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**DETERMINATION OF THE WIND ERODIBLE FRACTION OF SOILS USING
DIFFERENT METHODOLOGIES**

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1 **Abstract**

2 The wind-erodible fraction of the soil (EF) (percentage of aggregates <0.84 mm in
3 diameter) is a key parameter to estimate the soil susceptibility to wind erosion. The standard
4 method for EF determination is the dry sieving by means of a rotary sieve. Flat sieving with a set
5 of sieves and the use of the equation $EF = (29.09 + 0.31 \text{ sand} + 0.17 \text{ silt} + 0.33 \text{ sand/clay} - 2.59$
6 $\text{organic matter} - 0.95 \text{ CaCO}_3)/100$, $R^2=0.67$, Fryrear et al., 1994) are two alternative ways of
7 determining EF. As the flat sieving has still not been contrasted against the standard rotary sieve
8 method nor the Fryrear et al. equation tested for soils other than US soils, we estimated EF with
9 both dry sieving methods and tested the equation for soils of semiarid regions of Central Aragon
10 (NE Spain) and the Semiarid Pampas (centre of Argentina), two regions prone to wind erosion.
11 Results showed that EF values obtained with the flat sieve were comparable with those obtained
12 using the standard rotary sieve indicating that the flat sieving technique is suitable for EF
13 determinations. The estimation of EF with the model proposed by Fryrear et al. (1994) did not fit
14 with measured EF values, indicating that this model is not useful for predicting EF in Spanish and
15 Argentinian soils. This was attributed to the high CaCO_3 contents of Spanish soils and the low
16 sand/clay ratios and high organic matter contents of some Argentinean soils. The equation $EF =$
17 $9.98 + 6.91 \text{ sand/clay} + 14.1/\text{organic matter}$ ($r = 0.933$; $P < 0.001$) was proposed to predict EF in
18 the studied soils.

19

20 *Keywords:* Wind-erodible fraction; Dry sieving; Rotary sieve; Flat sieve; Model validation.

1 **1. Introduction**

2 Wind erosion is an important soil degradation process in arid and semiarid regions. It
3 produces not only negative effects on soil properties (Buschiazzo and Taylor, 1993; Zobeck and
4 Fryrear, 1986) but also a deterioration of the environment, including human health (Wilson and
5 Sprengler, 1996). Due to these negative consequences, the comparative prediction of wind erosion
6 in soils submitted to different management conditions is necessary to avoid irreversible
7 degradation processes of the ecosystem.

8 The relationships between soil losses by wind erosion and soil surface properties
9 (cloddiness, vegetative cover, roughness) were first established from wind tunnel tests as early as
10 1950s (Chepil and Woodruff, 1954). Based on soil sieving and wind tunnel experiments, Chepil
11 (1950) observed that aggregates larger than 0.84 mm in diameter were non erodible in the range of
12 wind speed used in the tests. Since then, the wind-erodible fraction of soils, EF, (aggregates <0.84
13 mm in diameter) has been a key parameter to estimate the soil susceptibility to wind erosion and,
14 thus, has been considered in the predictions models, as the current Revised Wind Erosion
15 Equation, RWEQ (Fryrear et al., 1998, 2000).

16 The standard method for EF determination is the dry sieving by means of the rotary sieve
17 (Chepil, 1962). This device simulates the destruction of soil aggregates by abrasion due to the
18 impact of particles transported by wind. The rotary sieve is not commercially available and several
19 authors have developed alternative methods to determine EF. The flat sieve is an alternative dry
20 sieving device more readily available in the laboratories of soil physics. Toogood (1978) adjusted
21 a dry sieving method based on the flat sieving of soil aggregates in a set of sieves. Buschiazzo et
22 al. (1994) modified the Toogood's dry sieving method adapting it for soils of the semiarid
23 Argentina. López et al. (2001) quantified the susceptibility of soils of semiarid Aragon (Spain) to
24 be eroded by wind determining EF with a flat sieve.

25 Fryrear et al. (1994) proposed a multiple regression equation for calculating EF in those
26 cases where a rotary sieve is not available. This equation considers the contents of organic matter,

1 sand, silt, clay and calcium carbonate as predictive variables. Fryrear et al. (1994) indicated that
2 this equation has restrictions and that must be tested for soils different from US soils, for which
3 this equation was developed.

4 EF results obtained with flat sieving methods have still not been compared with EF
5 obtained with the standard rotary sieve method. On the other hand, the usefulness of the equation
6 proposed by Fryrear et al. (1994) has been not tested yet for soils other than US soils. Because of
7 that the objectives of this study were to analyze the efficacy of dry sieving with a flat sieve
8 machine to measure EF and to test the equation proposed by Fryrear et al. (1994) to predict EF for
9 soils of semiarid regions of Central Aragon (NE Spain) and the Semiarid Pampas (centre of
10 Argentina), two regions prone to wind erosion.

11

12 **2. Materials and methods**

13 A total of 22 farmer fields were selected in the Semiarid Pampas (centre of Argentina) and
14 5 farmer fields were selected in Central Aragon (NE Spain). The fields from Argentina were
15 located between latitudes 35° 40'S and 37° 18'S and longitudes 63° 59'W and 64° 20'W. The
16 elevation of the fields ranged from 190 to 220 m.a.s.l. and all sampled fields were level. The fields
17 sampled in Spain were located between 41° 31'N and 41° 43'N latitude and 0° 46'W and 1° 8'W
18 longitude. The elevation varied from 260 to 610 m.a.s.l. and all fields were level. The Spanish
19 fields were selected from a previous study where the main dryland cereal production areas of
20 semiarid Aragon with a mean annual rainfed of <400 mm were characterized in terms of their
21 susceptibility to wind erosion (López et al., 2001). The selected fields were representative of the
22 different situations of the wind erodibility of the soils of each region, based mostly on their
23 different textural composition. Soils of the Semiarid Pampas were classified as Typic
24 Ustipsamments and Entic Haplustolls and those of Central Aragon as Calcixerolic Xerochrepts,
25 Petrocalcic Xerochrepts and Lithic Xerorthents (Soil Survey Staff, 1975).

1 Two soils submitted to two contrasting management conditions were sampled in each field
2 of Argentina: a virgin soil under *Calden* forest (*Prosopis caldenia*, Burk.), an ecosystem submitted
3 to extensive grazing and never ploughed, and an adjacent agricultural soil, under continuous
4 cropping since more than 50 years after *Calden* deforestation. This sampling design allowed the
5 comparison of the prevailing soil use situations of the region: extensive grazing and continuous
6 agriculture. In Spain, all fields were cultivated following the traditional cereal-fallow rotation (one
7 crop in two years) of Central Aragon. In this case the following tillage systems were considered:
8 conventional tillage (mouldboard ploughing), reduced tillage (chiselling) and no-tillage.

9 Soil sampling was carried out between February and March 2004 in both regions,
10 corresponding to the fallow period following primary tillage operations. In all cases three
11 undisturbed soil samples per field were collected from the upper 2.5 cm of the soil with a shovel.
12 After air drying, a portion of approximately 200 g of undisturbed soil samples was separated,
13 crushed with a mortar and sieved through 2 mm to determine the following soil properties: particle
14 size distribution with the pipette method (Gee and Bauder, 1986) for the Argentinian soils, and
15 with laser diffraction (Coulter LS230 laser grain-sizer) for the Spanish soils; organic matter and
16 CaCO₃ contents were determined with the standard methods (Page et al., 1982) in all samples. Soil
17 surface properties for the selected fields are shown in Table 1.

18 Two sieving techniques were used to determine aggregate size distribution in all
19 undisturbed soil samples: the standard dry sieving with the rotary sieve (Chepil, 1962) and the dry
20 flat sieving with an electromagnetic sieve shaker (FRITSCH *Analysette 3 PRO*). A nest of sieves
21 with 20, 6, 2, 0.84 and 0.42 mm openings was used in both cases. In the flat sieve, an
22 electromagnet transmits vertical vibrations to the sieves. In order to determine with this technique
23 the optimum combination of sieving time and amplitude (vertical vibration height), a series of
24 experiments testing different sieving times and amplitudes were carried out using soils with
25 contrasting EF values. After observing a good separation of soil aggregates, without clogging and
26 breakdown, a sieving time of 5 minutes and amplitude of 0.1 mm were finally fixed for 100-200 g

1 undisturbed soil mass. In the rotary sieve, 1-2 kg heavy undisturbed soil sample was used and
2 sieving through a 0.84 mm sieve was finished as soon as no aggregates remained in the sieve. In
3 both cases, large clods were gently hand broken before added to the sieve.

4 The EF was calculated as the percentage of dry aggregates <0.84 mm in diameter in
5 relation to the whole soil in both determination systems.

6 EF was also calculated with the equation proposed by Fryrear et al. (1994):

7
$$EF = (29.09 + 0.31 \text{ sand} + 0.17 \text{ silt} + 0.33 \text{ sand/clay} - 2.59 \text{ organic matter} - 0.95 \text{ CaCO}_3)/100 \quad R^2 = 0.67 \quad \text{Eq. [1]}$$

8 All these variables are expressed in %.

9

10 **3. Results and discussion**

11 The amount of the wind-erodible fraction determined with the rotary sieve (EFrs) varied
12 between 11 and 88% and with the flat sieve (EFfs) between 4 and 95%. Following the erodibility
13 classification of Shiyaty (1965), as cited by Zachar (1982), 32% of the studied soils were highly
14 erodible with EF values >50%, 7% moderately erodible (EF between 40-50%) and 61% slightly
15 erodible (EF <40%). From the highly erodible group, half of these soils presented EF >70%,
16 corresponding in all cases to agricultural soils. Exceptions to this general trend were the slightly
17 erodible *Calden* soils of the Semiarid Pampas, with EF values lower than 40%. In this group were
18 included, likewise, the Spanish soils managed with conservation tillage (reduced tillage and no-
19 tillage).

20

21 *3.1. Comparison of rotary and flat sieve techniques*

22 Figure 1 shows the strong relationship ($r = 0.939$; $P < 0.001$) found between EF values
23 obtained with both sieving methods. This result indicates that the flat sieving method adequately
24 measures EF and it can be used as an alternative technique to the standard rotary sieve.
25 Nevertheless, a moderate deviation from the 1:1 line was observed for soils with EF values higher
26 than 40-50%. It could be attributed to an underestimation of the finest fractions of aggregates

1 produced by the rotary sieve. In fact, some amount of the finest aggregates did not pass through
2 the corresponding sieves and was collected along with coarser aggregates. This effect was stronger
3 in soil samples with larger amounts of fine aggregates. We estimated that EF could be
4 underestimated in this way by about 7-10%. In spite of this and taking into account the different
5 method of aggregate separation and amount of soil sample used in each method, the relationship
6 found between the EF values obtained with both methods is considered acceptable.

7 The correlation between EFfs and EFrs was better for agriculture ($r= 0.972$, $P < 0.001$) than
8 for less disturbed soils (*Calden* in Argentina and no-till in Spanish soils, $r= 0.880$, $P < 0.05$). This
9 was attributed to the more homogeneous aggregate composition of agriculture soils, as a
10 consequence of tillage, which tends to create a uniform aggregate size distribution. Buschiazzo et
11 al. (2004) showed that the spatial variability of organic matter, an important factor in aggregation
12 formation, was lower in agriculture than in *Calden* soils, as a consequence of tillage
13 homogenization.

14 The repeatability of both sieving techniques, calculated on the basis of EF variability
15 among the three replicates of each sample, proved that both methods behaved relatively well. The
16 mean coefficient of variation (CV) was 16% for the rotary sieve and 20% for the flat sieve. The
17 range of CV was 1.4-49% and 1.4-55% with the rotary sieve and flat sieve, respectively, with
18 more than half of the cases below 15%. The CV values calculated from data given by Fryrear et al.
19 (1994) for US soils varied from 8.3 to 65% but more than half of the CV was higher than 30% and
20 only a 9% lower than 15%. The CV found in our study indicates that the sampling and sieving
21 procedures used were reproducible and reliable.

22

23 3.2. Validation of equation [1] for EF calculation in the studied soils

24 The relationship between measured and predicted EF with Eq. [1] (Fryrear et al., 1994) is
25 shown in Figure 2. It can be seen that this equation was not successful in predicting EF for
26 Spanish or Argentinian soils. The lack of adjustment between measured and predicted EF values

1 for Spanish soils can be attributed to their high CaCO₃ content (30-40%) which was above the
2 maximum value with which the Eq. [1] was established (25%). Likewise, in the case of
3 Argentinian soils, 32% had a sand/clay ratio lower than the lower limit of the variation range
4 established for using Eq [1] (1.2%). In some cases, the organic matter content was also higher than
5 the upper value of the equation range (4.79%). In addition, whereas the agricultural fields from
6 Argentina and Spain were non-irrigated, there were also irrigated fields in the USA study. In the
7 case of Argentina, native, undisturbed soils of the Caldén ecosystem.

8

9 *3.3. Development of prediction equations for EF in the studied soils*

10 In order to develop specific prediction equations for our study conditions, correlation
11 analysis among EF and different soil properties were carried out (Table 2). Results show that all
12 soil properties, excepting CaCO₃ content, were correlated significantly with EF. The strongest
13 relations were found with textural fractions, positive with sand content and negative with silt and
14 clay contents. Figure 3 shows that EF is adequately predicted by the quotient sand/clay and that
15 EF increases with higher sand and lower clay contents, corresponding the highest EF values (95%)
16 to loamy sand soils and the lowest to clay soils (11%). Although weaker than the relationship of
17 EF with texture, significant negative correlation was also observed between EF and soil organic
18 matter content (Table 2). This negative relation agrees with the general association of soil
19 aggregation with high levels of soil organic matter (Kay and Munkholm, 2004).

20 A multiple regression analysis confirmed that the quotient sand/clay and soil organic
21 matter content were the main properties affecting soil aggregation in the studied soils, explaining
22 80 to 90% of EF variability. The equations that better predicted EF were:

23

$$24 \quad \text{EFrs} = 9.98 + 6.91 \text{ sand/clay} + 14.1/\text{organic matter} \quad [2]$$

$$25 \quad r = 0.933; P < 0.001$$

$$26 \quad \text{EFfs} = 4.77 + 7.43 \text{ sand/clay} + 27.6/\text{organic matter} \quad [3]$$

1 $r = 0.881; P < 0.001$.

2

3 These significant relationships were considered satisfactory considering the great variety of
4 the soils studied.

5

6 **4. Conclusions**

7 The comparison of two dry sieve techniques, flat sieving vs. standard rotary sieving,
8 showed that the EF values obtained with the flat sieve were valid and comparable with those
9 obtained using the rotary sieve. Thus, flat sieving can be considered as a suitable alternative to the
10 standard method for EF determinations. The estimation equation of EF proposed by Fryrear et al.
11 (1994) was not useful for predicting EF for Argentinian and Spanish soils. The sand/clay ratio and
12 organic matter were the best predictive variables of EF ($r=0.933; P < 0.001$) in these soils.

1 **Acknowledgements**

2 This research was supported by the Spanish Council for Scientific Research (CSIC) and the
3 Argentinian Council of Science and Technology (CONICET) (Bilateral Project Ref.
4 2004AR0059).

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1 **Figure legends**

2

3 Figure 1. Relationship between the wind-erodible fraction of the soil surface (0-2.5 cm depth)
4 determined with the rotary sieve (EFrs) and the flat sieve (EFfs).

5

6 Figure 2. Relationship between measured (rotary sieve) and predicted wind-erodible fraction (EF)
7 of the soil surface (0-2.5 cm depth) using Eq [1] for Argentinian and Spanish soils.

8

9 Figure 3. Relationship between wind-erodible fraction (EF) of the soil surface (0-2.5 cm depth)
10 and sand/clay ratio.

11

Table 1. Main characteristics of the studied soils in the 0-2.5 cm depth.

Country	Site	Management	Sand 2000-50 μm (g kg ⁻¹)	Silt 50-2 μm (g kg ⁻¹)	Clay <2 μm (g kg ⁻¹)	Organic matter (g kg ⁻¹)	CaCO ₃ (g kg ⁻¹)
Argentina	1	Cultivated	257	495	248	27.5	0.0
		<i>Calden</i>	278	529	193	34.2	0.1
	2	Cultivated	755	138	106	12.5	0.6
		<i>Calden</i>	714	150	135	33.8	0.0
	3	Cultivated	801	107	92	14.6	0.0
		Natural grass	779	120	101	20.7	0.0
		Cultivated	825	88	88	10.8	0.4
	4	Natural grass	803	98	99	13.4	0.3
		Cultivated	576	243	181	20.9	0.7
		<i>Calden</i>	557	280	163	37.4	0.4
	5	Cultivated	638	222	140	17.0	0.7
		<i>Calden</i>	112	586	302	22.7	0.5
	6	Cultivated	91	603	307	62.1	0.0
		<i>Calden</i>	226	347	427	28.3	0.0
	7	Cultivated	196	584	220	62.2	2.6
		<i>Calden</i>	558	270	173	14.6	0.1
	8	Cultivated	576	288	136	34.7	0.0
		<i>Calden</i>	245	527	228	26.1	0.0
	9	Cultivated	335	470	195	38.7	1.0
<i>Calden</i>		357	439	204	22.3	0.1	
10	Cultivated	171	498	331	78.6	0.0	
	<i>Calden</i>	598	266	136	42.2	1.5	
Spain	11	Cultivated (CT) ^a	264	471	265	12.8	407
		Cultivated (RT) ^a	286	458	256	15.4	387
		Cultivated (NT) ^a	265	481	254	18.7	384
	12	Cultivated (CT) ^a	539	281	179	17.8	199
	13	Cultivated (CT) ^a	416	404	180	10.8	333

^a CT, conventional tillage; RT, reduced tillage; NT, no tillage.

Table 2. Correlation coefficients of physical and chemical soil surface properties (0-2.5 cm depth)

	EFrs	EFfs	Sand	Silt	Clay	Org. matter	CaCO ₃
EFrs ^a	1						
EFfs ^b	0.939**	1					
Sand (2000-50 μm)	0.841**	0.782**	1				
Silt (50-2 μm)	-0.792**	-0.742**	-0.960**	1			
Clay (<2 μm)	-0.732**	-0.669**	-0.837**	0.649**	1		
Organic matter	-0.384**	-0.386**	-0.454**	0.461**	0.330**	1	
CaCO ₃	-0.122	0.034	-0.245*	0.243*	0.190	-0.324*	1

^a Wind-erodible fraction obtained with the rotary sieve.

^b Wind-erodible fraction obtained with the flat sieve.

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

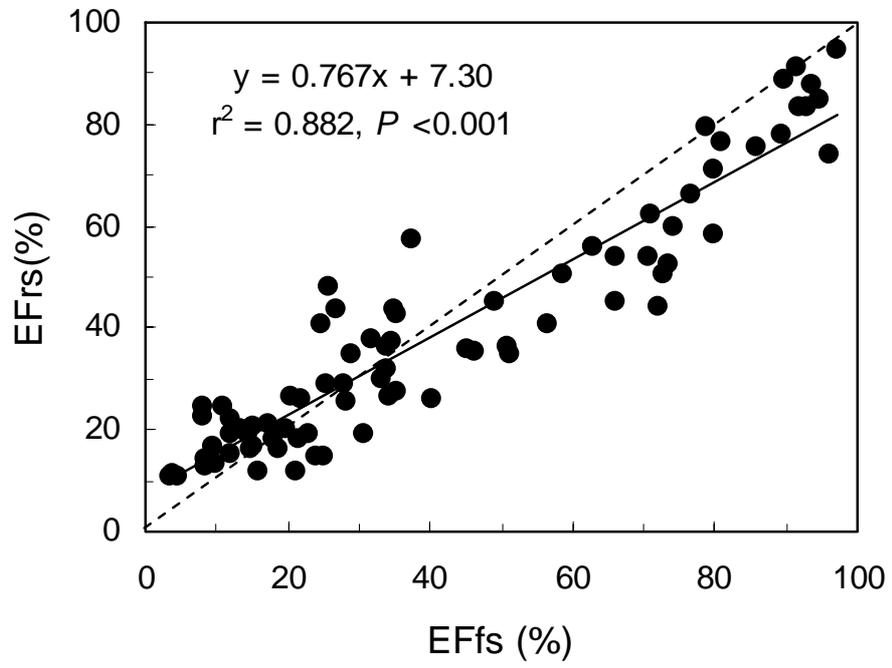


Fig. 1.

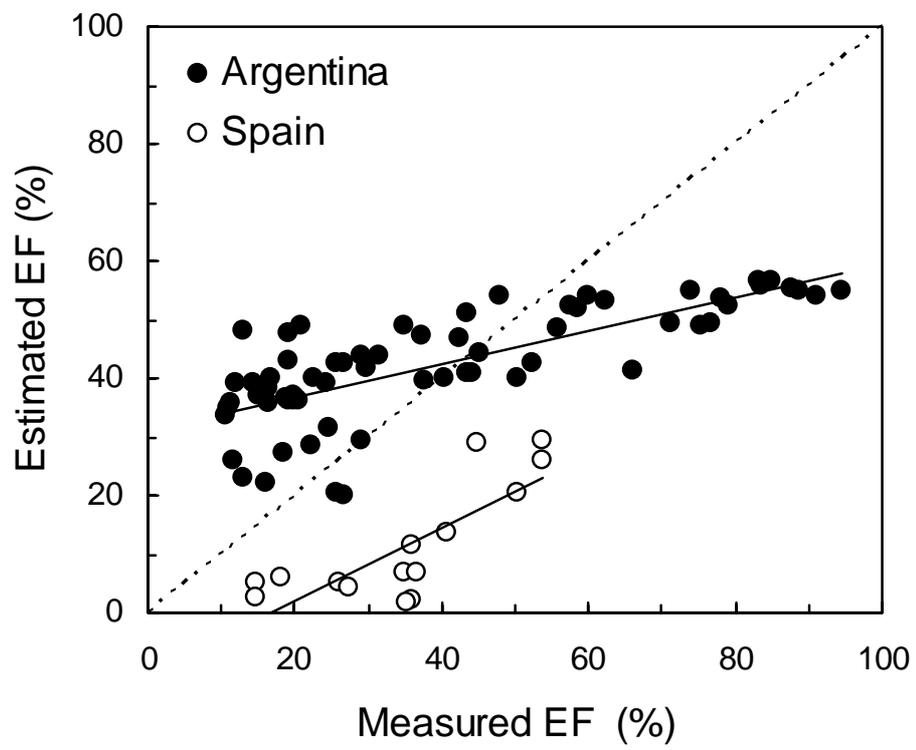


Fig. 2.

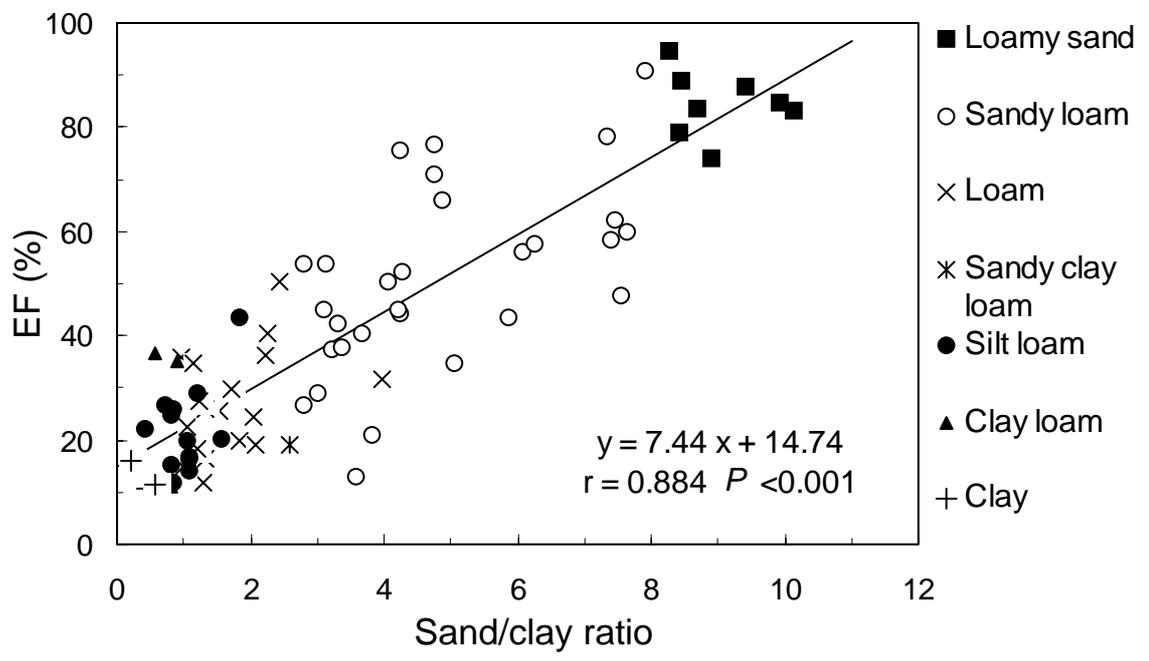


Fig. 3.