Clay Mineral Content of Soils and Fertilizer Use

P. STEFANOVITS

University of Agricultural Sciences, Gödöllő /Hungary/

Considerable differences are found if the fertilizer consumption of Hungary is compared to the fertilization practice in other countries. In countries which apply similar doses of fertilizer, the plant production is often more economical, i.e. the efficiency of the fertilizers is higher. At the same time the application of nitrogen, phosphorus and potassium fertilizers increases at more or less the same rate, while in Hungary the application of potassium exceeds that of nitrogen and phosphorus fertilizers to an ever greater extent. Consequently, the practice of potassium fertilization in Hungary needed revision and reevaluation. In addition, the characterization of the clay mineral composition and occurrence of various types of soils in Hungary also became necessary if potassium fertilization itself and the national fertilization advisory service were to be improved.

Materials and methods

The samples were collected from 300 representative soil profiles. The examinations were always made on complete soil profiles, so the processes taking place in the soils could also be studied. The clay fraction was separated, after which it was treated with magnesium, potassium chloride and ethylene glycol. X-ray diffraction analysis of these orientated samples was then carried out. A method was elaborated for the semi-quantitative evaluation of the clay mineral associations. The cation exchange capacity and the total potassium content of the clay fraction were also determined. The X-ray diffraction analysis of the total soil sample was also carried out, and periclase was used as an internal standard for the quantitative evaluation.

Maps /in scale of 1:500 000/ of clay mineral associations and of potassium-fixing clay minerals in the soils of Hungary have been prepared over the last ten years, taking into consideration not only the field surveys and laboratory results but the available soil, geological, geomorphological and groundwater maps.

Results and discussion

Clay mineral associations in the soils of Hungary

Eight kinds of clay mineral associations were distinguished in soil samples representing the ploughed layer. A 25-50% proportion of clay minerals is regarded as moderate /Table 1/. The map indicates both the clay

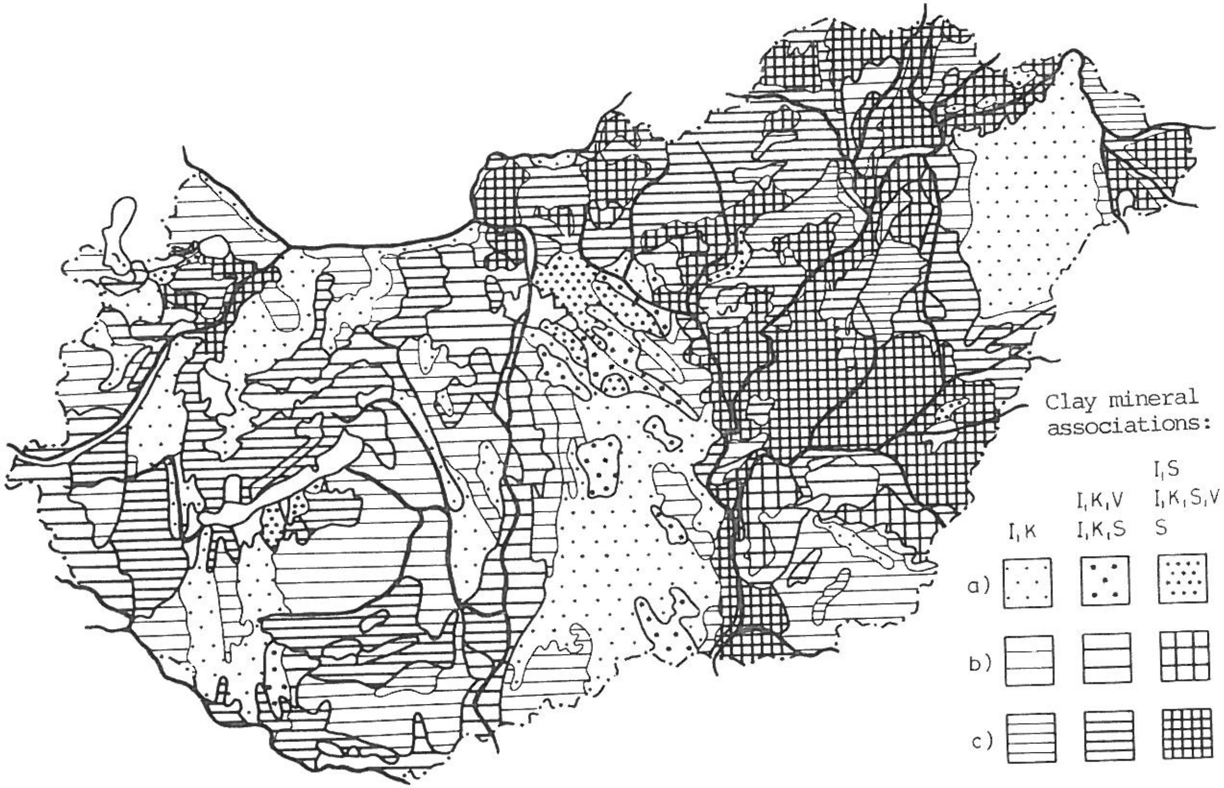

Fig. 1

The map of clay mineral associations. Clay mineral associations formed by illite /I/, chlorite and kaolinite /K/, vermiculite /V/ and smectites /S/. On the basis of the clay content: a/ low, b/ moderate, c/ high amount of clay

Table 1

Legend of the map of clay mineral associations
/on 1:500 000 scale/

Symbol of the association	Proportion of given clay minerals in the associations		
	Dominant	Moderate	Small
1	I	-	K, S, IS
2	-	I, K	S, V, IS
3	-	I, K, V	S, IS, IV
4	-	I, K, S, IS	-
5	-	I, S, IS	K, V, IV
6	-	I, K, S, V	IS, IV
7	-	I, S, V	K, IS, IV
8	S	-	I, K, V, IS
9	Other		

* I: illite; K: chlorite and kaolinite; S: smectites; V: vermiculite; IS, IV: mixed layer clay minerals

content and the clay mineral association of the soils. The mapping units were based on the clay mineral association of the soils and were arranged to show the increase in the possibilitiy of potassium adsorption /Fig. 1/.

The map shows that a wide variety of clay mineral associations may be found in soils located in different parts of Hungary; consequently, it is important to take these into consideration in fertilization. Soils characterized by a relatively low clay mineral content with low potassium adsorption can be found in the south western areas of the country. In sandy regions the dominant clay mineral is illite. The soils in the Tisza valley contain clay mineral associations of smectite. On the southern parts of the Northern Hills and on the hill slopes smectites are dominant.

The map indicates that the clay mineral content shows no direct or close correlation with either the type of soil formation or the quality of the soil forming rock, but is an unpredictable result of their interaction. The distribution of clay mineral associations depends to a certain degree both on geological conditions and on soil dynamics. In areas covered by alluvial deposits from the clay shale zone of the Alps and Carpathians chlorite and illite can be found in larger amounts. Soils derived from andesite and rhyolite are relatively rich in smectites. Loess, formed on the Hungarian Plain as well as in the basins of mountainous areas, contains illite, chlorite, smectite and vermiculite as well as their mixed layer minerals. Smectites are dominant in the lower parts of the Hungarian Plain which are covered by Holocene clay. Larger amounts of kaolinite occur in fossil and relict formations, particularly in soils developed on red, bauxitic clays and in small areas, mostly in the clayey facies associated with Permian red sandstone. Lepidocrocite, as a product of the change in the valency of iron, can also be found in fairly varied types of soils and rocks. In most cases the dynamic processes in the soil profile can be easily detected by the clay mineral composition, e.g. the illitization process in chernozem soils

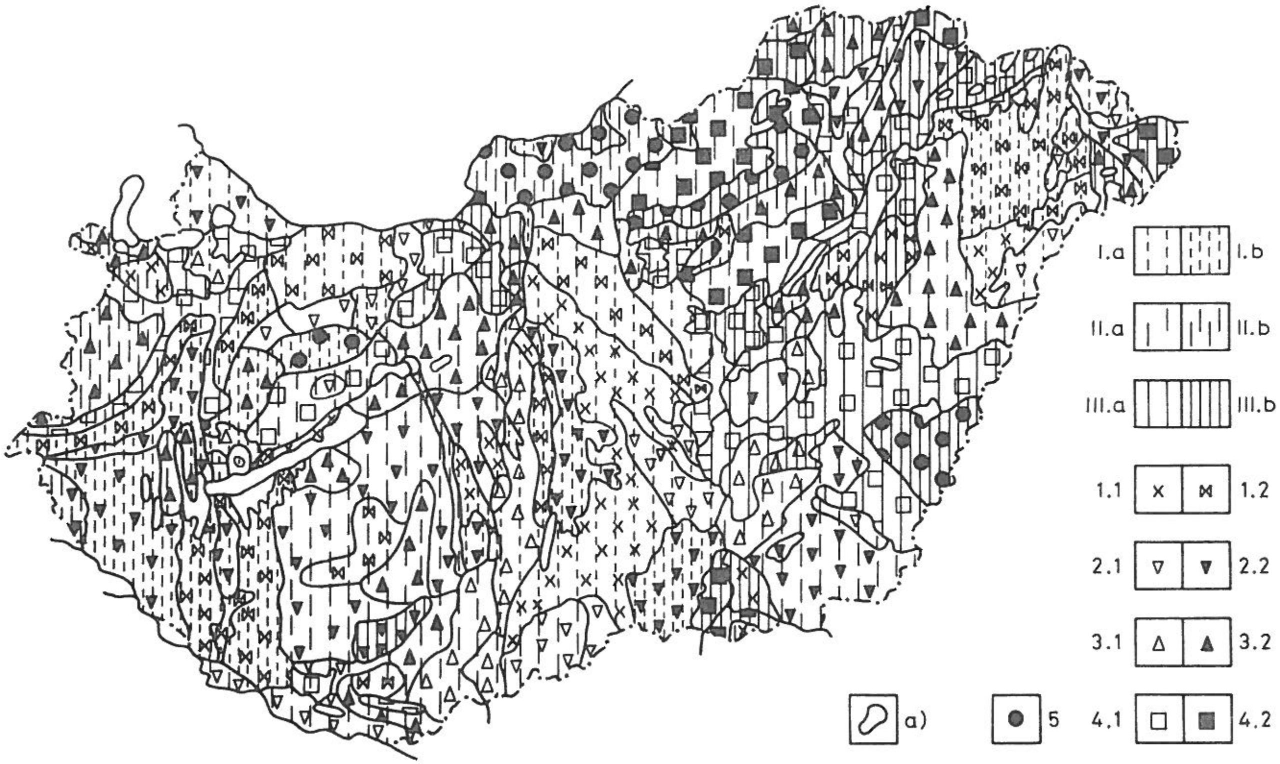

Fig. 2

The map of K-fixing clay minerals. On the basis of the clay content: I: <15%; II: 16-30%; III.: >30%. The value /a/ does not increase, /b/ increases in the upper 1 meter of the profile./ Proportion of K-fixing clay minerals in the clay fraction: 1.1-1.2: < 20%; 2.1-2.2: 20-30%; 3.1-32.: 31-50%; 4.1-4.2: 51-70%; 5: >70%. The decimal indicates the subcategory. In subcategory .1 the value does not increase in the subsoil, in subcategory .2 it does./ a/ lake, bog and the rearrangement of smectites within the profiles of Luvisols and solonetz soils.

The quality and quantity of clay minerals have several important consequences in soil processes. Soils which are dominantly illitic or rich in illite-chlorite do not fix potassium to a great extent, so the efficiency of potassium fertilizers is good. In the case of a high clay content the potassium reserves are important; the potassium supply of these soils is good. In soils which are rich in illite-chlorite, but where the smectite-vermiculite content is also not negligible, the potassium fixation is significant. These soils easily become potassium saturated and because of this their potassium supply also becomes favourable. In soils which contain mainly smectite or where the smectite-vermiculite content is larger than the illite content, potassium adsorption is strong, especially if the clay content is higher than 15%.

Effective potassium fertilizer doses were forecast on the basis of the quality and quantity of clay minerals. Similar results were obtained in other laboratory experiments /potassium determination by the electro-ultra-filtration technique and other desorption methods/. The conclusions were confirmed by several years of field experiments. For example, on one area the soil contained mainly illite, with a medium quantity of chlorite and its potassium content was very mobile. The suggested nitrogen-phosphorus treatment without potassium provided identical, or sometimes even higher yields than nitrogen-phosphorus-potassium fertilization did. In substantial parts of Hungary the clay content of the soils is medium or low and the clay minerals do not fix potassium. As a consequence of this no potassium is needed ever and above the amount removed from the soil by plants or crops. In other parts of the country, where smectites are dominant in the soils and only small quantities of potassium are released in the desorption experiments, potassium adsorption can be expected, so it is advisable to apply ameliorative doses /500 kg K_2O/ha/year/.

When analysing the present application of potassium fertilizers in different regions of the country, it became clear that comparatively large amounts of potassium are used in areas where the potassium adsorption of the soil is low, and less potassium is used where larger amounts would be justified. It is evident that the quality and quantity of the clay minerals should be taken into consideration in future fertilization practice.

The use of excessive amounts of potassium on soils which fix neither potassium nor ammonium ions may cause environmental pollution. These nutrients can be washed down into the soil, even as far as the underground water level. There are examples of this process in illitic sandy soils situated between the Danube and the Tisza. Fertilization practice should take into account the danger of environmental pollution. Most of the fertilizers used in Hungary, particularly the nitrogen fertilizers, can cause soil acidification. Even medium doses of fertilizers acidify soils lacking calcium carbonate /40% of the soils in Hungary do not contain $CaCO_3$/ if they have a low clay mineral content and if the buffer capacity of the soils is low. The titration curves for non-calcareous mineral soils indicate that the soils most susceptible to acidification are those in which the clay content is less than 15% and the dominant clay mineral is illite. In the past liming neutralized this acidification. Unfortunately, liming has radically decreased as a consequence of new economic rules and this decrease coincided with a rapid increase in fertilizer use, so the danger of acidification is more severe. Soils lacking calcium carbonate should be limed and acidification should be prevented by appropriate fertilization practices.

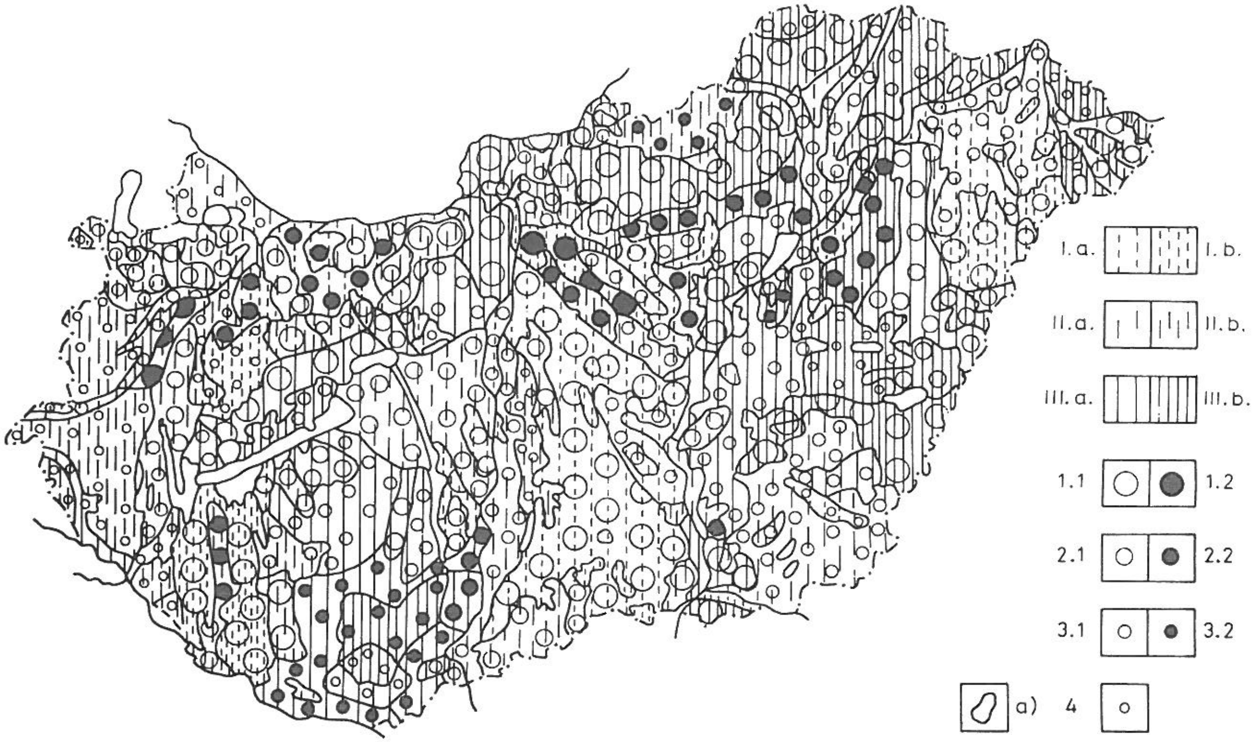

Fig. 3

The map showing the ratio of K supplying to K-fixing minerals in the soils of Hungary. Legend: The amount of physical clay in the plough layer: I: <15%; II. 15-30%; III: >30%. /The value /a/ does not increase, /b/ increases with depth in the profile./ The ratio of K-supplying to K-fixing minerals in the plough layer: 1.1--1.2: <2.5; 2.1-2.2: 2.5-5; 3.1-3.2: 5-10; 4: >10. /The decimal indicates the subcategory. In subcategory .1 the value does not increase in the subsoil, in subcategory .2 it does./ a/ lake, bog

Clay minerals play a role in the transformation of organic matter and in humus formation or decomposition. For instance, smectite can produce stable organo-mineral complexes. The efficiency of herbicides also greatly depends on the clay mineral content and composition of the soils.

Potassium-fixing clay minerals

The clay minerals of the ploughed layer determine the efficiency of fertilization to a great extent. Nevertheless, it is also necessary to take into consideration the characteristics of the total soil profile for accurate, appropriate potassium fertilization. It was for this reason that the map of potassium-fixing clay minerals /Fig. 2/ was compiled, showing the clay content, the proportion of potassium-fixing clay minerals in the clay fraction and their vertical distribution in the soil profile /Table 2/. The role of clay minerals in the nutrient regime of soils with a low /less than 15%/ clay content in the ploughed layer is generally not as significant as the role of the humus content, but even in this case the clay minerals are important if the clay content and/or the proportion of potassium-fixing clay minerals increases in the deeper layers. The quality and quantity of clay minerals and their distribution in the soil profile are of special interest in soils where the clay fraction is higher than 15%.

The factors taken into consideration during the compilation of the map make it possible to characterize the potassium fixation by a single number. This potassium-fixing index is calculated as follows:

$$\text{K-fixing index} = \frac{\text{clay content /\%/ . K-fixing clay minerals /\%/}}{100}$$

The potassium-fixing index provides valuable information for fertilization. The potassium-fixing index can be divided into different ranges. If the index is less than 8 potassium fixation is negligible; if the index is between 8 and 16 K fixation is moderate; if the index is between 16 and 32 K fixation is considerable; if the index is more than 32 potassium fixation is very intense.

Table 2

Legend of the map of K-fixing clay minerals /on 1:500 000 scale/

Amount of the clay fraction /particles < 0.002 mm in diameter/		Category	Proportion of K-fixing clay minerals in the clay fraction	
in the topsoil, %	in the upper 1 meter of the profile		in the topsoil, %	in the upper 1 meter of the profile
< 5	does not increase	1.1	< 20	does not increase
< 5	increases	1.2	< 20	increases
5-15	does not increase	2.1	20-30	does not increase
5-15	increases	2.2	20-30	increases
16-30	does not increase	3.1	31-50	does not increase
16-30	increases	3.2	31-50	increases
31-45	does not increase	4.1	51-70	does not increase
31-45	increases	4.2	51-70	increases
> 45	-	5	> 70	-

The map also enables various soil dynamic processes to be recorded. In the case of chernozem soils on loess becoming illitic the categories 2.2 and 3.2 are frequent. In lessivated forest soils categories 1.2 and 2.2 are characteristic, because of the clay illuviation and because of the relatively easy smectite migration. In solonetz soils the clay mineral quality results in category 1.2 for the smectite migrating from the A horizon to the B horizon.

Proportion of K supply to K-fixing minerals

The mineral composition of the total soil material was also determined by X-ray diffraction analysis. In this way eight kinds of minerals and the amorphous phase were distinguished and their quantities were calculated by the method elaborated.

The minerals participating in the potassium regime of the soils were dealt with separately, and a relative number was formulated, representing the ratio of potassium-containing illite plus mica and orthoclase to potassium-fixing smectite. If the amount of physical clay /smaller than 0.010 mm/ is taken into consideration, this ratio makes it possible to estimate the potassium reserves of the soil as well as their utilization. The dynamics of the minerals and the distribution of the physical clay within the profile, compared to that in the top layer, were also examined. The differences in quality have been indicated on the map.

The map shows considerable differences in the potassium reserves of soils in the various regions. The potassium reserves are largest if the physical clay content is high and the calculated proportion is also high. An increase in potassium-fixing minerals decreases the available potassium reserves. Plant roots may penetrate the soil to a depth of one metre, so the potassium reserves of the deeper layers must be taken into consideration, too. This is extremely important if the available potassium content decreases with depth, for instance because of an increasing smectite content.

The soils generally contain 50-300 tons K_2O in a soil layer of one metre per hectare. Experience shows that the potassium content of potassium-fixing minerals can adsorb 1% K_2O. Supposing a potassium-fixing mineral content of 25%, a soil layer of 1 m can fix 31.2 t K_2O/ha, which is equal to regular fertilization with 100 kg K_2O/ha for 312 years. This estimation demonstrates the importance of the clay mineral composition in potassium fertilization.