by decreasing α, we would be increasing the probability of committing Type II error. Thus, the level of α used in calculating the critical value must be supplemented by the computed R^2 as shown in Tables 1 and 2. The interpretation of critical value could become biased when standard error of the population is high while the numbers of samples are low. It must be noted that by using the simplified ANOVM, we will be finally fitting the data from a quadratic model into a linear-plateau model as suggested by Anderson-Nelson approach.

CONCLUSION

Results indicate that all of the four methods were suitable for identifying critical values of soil erosion data. As they gave statistically insignificant soil loss values, similar critical values can be assumed. The New Cate-Nelson procedure should be used due to its high R^2 value (0.84) which is extremely important. However, in view of the principle for obtaining critical value in soil erosion data, it might suffice to use simplified ANOVM at $\alpha = 0.001$. Further trials are underway to ascertain their use. It would be interesting to note which critical values obtained by the various approaches would stand the test of soil variability, climatic variability, spatial variability and crop effects.

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