

A New Method for Determining the Soil Erodibility Factor Based on Fuzzy Systems

H. A. Bahrami¹, H. G. Vaghei^{2*}, B. G. Vaghei³, N. Tahmasbipour⁴
and F. Taliey-Tabari⁵

ABSTRACT

Determination of the soil erodibility factor (*K-factor*) is a cumbersome and expensive undertaking in the effort to predict the soil loss rates. The percentage of soil particles less than 0.1 mm in diameter, the percentage of organic matter, the structural as well as the textural class and permeability are the most important factors constituting the soil erodibility factor. Various methods of direct measurement for indirect prediction using models have been introduced so far for the measurement of *K-factor*. Using the new topics in information technology, in particular the fuzzy system including the Mamdani Inference Engine, Singleton Fuzzyfier and Centriod Defuzzyfier can determine the soil erodibility factor. The *K* values obtained with this method were compared with those of *USLE* method. Over 394 samples based on the Wischmeier nemograph as a database were included in this research work by using the fuzzy system. Using some actual data in the fuzzy system and comparing it with the *K* values attained with the *USLE* model by calculation of the regression coefficient, the applicability of this system was revealed.

Keyword: Fuzzy systems, *RUSLE* model, Soil erodibility, *USLE* model.

INTRODUCTION

Soil erosion results from the detachment, the transportation and sedimentation of the soil particles. Factors such as wind characteristics and similar climatic conditions play paramount roles in the disintegration of soil structure. Rain as an external factor plays the most important role and, of soil factors, erodibility phenomenon is main importance (Giovannini *et al.*, 2001). The term soil erodibility has a different meaning from soil erosion (Bybordi, 1993 and Refahi, 1996). This is because soil erodibility is an expression of some inherent characteristic of soil

susceptibility to erosion and of the soil particles to be separated from their base and transported to other locations. By definition, the soil erodibility factor is the average soil erosion in terms of ton/ha due to one unit of erosivity factors (EI_m) from a control plot (Standard plot). A control plot would be 22.1m long with a 9% uniform slope and two consecutive years in fallow, without any plant cover and plowed down slopes (Refahi, 1997 and Torri *et al.*, 2001).

Up to now, various methods of direct measurement and indirect prediction using models have been introduced for the measurement of the soil erodibility factor. The

¹ Department of Soil Science, Faculty of Agriculture, Tarbiat Modares University, Tehran, Islamic Republic of Iran

² Department of soil science, Mohaghegh Ardabili University, Ardabil, Islamic Republic of Iran.

³ Electrical control Engineering, Iran University of Science and Technology, Tehran, Islamic Republic of Iran.

⁴ Faculty of Agriculture, Lorestan University, Khoram Abad, Islamic Republic of Iran

⁵ Department of Plant Pathology, Faculty of Agriculture, Tarbiat Modares University, Tehran, Islamic Republic of Iran.

* Corresponding author.



first method has good accuracy but it is cumbersome and expensive in the effort to predict the soil loss rates (Tran *et al.*, 2002; Mitra *et al.*, 1998). This is the reason for improving the usage of model base included Wischmeier nemograph in *USLE* model and suggested in *RUSLE* model. This factor is calculated on the basis of soil texture, organic matter, soil structure and basic permeability of the soil profile in the *USLE* model and only based on soil texture in the *RUSLE* model (Wang *et al.*, 2001).

Some investigators have reported that using a fuzzy system to predict soil erosion would improve our ability to predict predict (Tran *et al.*, 2002; Mitra *et al.*, 1998). In this paper, we consider this new idea about using a fuzzy system to predict the soil erodibility factor and we design a fuzzy system instead of the Wischmeier nemograph. Since five parameters are used in the *USLE* model to determine the soil erodibility factor, the fuzzy system must use them and determine the *K-factor* by using data obtained from the Wischmeier nemograph.

Fuzzy logic based modeling for the determination of soil erodibility factor is superior to the traditional statistical approaches and suggests a promising new avenue for other empirically based modeling needs. It has not only made possible a more flexible and more realistic procedure in describing the relationship between the soil erodibility factor and the variables contributing to make up this factor, but it also overcomes the problems of uncertainty in the model parameters.

The most important step in the fuzzy system is the expression of the process in the

IF-THEN logic. It is quite important to be able to determine which entry would produce the largest output with the smallest incremental change (Bardosy and Duckstien, 1995; Mokaidono, 2001). The studies by Wischmeier and Manning show that an incremental change in the percentage of silt often results in a considerable change in the value of the erodibility factor so that soils with a 40-60% silt exhibit the greatest erodibility among the soils (Refahi, 1997). Another report indicates that a percentage figure for soil particles of less than 0.1 mm shows a good regression with the maximum run off as well as soil erosion among a vast number of soils examined (Barthes and Roose, 2002; Loch, 1998). Soil organic regression with the maximum run-off as well as soil erosion among a vast number of scatter is the second most important parameter that affects the soil erodibility factor. Soil organic matter positively affects the stability of the soil permeability (Refahi, 1997).

In this paper, we consider the Fuzzy System based on the Singleton Fuzzyfier, Centeroid Defuzzifier and Minimum Mamdani Inference Engine. In this regard, at first, we define the inputs and outputs of fuzzy system and their membership functions. Then we construct the database including *IF-THEN* rules based on real results of sampled data from a Wischmeier nemograph. Finally, we apply this system to some actual data and show the fine performance of the fuzzy system for soil erodibility factor estimation.

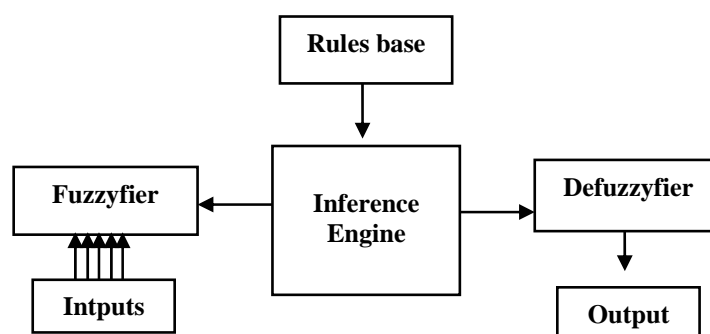


Figure 1. A block diagram of the fuzzy system.

MATERIALS AND METHODS

Since the determination of the soil erodibility factor (*K-factor*) in the *USLE* model depends on five parameters, it is the objective of this research to set up the fuzzy system so as to obtain the system output as *K-factor* with five inputs. These are the percentage of soil particles less than 0.1 mm (*FSS*), the percentage of coarse sand particles larger than 0.1 mm (*CS*), the soil structure class (*SC*), the permeability class and organic matter (*OM*) content. The output of the fuzzy system is the soil erodibility factor (*K*-

with the system output compared to other Defuzzifiers (Wang, 1997).

For derived analytical formula, we can select two approaches in the Inference Engine; the multiplier Mamdani and Minimum Mamdani. Since the membership function is in the range of [0, 1], the first approach results in a few values for the *K-Factor* with respect to the second approach. For this reason we selected the Minimum Mamdani Inference Engine.

The important point in the fuzzy system is the determination of limits, intervals and membership functions. The inputs and the outputs of the system under consideration,

Table 1. The fuzzy system inputs and output with the intervals.

K-Factor (SI)	OM%	PC (cm/h)	FSS%	SC	CS%
0-5-15	0, -0.5e-3, 1e-3	0-5-15	0.0-0.075-0.33	0.0-0.005-0.01	0.0-0.005-0.2
5-15-25	0.5e-3, 1.5e-	5-15-25	0.075-0.33-1.015	0.01-0.5-1	0.005-0.02-0.045
15-25-40	3, 3.5e-3	15-25-40	0.33-1.015-3.3	1-1.125-1.5	0.02-0.045-0.095
25-40-60	1.5e-3, 3.5e-	25-40-55	1.015-3.3-8.185	1.5-2-2.5	0.045-0.95-0.15
40-60-80	3, 5.5e-3	40-55-65	3.3-8.185-12.145	2.5-2.75-3	0.95-0.15-0.21
60-80-95	3.5e-3, 5.5e-3, 7e-3	55-65-75	8.185-12.145-13	3-3.25-3.5	0.15-0.21-0.26
80-95-100		65-75-85		3.5-3.75-4	0.21-0.26-0.3
		75-85-95		4-4.5-5	0.26-0.3-0.34
		85-95-100			0.3-0.34-0.36
					0.34-0.36-0.45
					0.36-0.45-0.585

Percentage of organic matter: OM% Soil particle size less than 0.1mm: FSS%
Soil Structure Code: SC Soil Permeability Class: PC
Percentage of Coarse Sand (0.1-0.02mm): CS%

Factor).

The Fuzzy system has the following block diagram (Wang, 1997). (Figure 1)

The design of the fuzzy system must include all of the four blocks in the diagram. Accordingly we selected the Singleton Fuzzifier, Minimum Mamdani Inference Engine and Centriod Defuzzifier. The Singleton Fuzzifier will involve the smallest volume of calculations. It has been shown that using the Singleton Fuzzifier offers a reasonable accuracy with calculations and provides possibility of mathematical analysis. The Centriod Defuzzifier gives the best accuracy

along with the rectangular membership function, are given in Table 1. The selection of the rectangular membership function is based on our experience and other studies.

The membership functions for any of the above parameters are given in figures 2, 3 and 4. It is obvious that the membership functions consist of overlap functions, which will increase the system accuracy. After deriving the membership functions for the inputs and output, the rule base should be set for this, for which it will be necessary to utilize the available information and experimental data. Therefore, 394 results (*K-factor*) taken from the Wischmeier nemo-

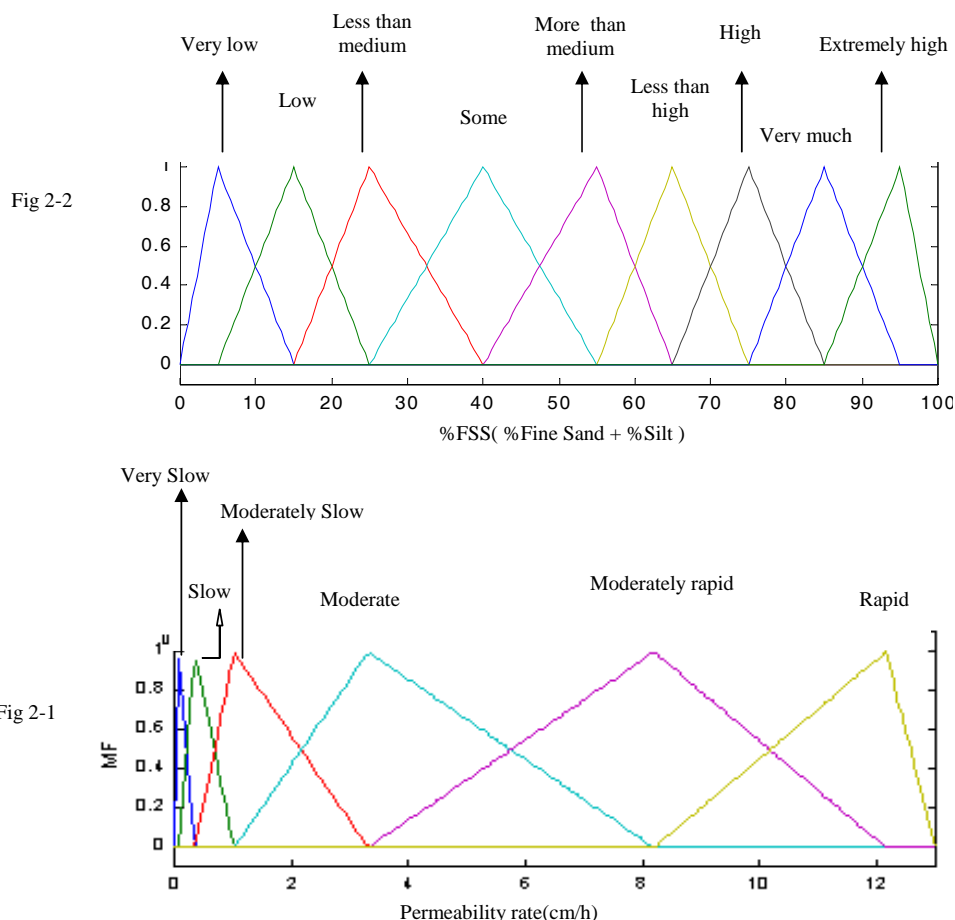


Figure 2. The membership function shows the permeability parameter and percentage of particles less than 0.1 mm for each of interval.

Figure 2-1. Membership function shows the permeability parameter in each interval.

Figure 2-2. Membership function shows percentage of particle less than 0.1 mm in each interval.

graph at various limits were extracted and used in the fuzzy system rule base. The typical L^{th} rule has the form below:

If x_1 is $\mu_{A_1}^{L_1}(x_1)$ & x_2 is $\mu_{A_2}^{L_2}(x_2)$ & & x_5 is $\mu_{A_5}^{L_5}(x_5)$ Then y is $\mu_{B_L}(y)$ (1)

where based on Table 1

$L_1 = 1 \dots 7$ $L_2 = 1 \dots 4$ $L_3 = 1 \dots$ (2)
 $L_4 = 1 \dots 6$ $L_5 = 1 \dots 8$ $L = 1 \dots 12$

$\mu_{A_i}^{L_i}$ Denotes the probable value of x_i is belonging the interval L_i and $\mu_B^L(y)$ denotes the probable value of y belong to the interval L . So, the statistical output of the fuzzy sys-

tem will be given as below:

$$\mu_B(K) = \max_{L=1}^{250} \left\{ \min \left[\mu_{A_1}^{L_1}(x_1), \dots, \mu_{A_5}^{L_5}(x_5) \right] \right\} \quad (3)$$

Therefore, based on the Centriod Defuzzifier (Wang, 1997) and calculated $\mu_B(K)$ in Equation (3) the soil erodibility factor for every unknown sample could be calculated once the values of x_1 to x_5 of any sample are known. Although this method is basically slow it is very accurate (Wang, 1997). Now we have a fuzzy system that can take the 5 inputs and give the K -Factor.

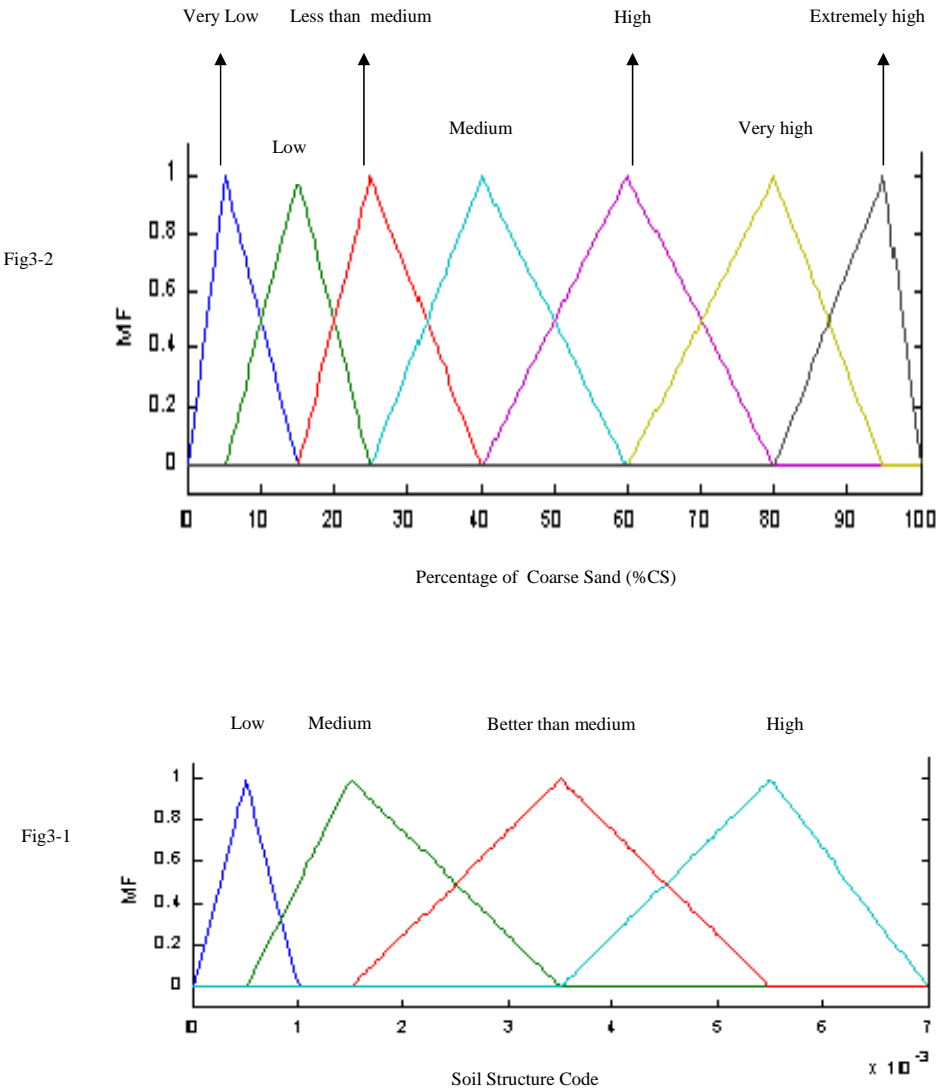


Figure 3. The membership function shows the soil structure code and percentage of sand particles larger than 0.2 mm in each interval.

Figure 3-1. Membership function shows the soil structure code in each interval.

Figure 3-2. Membership function shows percentage of sand particles larger than 0.1 mm in each interval.

RESULTS AND DISCUSSION

Several experimental data have been chosen and applied to the fuzzy system in order to verify the performance of designed Fuzzy system.

Table 2 shows a summary of the result. In

this table, the soil erodibility factor is given on the basis of the Wischmeier nemograph. The comparison in Table 2 indicates that the values of the soil erodibility factor calculated by the fuzzy system are quite close to the values obtained by the *USLE* model. In other words, the method given here results K-values completely equal to the Wisch-

**Table 2.** The results of soil erodibility factors obtained with the fuzzy system and with the USLE model

Row	C.S%	SC	F.S.S%	P.C	O.M%	K-USLE	K-Fuz
1	5	4	69	4	1	0.5	0.4667
2	10	3	53	5	2	0.3	0.3000
3	40	4	50	2	1	0.3	0.312
4	10	2	36	3	2	0.1	0.0969
5	60	2	20	3	2	0.1	0.0696
6	20	4	23	1	2	0.05	0.0549
7	16	3	70	2	4	0.05	0.0555
8	5	4	96	4	1	0.5	0.4667
9	40	4	23	4	1	0.2	0.2045
10	80	4	14	4	1	0.25	0.2465

Percentage of organic matter: OM% Soil particle size less than 0.1mm: FSS%
 Soil Structure Code: SC Soil Permeability Class: PC
 Percentage of Coarse Sand (0.2-0.02mm): CS%

meier nemograph. Predictions from the *K-USLE* and fuzzy model (*K-FUZ*) were compared by calculating the coefficient of determination R^2 defined by Nash and Sutcliffe (1970) which is calculated as follows:

$$R_{N-S}^2 = 1 - \frac{\left[\sum_{i=1}^N ((K_{FUZ}) - (K_{USLE}))^2 \right]}{\left[\sum_{i=1}^N ((K_{FUZ}) - (\overline{K_{FUZ}}))^2 \right]} \quad (4)$$

Where K_{FUZ} and K_{USLE} are computed values of sample i , based on the fuzzy system and *USLE* model, respectively, and $\overline{K_{FUZ}}$ is the mean of measured values.

The R_{N-S}^2 coefficient for our experiments yields the following value by applying the above formula to Table 2:

$$R_{N-S}^2 = 0.9886 \quad (5)$$

As we observed the correlation of the two models is near 1 and the fuzzy system can be used instead of Wischmeier nemograph to predict soil erodibility factor.

In this paper, we achieved a greater generality with the Wischmeier nemograph based on fuzzy system because the fuzzy system does not require the real model of *K-factor* and so has more flexibility. Also, the fine performance of the designed system has been shown by validated experimental data.

In the fuzzy system, we can combine some inputs and make new input. Also, we have a rule base that can be developed by new data and therefore high accuracy is achievable. The fuzzy system provides a base for more studies such as neglecting any input without losing accuracy in the estimation of the soil erodibility factor.

The experimental values of the five parameters of the Wischmeier nemograph have errors at various steps of laboratory work caused by the instruments and human error. Since we have considered an interval for each parameter and have obtained an accurate estimation of the *K-factor*, we have automatically resolved the uncertainty in Wischmeier nemograph parameters obtained by laboratory method.

The fuzzy system model can be a practical way to obtain a more general method to determine the soil erodibility factor in the world. In this regard, a greater value base and more accurate interval of inputs and output yield more a accurate value for the *K-factor*. Therefore, we have applied experimented data to the rule base of fuzzy system where the Wischmeier nemograph is not practical, and so we have designed a more generally applicable model.

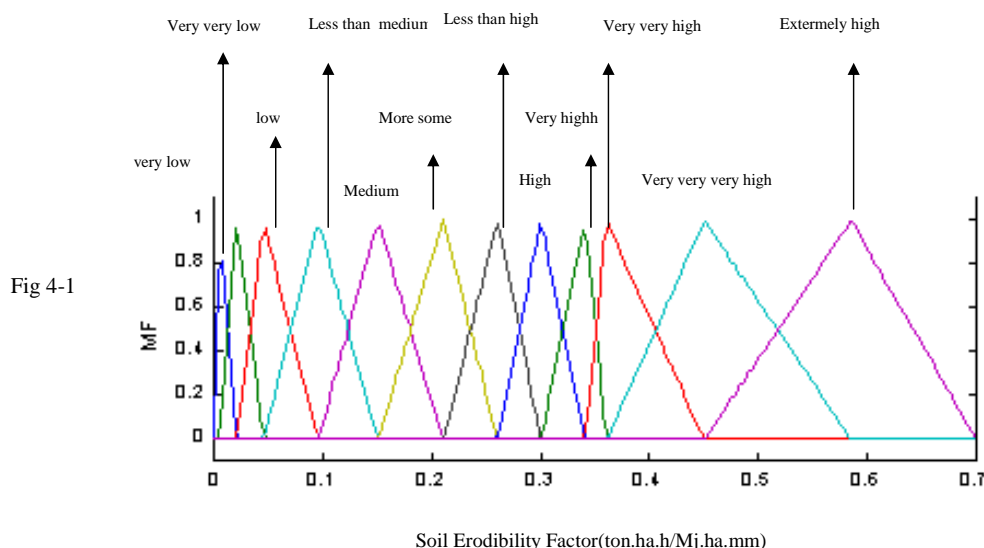
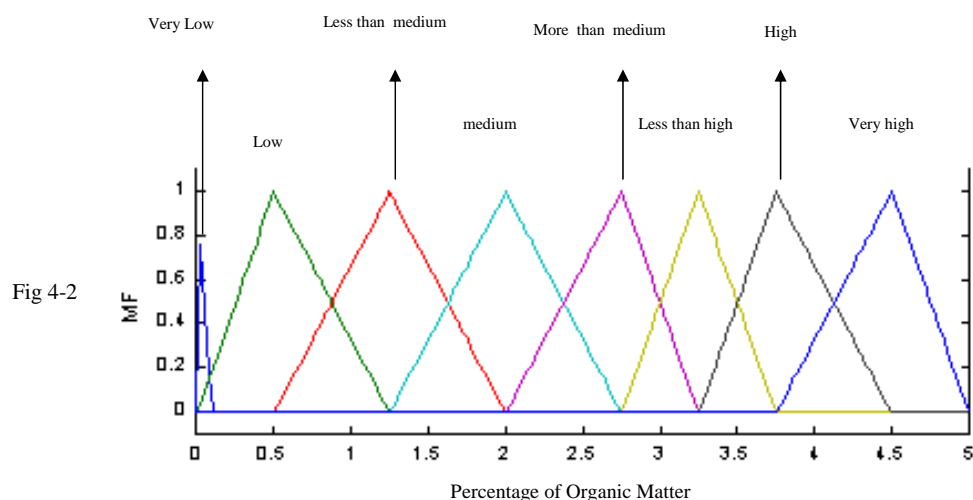


Figure 4. The membership function shows the organic matter factor and soil erodibility factor (ton.ha.h/Mj.ha.mm) in each interval.

Figure 4-1. Membership function shows soil erodibility factor (ton.ha.h/Mj.ha.mm) in each interval.

Figure 4-2. Membership function shows the organic matter factor.

CONCLUSION

The fuzzy system with the Singleton Fuzzyfier, the Minimum Mamdani Inference Engine and Centriod Defuzzyfier is able to calculate the soil erodibility factor quite accurately.

Comparing the value calculated using the

designed fuzzy system with K values obtained from the *USLE* model shows that the fuzzy logic based modeling for the determination of the soil erodibility factor is superior to the traditional statistical approaches and suggests a promising new avenue for other empirically based modeling needs. It has not only made possible a more flexible



and more realistic procedure for describing the relationship between soil erodibility factor and the variables contributing to make up this factor.

Since the approach is quite simple, and no other parameters than those used in calculating and thus the main structure of Wischmeier nemograph are maintained. Therefore the advantages of this approach become clear only when all the factors used in the USLE model are combined and incorporated in to the fuzzy model so as to be able to present a fuzzy system for the evaluation soil of erodibility.

ACKNOWLEDGEMENTS

We would like to thank Dr. M. S. Ardakani and Mr Farmani of the Central Computer Site of Tarbiat Modares University, School of Agriculture for helping us to prepare this paper.

REFERENCE

1. Ammor, S. and Wright, R. 2000. Applying Fuzzy Set Theory to Performance Evaluation. *Socio- Econ. Plan. Sci.*, **34**: 285-302.
2. Bardossy, A. and Duckstein, L. 1995. *Fuzzy Rule Based Modeling with Application to Geophysical, Biological and Engineering Systems*. CRC Press, Boca Raton. 221 pp.
3. Barthes, B., and Roose, E. 2002. Aggregate Stability as an Indicator of Soil Susceptibility to Run off and Erosion Validation at Several Levels. *Catena*, **47**: 133-149.
4. Bybordi, M. 1993. *Soil Physics*, Fifth Ed. Tehran University Publications. 648. pp.
5. Giovannini, G., Valijo, R., Lucchesi, S., Bautista, S., Ciompi, S. and Llovet, J. 2001. Effects of Land Use and Eventual Fire on Soil Erodibility in Dry Mediterranean Conditions. *Forest Ecol. Manage.*, **147**: 15 - 23.
6. Loch, R., and Slater, B. K. 1998. Soil Erodibility (Km) Value for Some Australian Soil. *Aus. J. Soil Res.*, **36**: 1045 -1055.
7. Mitra, B., and Scatte, H. D. 1998. Application of Fuzzy Logic to Prediction of Soil Erosion in Large Watershed. *Geoderma*, **47**: 12-21.
8. Mukaidono, M. 2001. *Fuzzy Logic for Beginners*. Word Scientific. N.Y. 103 pp.
9. Refahi, H. 1997. *Water Erosion and Control*. First Ed. Tehran University Publications. 547 pp.
10. Torri, D., Poesen, J., and Boreslly L. 1997. Predictability and Uncertainty of the Soil Erodibility Factor using a Global Dataset. *Catena*, **31**: 1-22.
11. Tran, L.T., Ridgley, M. A., and Duckstein, L. 2002. Application of Fuzzy Logic- based on the Revised Universal Soil Loss Equation. *Catena*, **47**: 203-226.
12. Wang, L. X. 1997. *A Course in Fuzzy Systems and Control*. Prentice Hall. N.Y. 572 pp.
13. Wang, W., Gertner, G. Liu, X and Anderson, A. 2001. Uncertainty Assessment of Soil Erodibility for Revised Universal Soil Loss Equation. *Catena*, **46**: 1-14.

ارائه روشی جدید، جهت تعیین فاکتور فرسایش پذیری خاک بر اساس سیستم‌های فازی

ح. بهرامی، ح. قربانی واقعی، ب. قربانی واقعی،
ن. طهماسبی پور و ف. طلیعی طبری

چکیده

تعیین فاکتور فرسایش‌پذیری خاک (K) یکی از کارهای طاقت فرسا و هزینه‌بر در پیشگویی میزان هدر رفت خاک می‌باشد. درصد ذرات کوچکتر از $0/1$ میلی‌متر، درصد ماده آلی، کلاس ساختمان و کلاس نفوذپذیری خاک بیشترین تأثیر را در اندازه‌گیری این فاکتور دارا می‌باشند. تا کنون روش‌های مختلفی به صورت مستقیم (اندازه‌گیری) یا غیر مستقیم (استفاده از مدل) برای تعیین این فاکتور معرفی شده‌اند. در این مقاله با استفاده از مباحث جدید در فناوری اطلاعات و با تکیه بر سیستم فازی که در برگیرنده موتور استنتاج فازی، فازی گر تکین و فازی‌زدای مرکز ثقل است، فاکتور فرسایش‌پذیری خاک (K) تعیین و برای اطمینان از عملکرد سیستم، نتایج آن با نتایج حاصل از روش USLE مقایسه گردید. برای این کار بیش از ۳۹۴ نمونه مطالعاتی بر اساس نمودار ویشمایر به صورت پایگاه داده در سیستم فازی گنجانده شد. در نهایت با اعمال چند داده عملی به سیستم فازی و مقایسه فاکتور-K محاسبه شده با مدل USLE عملکرد صحیح روش فازی نشان داده شد.