

APPLICATION OF ELECTRO- ULTRAFILTRATION (EUF) IN AGRICULTURAL PRODUCTION

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edited by

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Application of electro-ultrafiltration (EUF) in agricultural production

Preface

The First International Symposium on the Application of Electro-ultrafiltration in Agricultural Production was held in Budapest (Hungary) from May 6–10, 1980. Over 100 individuals from 15 different countries in Europe, Asia and Africa took part and 35 papers on experience with this method were presented. What was the idea behind this Symposium?

The procedure of electro-ultrafiltration as suggested by Bechold in 1925 has been further developed and improved over the past ten years. The introduction of varying voltage and temperature during the extraction process gives this method a considerable advantage in plant nutrient analysis, as it is now possible to obtain several nutrient fractions of different plant availability in one extraction run and to determine at the same time other soil properties such as K selectivity of clay minerals, content of K selective clay minerals, content of CaCO_3 etc. These data, in fact, make it possible to characterize a soil comprehensively and thus to ensure optimal plant nutrition, so meeting the economic requirements of agricultural production.

In 1974 and on the initiative of Dr. Wiklicky the Tulln Sugar Factory in Austria decided to introduce the EUF procedure in its soil testing laboratory for routine analysis. This meant a considerable step forward in the development of EUF. About 15 to 20 thousand soil samples every year are analysed at Tulln. The practical experience gained made it possible to improve the EUF procedure. In 1974 the UEF method was also introduced in Hungary by Dr. Eifert; he and his collaborators obtained remarkable results in grape production.

With the assistance of Dr. Wiklicky and his co-workers, a modern EUF soil testing laboratory has been established in Ormož, Yugoslavia, with the aim of improving fertilizer use on sugar beet. The EUF procedure is now being used in over 20 countries worldwide either on test or for the practical improvement of fertilizer advice. The worldwide interest in the method suggested that the time was ripe to collate existing information in a Symposium. The Hungarian Ministry of Agriculture favoured the proposal and preparations for the Symposium to be held in the Hungarian capital commenced in 1979.

The scientific content of the EUF Symposium was prepared at the Büntehof Agricultural Research Station in Hannover. Grateful acknowledgements are extended to Prof. Beringer, the Director of the Büntehof, and his predecessor Prof. Mengel, who contributed so generously to the development of the EUF programme. I am also very much indebted to the staff members of the Büntehof and in particular to the translator Mrs. Labrenz for the unfailing help they have always given me.

The Symposium was organized by the Hungarian Ministry of Agriculture and the Central Research Institute for Chemistry of the Hungarian Academy of Sciences. This arduous task was coordinated by Dr. Varju to whom I wish to express my appreciation for his whole-hearted assistance. After the Symposium the participants had the opportunity to visit the vineyards and cellars of the 'Balatonboglár' state holding which proved of great interest. The First International EUF Symposium owes its success to the excellent cooperation between the Bünthof Agricultural Research Station and the Hungarian Ministry of Agriculture, including the Central Research Institute for Chemistry of the Hungarian Academy of Sciences.

The objective of the Symposium was to present the first results and experience gained with the EUF procedure, so that the papers delivered are only a survey of the present-day state of knowledge. The bulk of the work of editing, including the selection of the articles, fell on Prof. Dr. van Diest, Wageningen, for whose valuable advice and untiring efforts I wish to record my special thanks. Some of the papers presented at the Symposium have already been published elsewhere and they will not appear in this issue.

Interest in the EUF procedure continues to grow. In Germany, for instance, Südzucker AG recently decided to organize a modern EUF soil-testing laboratory with the assistance of the Tulln Sugar Factory. The worldwide EUF activities and the positive results of the First International Symposium on EUF are an encouragement and a challenge to present an up-to-date account in the near future.

October, 1981

Hannover (Fed. Rep. Germany)

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Electro-ultrafiltration of aqueous soil suspension with simultaneously varying temperature and voltage

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Key words Fertilizer requirement Nutrient availability Nutrient fractions Nutrient reserves Soil analysis Soil solution

Summary The procedure of electro-ultrafiltration (EUF) with simultaneously varying voltage and temperature for the determination of nutrient fractions in soil as well as for the characterization of important soil properties such as kind of clay, content of K-selective clay minerals, of CaCO_3 etc. is described. The interpretation of the EUF-N, EUF-P and EUF-K fractions is discussed in detail with regard to their availabilities. Moreover the influence of soil properties and soil management on the EUF nutrient fractions is discussed.

For characterization of the EUF values needed for optimum plant nutrition, it is suggested to combine the EUF values at 20°C and 200 V on the one hand (easily available fraction) and the EUF values at 80°C and 400 V on the other (nutrient reserves). The higher, in fact, the nutrient contents at 80°C and 400 V are the lower can be the EUF values at 20°C and 200 V. In contrast to conventional methods of soil analysis, the nutrient contents determined by EUF are expressed in mg/100 g soil/time unit of desorption (min) at given temperature and voltage.

The EUF procedure proved highly advantageous for an assessment of the fertilizer requirements of soils as this method allows for the determination of soil properties such as kind of clay, content of K-selective clay minerals, of CaCO_3 , and of easily desorbable heavy metals in one single operation. These soil properties play a decisive role in the sorption of K and P.

Introduction

In agricultural practice, soil analysis is expected to answer the following questions:

- a) What is the amount of nutrients in the soil which can be supplied to the plant root in the course of a vegetation period?
- b) Which of the changes in these easily available amounts are due to crop withdrawal, leaching, weathering etc.?
- c) Which are the amounts of nutrients to be applied to the soil in order to raise the easily available amounts to the required values (fertilizer requirements)?

It will be explained how this information can be obtained through the use of electro-ultrafiltration (EUF) when voltage and temperature are varied during the extraction process.

Procedure of extraction

Several other publications^{4,5,6} give a full description of the component processes of electro-ultrafiltration (dialysis, ultrafiltration and electrodialysis) and the development of electro-ultrafiltration since 1925¹, so that these details need not be discussed further here. The present paper will be concerned with the consequence of introducing variations in voltage and temperature during the extraction process which has resulted into a considerable increase in the usefulness of the EUF procedure.

Significance of simultaneously altering temperature and voltage

The speed of ion migration in electro-ultrafiltration is proportional to the field strength and inversely proportional to the frictional forces. Furthermore, at a given field strength ion migration increases with increasing concentration. Temperature also plays a decisive role in EUF extraction. When the temperature is raised, higher amounts of nutrients are extracted at constant voltage within a unit of time^{5,6}.

It is, however, necessary to examine which additional nutrient fractions are withdrawn from a soil when temperature and voltage are increased and whether or not these fractions are important from a standpoint of plant nutrition.

For the determination of the fractions of nutrients which can most easily be made available to plant roots in the course of a vegetation period it is suggested to apply a 30 min extraction at 200 V and 20°C. The nutrient reserves will be assessed when the temperature is raised from 20°C to 80°C and the extraction continued for another 5 min or more. Extending the extraction for 5 min at 80°C and 400 V proved most suitable for practical purposes.

The significance of altering voltage and temperature as well as working at constant voltage and temperature is demonstrated in Fig. 1 for the extraction of the nutrient K. This figure shows the EUF–K curves of a humid tropical soil with kaolinitic clay minerals (exchangeable K = 13.6 mg/100 g soil) and of a grey-brown luvisol with illitic clay minerals (exchangeable K = 16.9 mg/100 g soil). The amounts of exchangeable K in the kaolinitic soil are quantitatively desorbed by means of EUF at 200 V and 20°C within 20 min ($t_{0.5} = 4$ min). No more K ions are released when voltage and temperature are raised. It may, therefore, be concluded that this soil has no K reserves (Fig. 1, on the left). In the illitic soil, on the contrary, only part of the exchangeable K ions, namely 8.6 from 16.9 mg, are released at 200 V and 20°C within 30 min. The maximally desorbable K amounts (dm) of 17.9 mg at 200 V and 20°C are almost equivalent to the contents of exchangeable K, the half time value being 31 min. When voltage and temperature are raised from 200 V and 20°C to 400 V and 80°C, the illitic soil, unlike the kaolinitic soil, continues to release K ions which attests to the K reserves of this soil. In this soil, therefore, the sum of the maximally desorbable K amounts at 200 V and 20°C and at 400 V and 80°C is higher (28.9 mg) than the contents of exchangeable K (16.9 mg).

K desorption at 400 V and 80°C, in contrast to the results obtained when varying voltage and temperature are applied, is similar in both soils (Fig. 1, on the right). Only the half time values of 1.4 (for the kaolinitic soil) and 7.2 (for the illitic soil) indicate different characteristics of desorption. When voltage and temperature are varied, the EUF–K curve for the kaolinitic soils shows a completely different course than for the illitic soils. The maximally desorbable K amounts of illitic soils at 400 V and 80°C are lower (21.6 mg) than the sum of maximally desorbable K amounts when voltage and temperature are varied (28.9 mg). For the assessment of the K reserves it is therefore more suitable to raise temperature and voltage during the extraction than to work at constant temperature and voltage.

In which way high K reserves are indicated by varying voltage and temperature is also demonstrated in Fig. 2. This figure shows the EUF–K curves of an alluvial soil (illitic clay minerals) with a high content of exchangeable K (79 mg/100 g). Despite the high contents of exchangeable K, only small amounts of K were desorbed at 20°C and 200 V. K desorption is, however, considerably accelerated, when voltage and temperature are raised, thus indicating a high K reserve. An increase in voltage alone (20°C and 400 V) is not sufficient to indicate this high reserve.

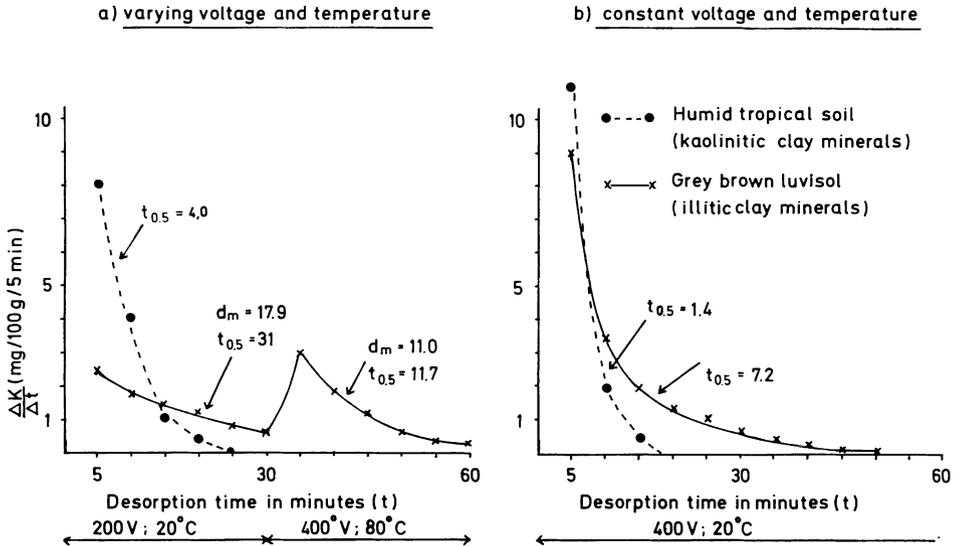


Fig. 1. EUF-K desorption rates at constant temperature (80°C) and constant voltage (400), on the one hand, and at varying voltage (200, 400 V) and temperature (20°, 80°) on the other hand.

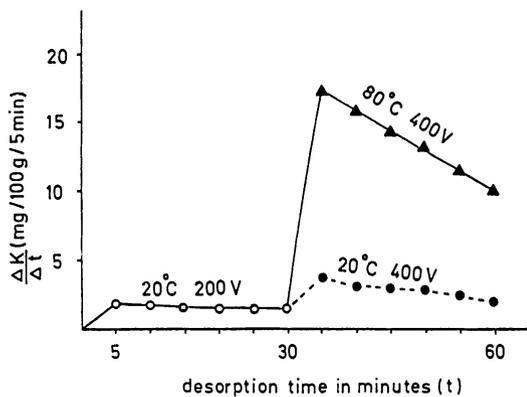


Fig. 2. EUF-K desorption rates of an alluvial soil (60% clay; illitic clay minerals) with a high content of exchangeable K (79 mg/100 g).

Interpretation of EUF results for plant nutrition

EUF-nitrogen fractions

EUF-NH₄ fractions The EUF-NH₄ contents of well-drained soils are lower than the EUF-NO₃ fractions. In soils well supplied with K the EUF-NH₄ contents are often so low that they are hardly measurable. In rice soils, however, the EUF-NH₄ contents can be rather substantial and they are correlated with the N absorbed by the rice plants¹¹.

In well-drained soils low in K, the EUF-NH₄ contents increase with increasing contents of K-selective clay minerals⁶. The desorption rate of NH₄⁺ ions becomes higher with increasing voltage and temperature. Thus, an increase in voltage and temperature seems advisable to obtain the necessary information on N release from the exchangeable NH₄ reserves.

EUF-NO₃ fractions It is known from earlier investigations that within 15–20 min the NO₃⁻ ions in a solution are quantitatively transferred by electro-ultrafiltration at 20°C and 200 V. An experiment was carried out to study the influence of the presence of a soil on the transfer of NO₃⁻ ions. A grey-brown luvisol was treated with KNO₃ and subsequently extracted by EUF for NO₃ analysis in the extracts. The results are given in Table 1.

Table 1. EUF-NO₃ contents of a grey-brown luvisol before and immediately after applying KNO₃ (0.5 mg N/100 g soil)

Soil status	EUF-NO ₃ (mg N/100 g)	
	20°C, 200 V (0–30 min)	80°C, 400 V (30–60 min)
Before KNO ₃ application	1.44	0.80
After KNO ₃ application	1.95	0.82

It can be seen that the NO₃ applied to the soil can be quantitatively recovered in the EUF fractions obtained at 20°C and 200 V. The transfer of the NO₃⁻ ions from a soil suspension is, therefore, very similar to the transfer from a solution. It is not easy to provide an explanation for the finding that additional NO₃ is extracted, when temperature and voltage are raised to 80°C and 400 V for an additional 30 min period after an initial 30 min extraction at 20°C and 200 V. It is conceivable that low-molecular organic N compounds are anodically oxidized to NO₃, but there is still no actual evidence for this assumption.

The EUF-NO₃ fraction at 80°C and 400 V was not influenced by KNO₃ application. It was, therefore, investigated which factors influence the EUF-NO₃ fractions. For this purpose, a field experiment (Büntehof) was carried out with different soils (1-m² plots) which for a 10-year period had been managed alike (uniform N-application, uniform crop rotations). Table 2 shows the EUF-NO₃ fractions as well as the Kjeldahl-N values which were obtained in the above experiment for the various soil types included in the trial. It can be seen that the EUF-NO₃ values obtained after uniform N applications over a 10-year period show soil-specific differences. The data furthermore show that a correlation exists between Kjeldahl-N values and EUF-NO₃ contents.

Table 2. Influence of variation in soil type on the EUF-NO₃ value after uniform N applications over a 10-year period

Soil type	EUF-NO ₃ (mg N/100 g)		Kjeldahl-N (mg/100 g)
	20°C, 200 V (0-30 min)	80°C, 400 V (30-60 min)	
Chernozem	1.10	0.80	142
Pararendzina	0.80	0.51	50
Grey-brown luvisol	1.00	0.54	91
Alluvial soil	0.80	0.60	116
Humic sand	1.50	2.06	290

$$\text{EUF-NO}_3 \text{ at } 20^\circ\text{C} = 0.0029 \text{ Kjeldahl-N} + 0.63$$

$$r = 0.93^{**}$$

$$\text{EUF-NO}_3 \text{ at } 80^\circ\text{C} = 0.007 \text{ Kjeldahl-N} - 0.057$$

$$r = 0.97^{***}$$

These correlations between EUF-NO₃ and Kjeldahl-N cannot be found very often, as they require uniform climatic and management conditions. A certain degree of correlation was only observed between the EUF-NO₃ fractions at 80°C and 400 V and Kjeldahl-N³. Differences in K and P supply of a soil will already lead to different NO₃ values under uniform cropping (vine) as demonstrated in Table 3. The results indicate that the EUF-NO₃ contents decrease with improved K and P supply, as the vine optimally supplied with K and P takes up more NO₃. The EUF-NO₃ values at 80°C remain, however, relatively unchanged and thus prove to be more a function of the type of soil involved (except soil No. 228). It is frequently observed that EUF-NO₃ values at 80°C increase with improved nutrient supply as can also be seen in Table 3 (soil No. 228).

Application of organic N can also affect the EUF-NO₃ values considerably (Table 4). In this table it is, however, clearly demonstrated that application of organic N in the form of slurry raised only the EUF-NO₃ values at 20°C.

EUF-extractable N fractions without EUF-NO₃ The cathode and anode filtrates contained more N than the sum of EUF-NH₄ and EUF-NO₃. This means that other N-containing compounds (serine, glycine, alanine, asparagine, glutamic acid *etc.*) also migrated in the electric field⁶.

Table 5 gives information on the influence of soil properties on the EUF-extractable N fractions. It is clearly shown that the content of EUF-extractable N depends on soil properties. Like for the EUF-NO₃ values, a correlation appeared to exist between the Kjeldahl-N values and the EUF-extractable N values.

Table 3. EUF-NO₃ values as affected by variations in K and P status of soils in field experiments with vine*

Soils No.	EUF-K (20°C)	EUF-P (20°C)	EUF-NO ₃ (20°C)	EUF-NO ₃ (80°C)	Kjeldahl-N
	mg/100 g		mg N/100 g		
201	6.0	0.24	2.14	0.70	136.7
200	6.8	0.60	1.90	0.80	142.8
211	10.7	0.56	1.50	0.76	144.2
228	16.0	2.10	1.40	1.10	146.2

* The soil samples were provided by courtesy of Dr. Eifert, Research Institute for Viticulture and Enology, Kecskemét (Hungary).

Table 4. EUF-NO₃ values determined after harvest of a wheat crop that had been supplied with organic N in the form of slurry

Soils	EUF-NO ₃ (mg N/100 g)		Kjeldahl-N (mg/100 g)
	20°C (0–30 min)	80°C (30–60 min)	
Grey-brown luvisol	4.74	0.90	139.4
Chernozem- grey-brown luvisol	6.64	0.92	175.5
Chernozem- grey-brown luvisol (without slurry)	1.06	0.98	163.0

$$\text{EUF-extractable N at } 20^{\circ}\text{C} = 0.009 \text{ Kjeldahl-N} + 1.12$$

$$r = 0.93^{**}$$

$$\text{EUF-extractable N at } 80^{\circ}\text{C} = 0.018 \text{ Kjeldahl-N} + 0.14$$

$$r = 0.97^{***}$$

It should, however, be noted that the soils concerned had received uniform N dressings over a 10-year period at uniform climatic conditions. In contrast to this, Németh⁶ and Harrach *et al.*³ did not find any correlation between the total N (Kjeldahl-N) and EUF-extractable N in different soils under different management conditions.

Relationship between EUF-NO₃ and EUF-extractable values (without EUF-NO₃) At uniform N applications and uniform climatic conditions a correlation

Table 5. EUF-extractable N fractions in different soils that received uniform N-applications over a ten-year period

Soil type	EUF-extractable N (without NO ₃) (mg N/100 g)		Kjeldahl-N (mg N/100 g)
	20°C, 200 V (0–30 min)	80°C, 400 V (30–60 min)	
Chernozem	2.4	2.2	142
Pararendzina	1.7	1.5	50
Grey-brown luvisol	2.4	2.0	91
Alluvial soil	1.7	2.0	116
Humic sand	4.0	5.8	290

can be observed between the EUF-NO₃ values and the EUF-extractable N values. These data were presented in Tables 2 and 5.

$$\text{EUF-NO}_3 \text{ at } 20^\circ\text{C} = 0.30 \text{ EUF-extractable N at } 20^\circ\text{C} + 0.29$$

$$r = 0.98^{***}$$

$$\text{EUF-NO}_3 \text{ at } 80^\circ\text{C} = 0.37 \text{ EUF-extractable N at } 80^\circ\text{C} - 0.10$$

$$r = 0.99^{***}$$

Such correlations cannot be found when management conditions differ (*e.g.* when large quantities of slurry are applied)³.

The application of large quantities of slurry disturbed the equilibrium between the EUF-NO₃ values and the values on EUF-extractable N. A balance is not restored, until after the quantities of EUF-NO₃ has been incorporated into the biomass or removed by leaching.

Calculation of the easily available quantities of N in a soil After numerous field experiments conducted on several sites⁸, it was found that 1 mg N/100 g soil (measured as EUF-NO₃ at 20°C in soils after harvest of cereal crop) is equivalent to approximately 90 kg N/ha. This figure proved highly reliable over the years 1976–1979 in Lower Austria and Burgenland (province of East Austria). Investigations in other European countries and in the USA have, however, revealed that, depending on climatic conditions and soil management, 1 mg EUF-NO₃ at 20°C is equivalent to sometimes more and sometimes less than 90 kg fertilizer N/ha.

Further investigations (*cf* Wiklicky¹²) have shown that the easily available quantities of N can more reliably be calculated on the basis of EUF-extractable N (Σ EUF-N) values. In this case, however, 1 mg EUF-extractable total N/100 g soil corresponds to 30 kg fertilizer N/ha. An example is given in Table 6.

Table 6. Calculation of the quantities of easily available N in different soils at uniform N applications

Soils	EUf-NO ₃ 20°C (mg N/100 g)	Easily available N (kg N/ha)	EUf-N 20°C (mg N/100 g)	Easily available N (kg N/ha)
Chernozem	1.1 × 90 =	99	3.5 × 30 =	105
Pararendzina	0.8 × 90 =	72	2.5 × 30 =	75
Grey-brown luvisol	1.0 × 90 =	90	3.4 × 30 =	102
Alluvial soil	0.8 × 90 =	72	2.5 × 30 =	75
Humic sand	1.50 × 90 =	135	5.5 × 30 =	165

As demonstrated in Table 6 it is possible to calculate the easily available N quantities in soils under uniform N fertilization by using either the EUf-NO₃ fractions or the EUf-extractable N fractions. This finding is based on the observation that in this case a close correlation exists between the EUf-NO₃ and EUf-extractable N values. Such a correlation depends on an equilibrium existing between the different EUf-N fractions.

This equilibrium can for instance be disturbed by leaching of NO₃ or when high amounts of NO₃ are added in the form of slurry. If this equilibrium between the EUf-N fractions does not exist, the EUf-NO₃ fraction cannot be used for the calculation of the quantity of easily available N. In fact, this quantity is underestimated in the case of leaching of NO₃ on account of the fact that easily soluble organic N compounds (Σ EUf-N - EUf-NO₃) from which NO₃ is formed by mineralization are not as easily removed by leaching as are the NO₃ ions. This quantity, if calculated by means of EUf-NO₃, is overestimated, when high amounts of NO₃ are added to the soil, for instance in the form of slurry, as the addition of slurry³ does not increase the amount of EUf-N without NO₃. When the quantity of easily available N is calculated, it is, therefore, advisable to use the sum of EUf-extractable N and to base the calculation on 1 mg EUf-N/100 g soil being equivalent to 30 kg N/ha¹².

EUf-phosphorus fractions

Depending on the level of P concentration in the soil solution, about 5–10% of the lactate-P, as determined in many European soil testing laboratories, can be extracted by EUf. If soils differ widely in certain properties (exchangeable Al, CaCO₃ etc.), there is a poor correlation between the EUf-P and the lactate-P values. When the voltage is increased from 200 V to 400 V and the temperature raised from 20°C to 80°C, the amount of P extracted by EUf can be twice as high as that extracted at 200 V and 20°C.

For plant nutrition, however, not so much the quantity of extractable P but the quantity of available P is of primary importance. The easily available P can be

- × Grey brown luvisol ; Lactate P₂O₅ : 24.5 mg/100 g (pH: 6.0)
- Pararendzina ; Lactate P₂O₅ : 21.3 mg/100 g (10% CaCO₃)

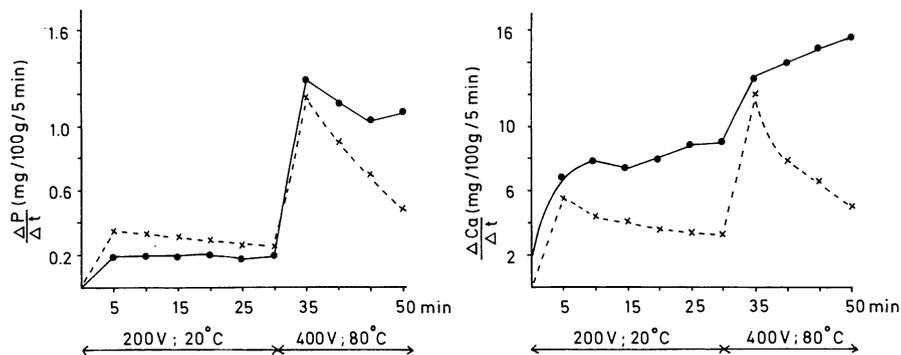


Fig. 3. EUF-P extraction rates of two different soils at varying temperature and voltage.

obtained at 200 V and 20°C within 30 min^{8,12}. The subsequent extraction at 400 V and 80°C gives information on the P reserves.

Fig. 3 shows that the calcareous pararendzina has a relatively low level of easily available P (200 V and 20°C) but high P reserves (400 V and 80°C). In contrast, the grey-brown luvisol is higher in easily available P, but the P reserves are lower than in the pararendzina. The lactate P₂O₅ values do not show these differences in P reserves (*cf* Fig. 3). The patterns of the EUF-P and EUF-Ca curves are very much alike. In the pararendzina, the nearly constant extraction rates at 20°C and 80°C indicate the presence of P reserves which will only be released at higher voltage and temperature, as is also found for Ca.

Correlations between EUF-P fractions and P-water values The correlation between the P-values obtained by water extraction according to van der Pauw⁹, and the EUF-P values at 200 V and 20°C during 30 min is very close⁵:

$$y = 1.0x + 0.027; r = 0.97***; n = 109$$

y = P water values (mg/100 g)
 x = EUF-P (mg/100 g)

The P-water values in calcareous soils with high pH values are often lower than the EUF-P values at 20°C⁸:

$$y = 0.26x + 0.26; r = 0.81***; n = 21$$

y = P-water values in calcareous soils (pH > 8.0)
 x = EUF-P

This difference is probably due to high Ca concentrations in the soil solution

and high pH values which hamper P extraction by water. In the EUF procedure, on the contrary, Ca ions are continuously withdrawn from the soil solution, thus allowing continuous mobilization of phosphate ions⁷.

EUF-P values required for optimal plant nutrition Long-term field experiments have shown that the quantities of P that are easily available to a crop during a vegetation period can be well characterized by EUF extraction at 20°C and 200 V during 30 min^{2, 5, 7, 8, 12}. These studies also showed that EUF-P value of 1.4–1.6 is necessary for optimal plant nutrition. The higher, however, the P reserves (EUF-P values at 80°C and 400 V within 30 to 35 min) are, the lower can be the required EUF-P values at 20°C. For calculation of the amounts of P fertilizer needed to raise the EUF-P values to 1.6 mg/100 g/30 min at 20°C, see Németh^{6, 7}.

EUF potassium fractions

The course of the EUF-K curves at low and at high selectivity of the adsorption complex has already been thoroughly discussed in previous publications^{4, 5, 6}. This paper will, therefore, concentrate on the relationship between EUF-K fractions and contents of exchangeable K (extracted with NH₄-acetate), as the content of exchangeable K is internationally used to characterize K availability.

The quantities of K desorbed within 30 min at 20°C and 200 V are generally lower than the contents of exchangeable K, i.e. they decrease with increasing contents of K-selective clay minerals in the soil and with decreasing degrees of K

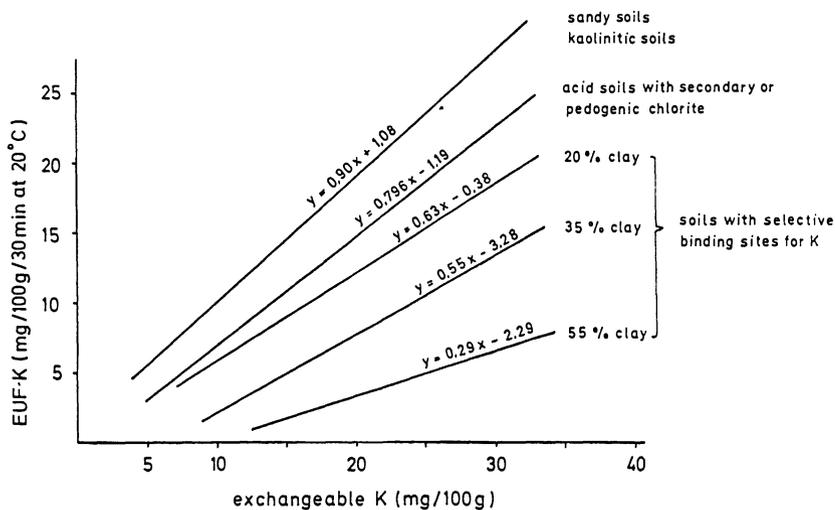


Fig. 4. Correlations between EUF-K (mg/100 g/30 min at 20°C) and exchangeable K (mg/100 g) of different soils with different clay contents and different types of clay minerals.

saturation of these clay minerals (Fig. 4). In sandy soils and in kaolinitic soils, the contents of exchangeable K are nearly the same as the amounts of K obtained by EUF at 20°C and 200 V within 30 min, which can also be seen in Fig. 4. In acid soils where the sites which bind K selectively are occupied by Al and Al-hydroxy compounds, the differences between exchangeable K and EUF-K values are likewise small.

The correlation between exchangeable K contents and EUF-K values at 20°C can, therefore, only be significant, when clay content and type of clay are almost the same. The slopes of the regression lines ($y = bx + a$) clearly indicate in Fig. 4 that EUF-K values at 20°C (y) are lower than the values of exchangeable K (x) in soils having selective binding sites for K. At low K selectivity the slope is nearly 1.0. The higher the selectivity, the lower are these b values.

Correlations between K uptake, yield and EUF-K fractions Long-term pot and field experiments show that the quantities of K which are easily available to a crop during a vegetation period can be well characterized by EUF extraction for a 30 min period at 20°C and 200 V^{5,8}. Statistically significant correlations were found between EUF-K fraction and K uptake as well as between this fraction and yield^{2,11,12}.

Fig. 5 shows an example with sugar beet as test crop. It can be clearly seen that sugar yield increases up to a K content of 15 mg/100 g/30 min at 20°C. This EUF-K value of 15 mg can be associated with exchangeable K contents (NH₄-acetate) of 15–45 mg/100 g depending on the soil properties. However this range becomes narrower, with decreasing strength of the solutions which are used for the extraction of K (0.025 M CaCl₂ or even water).

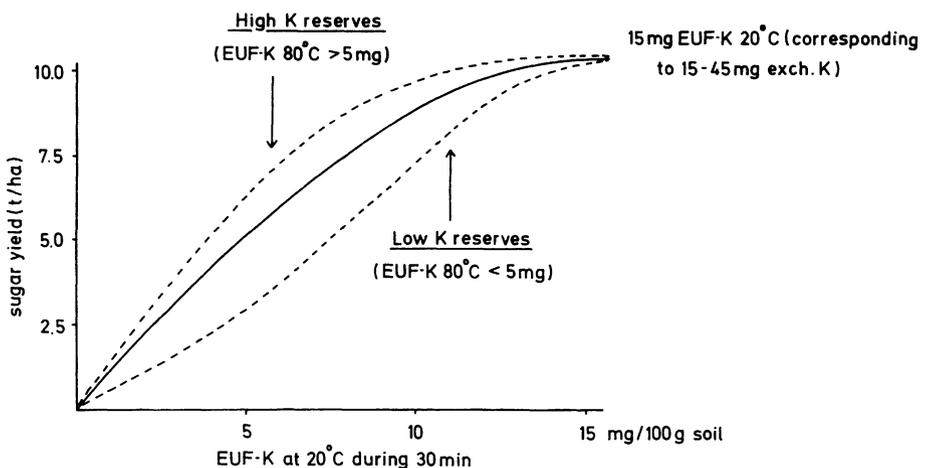


Fig. 5. Relationship between EUF-K fractions and yield of sugar beet as established in long-term experiments.

Fig. 5 furthermore shows that sugar yields of 10 tons/ha can also be obtained at EUF-K values lower than 15 mg/100 g/30 min at 20°C. Such a variability indicates that the parameter of mg/100 g/30 min at 20°C does not satisfactorily predict the quantities of K that can be supplied to plant roots in the course of a vegetation period. Likewise, a 30-min extraction period at 20°C is not sufficient to characterize the K reserve (K-buffering capacities). The same applies to extraction with weak extractants like water or 0.025 M CaCl₂.

These K reserves can, however, be well characterized by means of EUF when extraction is carried out at 80°C and 400 V. For this purpose the extraction of 30 min at 20°C is continued for a further 5 min at 80°C and 400 V. The higher the K amounts obtained from 30 to 35 min at 80°C, the lower can be the EUF-K values at 20°C required for optimal plant nutrition (*cf* Fig. 5). For calculation of the amount of K fertilizer needed to raise the EUF-K value to 15 mg/100 g/30 min at 20°C, see Németh^{5,6}.

These threshold values proved highly suitable for sugar beet crops at a yield potential of 50–55 t beets/ha^{8,12}. At a higher or a lower yield potential, these values have to be modified accordingly. The influence of differences in rooting depth on the required EUF-K values has also to be taken into account¹⁰.

Determination of quantity of clay minerals by means of EUF-K fractionation It is possible to determine the clay content of a soil by measuring the rate of anodical water flow⁵, but the manufacturing of appropriate EUF filters allowing a constant water flow still poses some problems. It was, therefore, attempted to find other ways to determine the amount of clay minerals. As the speed of K desorption depends on the type and quantity of clay minerals, it was investigated, whether the clay minerals can be determined quantitatively with the aid of EUF-K fractions.

Fig. 6 shows that the EUF-K values at 80°C (F₂) increase with increasing clay content. This is the case for both low EUF-K values (a) and high EUF-K values (b). This means that at equal clay content the EUF-K values at 80°C increase with increasing K contents in the soil. The EUF-K values at 80°C are, therefore, not suitable as an index of the clay content.

Fig. 6 furthermore shows that the value $\frac{\text{EUF-K } 80^\circ\text{C}}{\text{EUF-K } 20^\circ\text{C}}$ also depends on the clay content. In sandy soils this value is rather low (Ia = 0.2). In a heavier soil (38% clay) this value is much higher (IIIa = 1.3) and it changes slowly with increasing K content (IIIb = 1.06).

When plotting the EUF-K values at 80°C (x) against $\frac{\text{EUF-K } 80^\circ\text{C}}{\text{EUF-K } 20^\circ\text{C}}$ (y), the relationship turns out to be negative (Fig. 7). The slopes of the regression depend on the clay contents, and an unknown clay content can, therefore, be estimated from these regression lines, when the values of EUF-K 20°C and EUF-K 80°C are known.

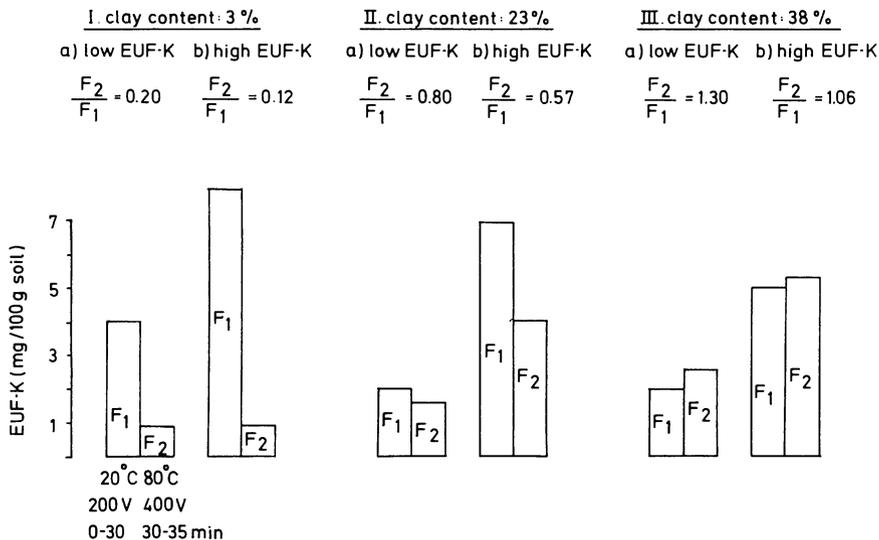


Fig. 6. Changes in the values of $\frac{\text{EUF-K } 80^\circ\text{C}}{\text{EUF-K } 20^\circ\text{C}} \left(\frac{F_2}{F_1} \right)$ with increasing amounts of EUF-K in the soils at different contents of K-selective clay minerals (3–38%).

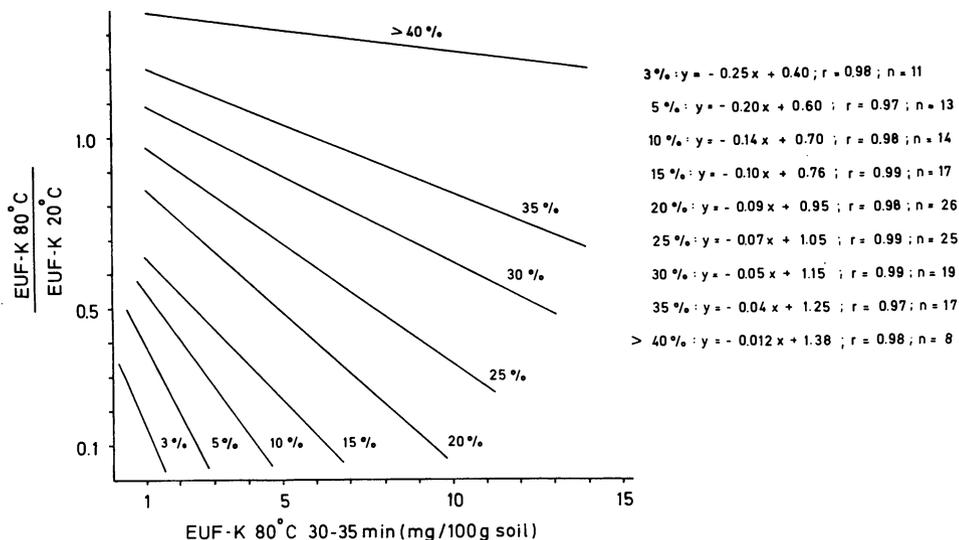


Fig. 7. Evaluation of the quantity of K-selective clay minerals by means of EUF-K fractionation.

Example a) A soil has an EUF–K value at 20°C of 13.9 mg/100 g and an EUF–K value at 80°C (x) of 6.7 mg/100 g. Consequently, the value of $\frac{\text{EUF–K } 80^\circ\text{C}}{\text{EUF–K } 20^\circ\text{C}}$ is 0.48 (y). At y = 0.48 and at x = 6.7, according to Figure 7, the clay content of this soil is approximately 20%.

Example b) A soil has an EUF–K value at 20°C of 9 mg and an EUF–K value at 80°C (x) of 3.0 mg/100 g. Consequently, the value of $\frac{\text{EUF–K } 80^\circ\text{C}}{\text{EUF–K } 20^\circ\text{C}}$ is 0.33 (y). At y = 0.33 and at x = 3.0, the clay content of this soil is approximately 10%.

Close correlations between the clay contents determined by EUF and those measured by conventional methods (sedimentation analysis) are, however, only found, when minerals of the clay fraction consist of illites, expanded illites and smectites with high charge. The EUF–K fractions do not assess the particle size distribution of a soil, but indirectly measure the quantities of those minerals which release K ions from their interlattice sites.

EUF heavy metal fractions

As the hydroxides and hydrated oxides of heavy metals are hardly soluble in the alkaline cathode filtrate, they remain in the cathode filter and cannot be obtained in fractions at 5-minute intervals. However, since it consists of soluble and desorbable ions, this EUF-heavy metal fraction is important for plant nutrition. Heavy-metal oxides of the soil do not migrate in the electric field. Therefore they cannot be extracted by EUF and have to be determined by conventional methods (extraction with acids).

Some of the heavy metals may become partly dissolved in the alkaline cathode filtrate in the form of complex compounds which will then be found in the cathode filtrate. This is the reason why the reproducibility of the heavy-metal values in the cathode filter is low.

Relationship between EUF-micronutrients and plant uptake Significant correlations could be found between EUF–Mn values and Mn contents in roots as well as in leaves of sugar beet¹². This finding confirmed the results of previous investigations carried out with red clover⁵.

Close correlations have also been observed between the EUF–Zn values and the Zn uptake of red clover, where the influence of K supply on Zn uptake becomes evident. Fig. 8 clearly shows that at a given EUF–Zn content (e.g. at 5.0 ppm) Zn uptake decreases with increasing K content in red clover.

Evaluation of anaerobic conditions in soils by means of EUF–Mn values If soils that are well supplied with Ca show high EUF–Mn values (< 2 ppm), this indicates that in these soils temporarily anaerobic conditions prevail which are mostly due to incorrect soil cultivation.

Fig. 9 gives the EUF–Mn contents and pH values in the profile of a grey-brown

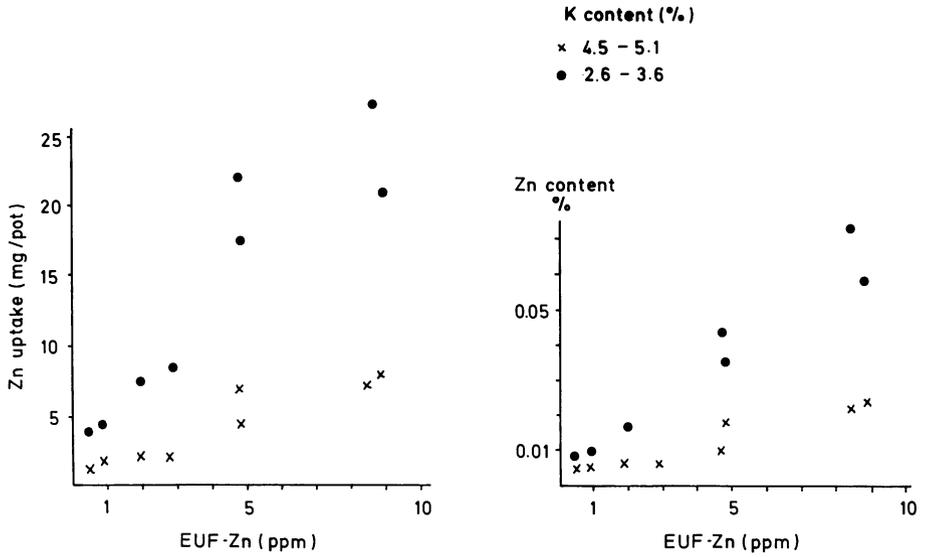


Fig. 8. Relationship between EUF-Zn content in soil and Zn uptake and Zn content of red clover varying in K content.

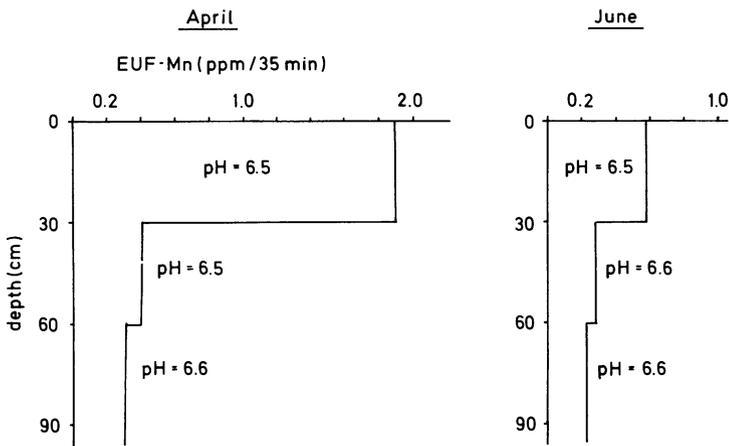


Fig. 9. EUF-Mn values at various depths of a grey-brown luvisol having temporarily anaerobic conditions in the topsoil.