Assessment of the agrochemical properties of the soil using the extraction solution Mehlich 3 in Estonia

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Abstract. To determine the requirement of macro- and microelements, seven extraction solutions have been employed in Estonian practice. Double lactate (DL) extraction has been used for determination of the phosphorus and potassium requirement, ammonium lactate (AL) extraction for determination of the calcium and magnesium requirement, and five more different extractions have been used for determination of microelements. Hence the need for a more appropriate extraction solution was due to the large number of the extraction solutions used until now, which made determination of the fertiliser requirement less efficient; also, in some cases, use of some extraction solutions did not yield reliable results in the case of particular plants. It was found in this study that the extraction solution Mehlich 3 is suitable for determining the fertiliser requirement of the soils of Estonia, considering their diverse agrochemical properties, while it allows to reduce the number of the extraction solutions. Also, employment of the extraction solution Mehlich 3 yielded more reliable results with respect to plants in the case of phosphorus, potassium, copper and, particularly, magnesium and manganese.

Key words: fertiliser requirement, available phosphorus, potassium, calcium, magnesium, copper, manganese, double lactate extraction, ammonium lactate extraction, 1 *N* HCl extraction, 1 *N* $(NH_4)_2SO_4$ extraction, Mehlich 3 extraction

INTRODUCTION

The universal extraction solution Mehlich 3, elaborated by A. Mehlich (1984), allows to determine most of the necessary plant nutrients from one and the same extraction solution. The hitherto used double lactate (DL) and ammonium lactate (AL) extractions and five more extraction combinations for microelements have displayed relatively low efficiency in determination of fertiliser requirement. Also, in consideration of the assimilation of nutrient elements by plants, the fact that such antagonistic elements as potassium and magnesium had to be determined from different extractions was inconvenient. Moreover, AL extraction proved to be unsuitable for determination of the magnesium requirement of soils rich in total magnesium as ammonium lactate extraction extracted also non-assimilable magnesium. Considering this, the aim of the present study was to find out the suitability of the extraction solution Mehlich 3 for assessment of the agrochemical properties of Estonian soils and to make an attempt to solve the existing problems related to determination of fertiliser requirement. Below, the results of analysing the relations between the contents of the plant nutrients phosphorus, potassium, magnesium, calcium, copper and manganese, determined from the extraction solution Mehlich 3, will be compared with the results obtained with the use of conventional extractions.

MATERIALS AND METHODS

To establish the suitability of the extraction solution Mehlich 3 for assessment of the agrochemical properties of the soil, chemical analyses of the soil were carried out both with the hitherto used extraction solutions and Mehlich 3. The set of the analysed soil samples (more than 500 in number) characterises the predominant soil types of Estonia (pebble-rendzina, typical brown soils, brown lessive soils, sod podzolic soils). The following characteristics were determined from the soil samples: pH_{KCl}, humus content by Tyurin; content of available elements (mg kg^{-1}): phosphorus and potassium by DL extraction, calcium and magnesium by AL ectraction, copper by 1 *N* HCl extraction and manganese by 1 *N* $(NH_4)_2SO_4$ extraction.

The suitability of the extraction solution Mehlich 3 for determination of fertiliser requirement was tested using the correlations between the contents of the corresponding plant nutrients in the parallel soil-plant samples. The study plants were winter wheat plants in the 6th leaf phase, collected from predominant soils all over Estonia.

By Sen Tran & Simards (1993) the extraction solution according to the Mehlich 3 method consists of :

1. 0.2 *N* CH_3COOH – buffers pH up to 2.5 and avoids precipitation of Ca.
2. 0.25 *N* NH_4 NO_3 – extracts Ca, Mg, K, Na.
3. 0.013 *N* HNO_3 – extracts part of Ca phosphates.
4. 0.015 *N* NH_4F – fluoride extracts Fe and Al phosphates and NH_4 complements ammonium nitrate.
5. 0.001 *M* EDTA – combines microelements into complex compounds and avoids precipitation of Ca.

Phosphorus, potassium, magnesium, copper and manganese were determined from the plant material by dry ashing of office analytical methocal: P – 71/393 EEC; K – 71/250 EEC; Mg, Cu, Mn – 78/633 EEC. Chemical analyses were made at the Agricultural Research Centre.

Data processing was performed using correlation analysis and regression analysis in MS Excel.

RESULTS AND DISCUSSION

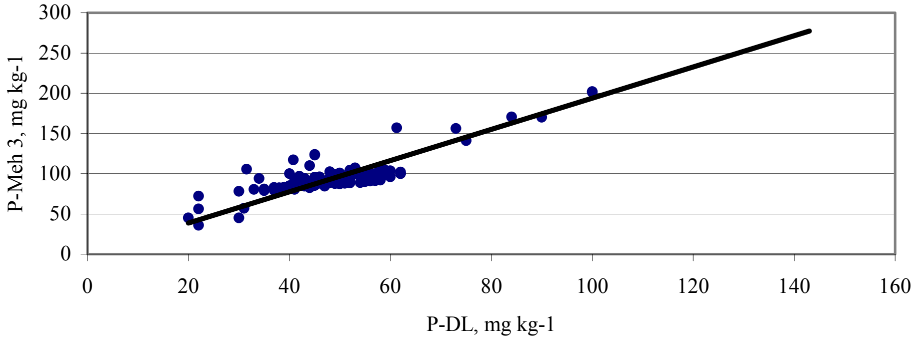
Transfer of available phosphorus from the soil into the extraction solution is affected by several factors. In the soil, phosphorus occurs in different forms (mineralogical and organic, which in turn contain different chemical forms, or salts) have different transformation rates and are differently dissolved in different extraction solutions (Sallade & Sims, 1997). Estonian soils are characterised by a large range of types, there occur both carbonate and non-carbonate soils, which should be taken into account in the choice of the extraction solution. Through research into the role of extraction solutions in estimating the content of available phosphorus has been carried out by several investigators. According to J. Matula (1999), the phosphorus content determined by the Mehlich 2, Mehlich 3, $CaCl_2$ extraction, soil solution, electroultrafiltration and UNIBEST methods correlated best with the phosphorus content determined from the water-solution. In the Czech Republic, it was found under the guidance of J. Zbíral (2001), when the results of Mehlich 3 and Egnér-Riehm (DL) extractions were compared, that phosphorus is better released on the Mehlich 3 extraction. As the difference was particularly significant for carbonate soils, DL extraction was regarded as unsuitable for these soils.

Comparative assessment of the Egnér-Riehm (DL) extraction solution and the Mehlich 3 extraction solution in the present study yielded the following results. A comparative analysis of the set of the soil samples from the predominant soil types (Table 1) revealed a significant correlation between the contents of available phosphorus determined with the two methods (correlation coefficient r = 0.809**). At the same time, it appeared that this correlation involved the soils whose humus content was in the range 2 – 15%. It was found that the correlations (Fig. 1) for the lower or higher humus content values were expressed in different ways, which might be due to the occurrence of different phosphorus forms in these soils.

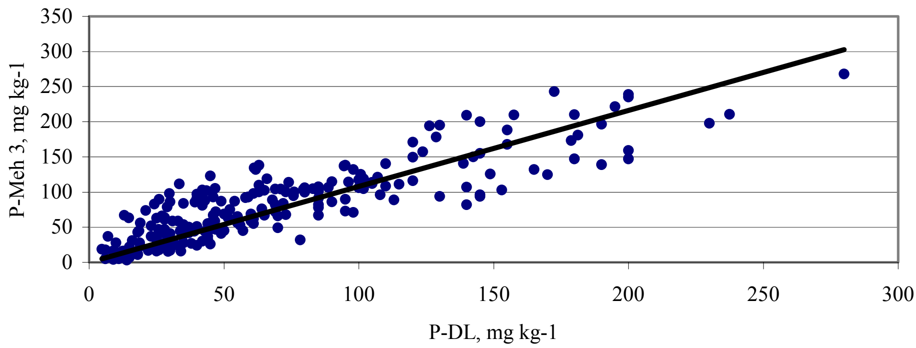
Table 1. Linear correlation between the contents of available elements determined from the DL extraction solution and from the extraction solution Mehlich 3.

Element	*n*	Regression equation [1)]	*r*
P	438	y = 1.195x	0.809**
K	446	y = 1.319x	0.955**
Mg	338	y = 0.705x	0.916**
Ca	337	y = 1.207x	0.939**
Cu	327	y = 0.487x	0.893**
Mn	440	y = 0.689x	0.853**

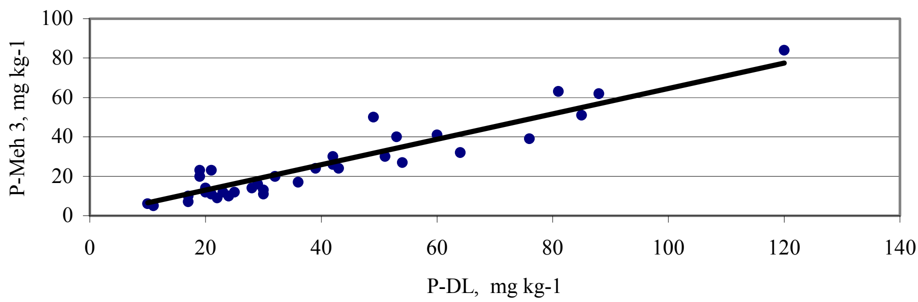
[1)]- y – content of the element in the soil, mg kg^{-1}; Mehlich 3 extraction
x – content of the element in the soil, mg kg^{-1}, P, K - DL; Mg, Ca - AL:, Cu – HCl; Mn – $(NH_4)_2SO_4$ extraction
*- correlation reliable at 95% probability level
** - correlation reliable at 99% probability level



a) Linear correlation for soils containing up to 2% of humus
y = 1.9634x, *n* = 125, *r* = 0.821**



b) Linear correlation for soils containing 2%–15% of humus
y = 1.0812x, *n* = 220, *r* = 0.867**



c) Linear correlation for peaty gleysoils
y = 0.6457x, *n* = 36, *r* = 0.940**

Fig. 1. Linear correlations (a, b, c) in determination of the content of available phosphorus from the DL extraction solution and from the extraction solution Mehlich 3 depending on the soil humus content.

Table 2. Regression correlations between the contents of soil and plant nutrients depending on the extraction solution[1)].

Element	Extraction	*n*	Regression equation	*r*
P	DL	30	y=0.0004x + 0.2642	0.613**
P	Mehlich 3	30	y=0.0007x + 0.2096	0.849**
K	DL	27	y=0.014x + 1.6492	0.829**
K	Mehlich 3	27	y=0.0143x + 1.2953	0.837**
Mg	AL	21	y=1E-0,5x + 0.0876	0.334
Mg	Mehlich 3	21	y=0.0005x + 0.301	0.894**
Cu	1 *N* HCl	18	y=1.407x + 0.2874	0.710**
Cu	Mehlich 3	18	y=2.5164x + 0.1238	0.838**
Mn	1 *N* $(NH_4)_2SO_4$	23	y=0.0271x + 27.316	0.562**
Mn	Mehlich 3	23	y=0.2213x + 17.939	0.798**

[1)]- y – content of the element in plant dry matter, %
x – content of the element in the soil, mg kg^{-1}
*- correlation reliable at 95% probability level
** - correlation reliable at 99% probability level

Assessment of the correlations between soil phosphorus and the phosphorus contained in the plants (Table 2) showed that the content of phosphorus contained in the plants was more strongly correlated with the corresponding phosphorus content when it was determined with the Mehlich 3 extraction solution compared with the DL extraction solution (correlation coefficients 0.849** and 0.613**, respectively). Thus the results of the determination of phosphorus content with the use of the Mehlich 3 extraction solution can be considered satisfactory and also relatively more reliable compared with those obtained by the DL extraction.

Potassium occurs as part of the mineral crystal lattice in the soil and is bound in the composition of clay minerals. Several investigators have shown the advantage of Mehlich 3 over different extraction solutions (Wendt, 1995; Mamo et al., 1996). The comparative analysis (Table 1) of the estimated potassium contents obtained with the use of the Mehlich 3 solution and the DL extraction solution in this study revealed a strong correlation between the potassium contents determined from either solution, the correlation coefficient being r = 0.955**. A significant correlation was also found between the potassium contents determined from the two extraction solutions for the clay-soil (r = 0.972**). The correlation between the potassium contents of the soil and the winter wheat plants (Table 2) was significant for the DL extraction solution (r = 0.829**), while a practically similar result (r = 0.837**) was obtained for the Mehlich 3 extraction solution. Thus the Mehlich 3 extraction can be assessed as no less than equal with DL extraction in determination of potassium content and suitable for estimation of fertiliser requirement.

Until now, magnesium requirement was determined by AL extraction, which has proved unreliable with respect to plants, especially on carbonate soils. When the estimates of available magnesium, determined from several extraction solutions, including the Mehlich 3 extraction solution, were not correlated with total soil magnesium sontent, then the estimate determined by AL extraction was in a strong positive correlation with total magnesium content. Thus the ammonium acetate solution extracts part of the magnesium not available to plants, which was also confirmed by the fact that the plants that had grown on such soils were as poor in magnesium as the plants that had grown on magnesium-poor soils (Loide, 2001, 2002, 2004). As Estonian soils are quite magnesium-poor in places, reliable assessment of magnesium content is highly important. Besides, in the case of such antagonistic plant nutrients as magnesium and potassium, it is necessary to take into account their ratio in fertilisation. This is easier to do when both elements are determined from one and the same extraction.

A comparative analysis of the estimated magnesium contents, determined from the AL extraction solution and from the Mehlich 3 extraction solution, yielded the following results. The estimates obtained with the use of either extraction solution (Table 1) were in good correlation (r = 0.937**) for the soils which contained available calcium (AL extraction) below 2500 mg kg^{-1}. In the presence of a higher calcium content, the correlation between the estimates of magnesium content was nonsignificant. This was due to the high total magnesium content, characteristic of these soils, as well as to the relatively higher solubility of magnesium in the case of the AL extraction compared with the Mehlich 3 extraction (Loide, 2002).

A comparative soil-plant analysis (Table 2) showed that the magnesium content of the winter wheat plants was significantly correlated with the soil magnesium content determined from the Mehlich 3 extraction solution, while the correlation between the results obtained by the AL extraction was moderate but did not exceed the level of significance at 0.95 and the respective correlation coefficients being 0.894** and 0.334.

The fact that magnesium and potassium are determined by one and the same extraction allows to assess the ratio K/Mg more reliably and take it into account in fertilisation. A good correlation occurred also between magnesium content in the soil and in the plants for the extraction solution Mehlich 3.

The estimates of available calcium too (Table 1), as determined from the Mehlich 3 and the AL extraction solutions, displayed strong correlation (r = 0.939**), except for very low contents (< 500 mg kg^{-1} AL), in which case significant correlation differed from the rest, and for very high contents (> 5000 mg kg^{-1}), in which case significant correlation was lacking.

Regarding microelements, the estimate of copper soluble in 1 *N* HCl and the estimates of manganese soluble in 1 *N* $(NH_4)_2SO_4$ and as determined from the extraction solution Mehlich 3 were compared. Good correlation was found between the contents of copper determined by the Mehlich 3 extraction and by 1 *N* HCl extraction, correlation coefficient r = 0.893**. The estimates of soil copper as determined by both extractions were significantly correlated with the copper content of the plants (Table 2). However, compared with the result obtained by HCl extraction, the given correlation was somewhat stronger for the result obtained with the use of the extraction solution Mehlich 3 (r = 0.710** and 0.838**, respectively).

Regarding the estimates of active manganese (Table 1), the results obtained with the use of the extraction solution 1 *N* $(NH_4)_2SO_4$ and the extraction solution Mehlich 3 were compared. A significant correlation was found between the estimated manganese contents determined from the extraction solution 1 *N* $(NH_4)_2$ SO_4 and from the extraction solution Mehlich 3. However, there were also soils for which the difference between the results was significant. Often these soils were rich in carbonates.

According to the data of R. Kalmet (1979), carbonate soils are the richest in manganese among dry soils. Evidently, relatively more manganese not available to plants is dissolved in the extraction solution 1 *N* $(NH_4)_2SO_4$ than in the extraction solution Mehlich 3. Hence the correlation between the manganese content of the plants and the soil (Table 2) was expressed more significantly by the Mehlich 3 extraction compared with 1 *N* $(NH_4)_2SO_4$ extraction, the correlation coefficients being 0.798** and 0.562**, respectively.

Based on the results of the comparative analysis of the studied extraction solutions, it was concluded that the extraction solution Mehlich 3 is suitable for assessment of the content of plant nutrients in Estonian soils. The correlation between the estimated contents of the plant nutrients and the chemical composition of plants was more significant compared with the correlations obtained by the other extractions. A good correlation between the results obtained with Mehlich 3 and those obtained with the other extraction solutions enabled to establish a new fertiliser requirement scale using coefficients for transition from one extraction solution to another. Application of Mehlich 3 reduced the amount of work needed for making soil analyses, and the determination of fertiliser requirement as a whole became more efficient.

CONCLUSIONS

Using the results of the comparative analysis of the suitability of the extraction solution Mehlich 3 for determining the fertiliser requirement of Estonian soils, the following conclusions can be drawn.

The study showed that determination of fertiliser requirement from the extraction solution Mehlich 3 tentatively allows to replace at least four extraction solutions which, until now, have been used for determination of the content of P, K, Mg, Ca, Mn, and Cu. The results of the comparative analysis of the extraction solutions demonstrated that the estimated contents of phosphorus, potassium, calcium, magnesium, copper and manganese determined by the Mehlich 3 extraction were moderately up to strongly correlated with the results obtained with the hitherto used extraction solutions. Of particular importance is determination of the content of the antagonistic elements potassium and magnesium from one and the same extraction solution. When suitable nutrition conditions are to be guaranteed for plants, it is also necessary to consider the K/Mg ratio in fertilisation. At the same time, the correlation between the content of the elements in the soil and the corresponding content of the elements in the plants was better to some degree, especially in the case of the estimated content of magnesium and manganese, compared with the extractions used earlier.

Application of the extraction solution Mehlich 3 not only improved the reliability of the estimated content of the plant nutrients but also reduced the amount of work needed for performing soil analyses; determination of fertiliser requirement became more efficient.

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