THE HYDROBIOLOGICAL, CLIMATIC AND PEDOLOGICAL FACTORS IN THE ALKALIZATION OF SOILS OF THE GREAT HUNGARIAN PLAIN

BY

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The alkali soils of the Hungarian Lowland developed mostly on the sediments deposited by the Danube and Tisza, respectively by their effluents. The former brings its sediments mainly from the Alps, so its deposits are limely. The latter, however, laid down a sort of acidic deposit derived from eruptions and from leached forest soils. In this deposit lime occurs only in the ground soils. In these soils of two different origins there are alkali spots of solonchak and solonetz types. Figure 1 presents
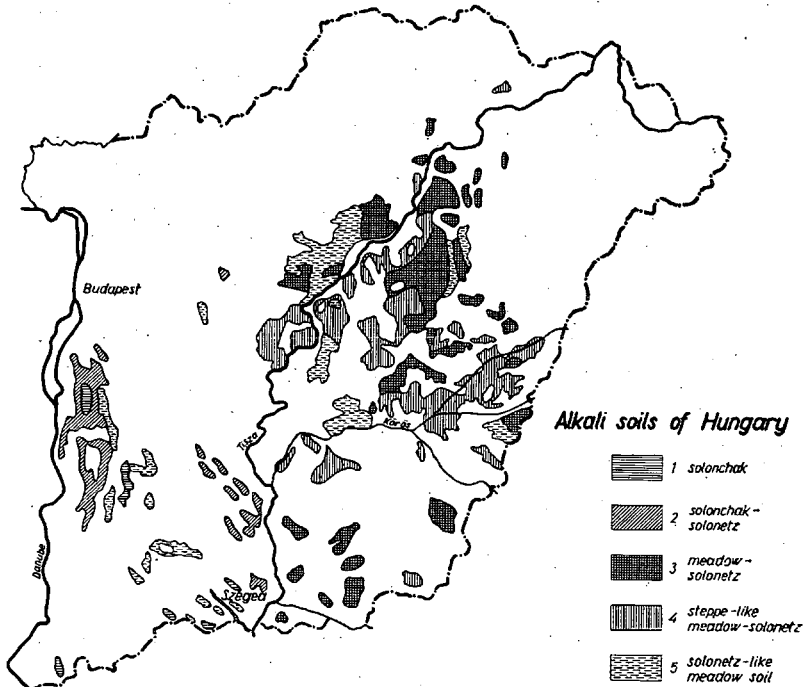

Fig. 1. Alkali soils in the Hungarian Lowland

general information on the localisation of alkali soils according to Stefanovits and Szűcs (1961). The surface of both types of alkali soil are covered in some places by amorphous silica. The light color of the bare surface of the solonetz and solonchak is due to their similar origin. How-

ever, on the surface of the solonchak soils efflorence of soda is possible, and occurs quite frequently. Soda efflorence has never been observed on the solonetz. This important difference was recognized by Szabó (1861) more than 100 years ago. In the solonchak-solonetz and solonchak soils the lime and soda occur in the whole profile, but in the solonetz soil only in B, and C horizons. The latter soil is characterized by spheric limonite-containing iron-concretions beneath the leached layer and by gypsum crystals, which are to be found frequently below the B horizon, where sulphates accumulate (Treitz, 1924; Arany, 1956; Szabolcs, 1961). The unfavourable properties of solonetz soils are due to the abundance of Na in the adsorption complex (Prettenhoffer, 1955; 1969). In solonchak-solonetz soils the undesireable effects are aggravated by the abundace of soluble sodium salts. Szabolcs (1954) classified the alkali soils on genetic principles, though they can be classified also on the basis of their native vegetation (Prettenhoffer, 1951). In the light of 'Sigmond's classification Magyar (1930) calls attention to this sort of relationship. The synocological classification of these indicatorlike associations has been worked out by Bodrogközy (1962, 1965). His work is based on the modern genetic analysis of the alkali soils and partly on halophylic phytocoenoses.

Theories of the alkalization and soda production

Younger scientists working on alkalization problems confirmed the results of the previous generation according to which sodification — independently of the type — takes place on soils which are periodically covered or saturated by water. It was a further step, in the elucidation of this question, when scientists recognized the importance of biological processes in the submerged soils. Muraközi suggested in 1902, that biological processes taking place in mud are responsible for alkalization. His view did not fit the ideas of Hilgard's book (1894) — which has been translated into Hungarian — and therefore has been neglected. Hilgard considered alkalization to be due to inorganic processes. According to him, soda is produced in soils by the reaction of lime and sodium-salts such as NaCl and Na_2S_4. The fact, that soda can not originate in this way was pointed out by Irinyi (1839).

Gedroic (1926) explained soda production as hydrolitic decomposition of the sodium complex. According to him soda is produced under the influence of carbon dioxide on the sodium adsorbed to colloid particles. Hence, the latter theory is related to the cycle of carbon, i. e. with biological processes. However the theories outlined above proved to be insufficient in explaining soda production and the formation of alkali soil profiles (Vámos, 1955; Arany, 1956; Kovda, 1964).

,Sigmond focused attention on arid climate, periodical water-covering, and the role of a water-impermeable layer as factors of alkalization. According to him in the simultaneous presence of these three factors sodification will always occur. Treitz (1924) in addition to these factors emphasized the importance of biological processes as well, and suggested the study of microbiological processes taking place in swamps and in wa-

ter with particular reference to the transformation of sulphur and nitrogen. He recognized furthermore the possibility of soda production as a result of the reaction between ammonium carbonate and sodium salts taking place during the nitrogen cycle. In essence he recognized the Solway and Leblanc-type of soda production in soils, but besides that — like Gedroic — he referred to the possibility, that soda can be produced by the reaction between sodium-containing clay-colloids and carbon dioxide. With the passage of time more and more scientists recognized the importance of sulphur compounds in alkalization (Starkey, 1950; Kovda, 1964; Joneda, 1964; Bloomfield, 1969.).

In our lowland there are still today quite spacious alkail ponds and marshes, and there are areas, which become dry only in midsummer. Hence, it is possible to study processes and changes which take place during wet and dry periods. Furthermore, there is considerable rice production and fish-cultivation on salt affected soils in Hungary. These two types of farming present different problems, such as plant and fish diseases caused by the soil, for instance root-rot, and fish-decay which are in a large measure due to H_2S and free NH_3. All of these matters require a knowledge the changes that occur in periodically submerged soils, with special regard to alkalization.

Climatic features

The climate of the alkali areas in Hungary is temperate warm, continental, but from the point of view of sodification we are interested only in the climate of the vegetation period. The fluctuation of temperature and the distribution of precipitation in time and space alters irregularly. The average temperature of the warmest month is 22—23 °C, but a rise in temperature to 39—40 °C is not rare. The intensive warming up is followed by relatively low night temperatures. Intensive irradiation both in time and energy has been measured at Szeged, also the loss of heat due to emission processes is the greatest in Hungary. The warming up caused by intensive irradiation, — even in the case of the same absolute humidity — leads to a lower relative moisture content than in other regions of the country. The amount of precipitation per year is 5—600 mm, and the distribution of the precipitation is irregular. The area inclines to drought but in spite of this great showers are not rare. Table 1. shows the distribution of precipitation.

Andó (1966) reported on the effect of climatic factors on alkali deadwater and on periodic waters. Due to climatic influences, the sodic waters belong to the astatic water group. The temperature of the water follows the temperature of the macroclimate quite closely but with some insignificant differences (Table 2). The distribution of oxygen in depth is influenced by the stratification of temperature due to the warming up of the water layer. The fluctuation of temperature exerts an effect on the biological processes; this will be dicussed later.

TABLE 1.

Percentage of probability of more than 5 day (A) and 10 day long dry periods in South Hungarian Plain. (1930—1960)

Data of VITUKI

Months	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
(A)	17	21	28	17	14	17	32	30	39	30	19	20
(B)	4	7	12	5	4	2	11		15	11	6	6

Table 1. Percentage of possibility of more than 5 day (A) and 10 day long (B) periods in the South Hungarian Plain. (1930—1960)

TABLE 2.

(Kunfehér-tó 1964)

Months	1	2	3	4	5	6	pentads
June							
air	26,0	25,0	28,0	28,0	27,0	29,0	
water	23,0	22,0	23,0	24,0	24,0	26,0	
△	3,0	3,0	5,0	4,0	3,0	3,0	
July							
air	32,0	25,0	25,0	28,0	30,0	28,0	
water	30,0	22,0	22,0	23,0	22,0	23,0	
△	2,0	3,0	3,0	5,0	8,0	5,0	
August							
air	21,0	25,0	23,0	25,0	24,0	28,0	
water	19,0	22,0	19,0	22,0	22,0	22,0	
△	2,0	3,0	4,0	3,0	2,0	6,0	
September							
air	20,0	22,0	23,0	23,0	15,0	19,0	
water	15,0	19,0	16,0	15,0	14,0	16,0	
△	5,0	3,0	7,0	8,0	1,0	3,0	

Table 2. Changes of temperature of water and air in sodic-pond (Kunfehértó). 1964.

Changes in submerged soils

In the submerged or water saturated soils the decomposition of organic matter starts in the spring with rising temperature. Under optimal circumstances the bacteria rapidly proliferate, their number may reach more than a hundred or thousand times the original. The main factors governing their growth are the amount and quality of the organic material destined for decomposition and the temperature. According to our investigations the abundant reserves of organic and inorganic nitrogen in the soil are a stimulating factor for the growth of bacteria. Under fa-

vourable circumstances the proliferation of bacteria involves intensive oxygen consumption. The reduction of nitrates commences with the disappearance of oxygen and at about the same time the reduction of manganese and iron starts as well (Fig 2). This is followed later — at lower
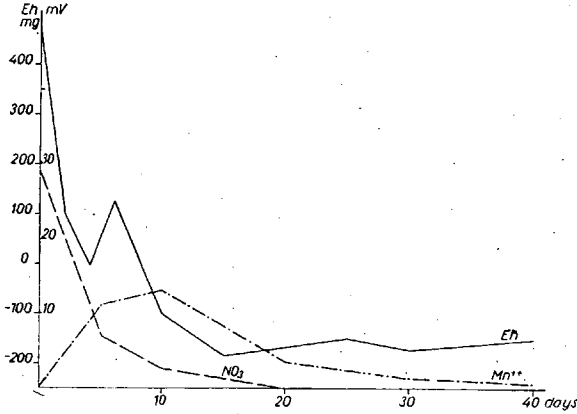

Fig 2. Changes of Eh, Mn ++ nitrate in solonchak-solonez soil. Fehértó near Szeged

redox potential — by the reduction of sulphates and phosphates (Ponnamperuma, 1955; Vámos, 1955; Takai et al. 1956; Bloomfield, 1969).

Since the soil solution contains only a few mgs of nitrate and phosphate ions, the change taking place in the soils is mainly the reduction of sulphate ions and sulphur, which are present in abundance.

Figures 3, 4 and 5 show the changes in pH, redox potential, Fe^{2+} and Mn^{2+} in the mud on meadow solonetz and solonchak-solonetz soils.
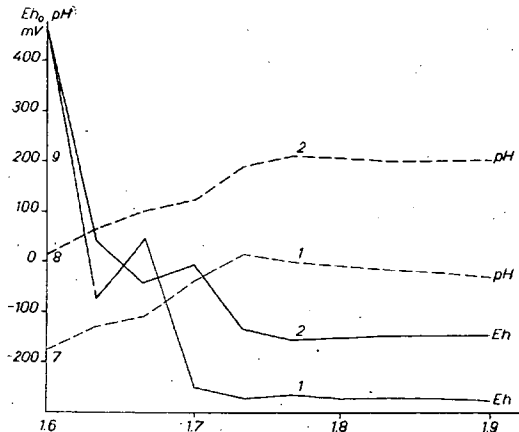

Fig. 3. Changes of pH, Eh in submerged solonchak-solonetz and meadow-solonet soils.
     1=meadow-solonetz, 2=solonchak-solonetz

The reduction processes are associated with the decomposition of organic materials. The electrons produced by the respiration of bacteria transform manganese and iron-oxides, as acceptors to Mn^{2+} and Fe^{2+} ions. Under anaerobic conditions the decomposition of organic matter and
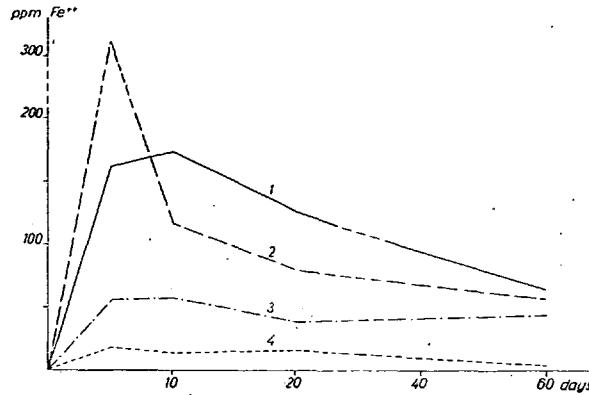

Fig. 4. Kinetics of Fe^{++} in meadow-solonetz and solonchak-solonetz submerged soils.
1,2=meadow-solonetz, 3,4=solonchak-solonetz

the residues of floral origin are accompanied by the production of organic acids and gases. The gas is mostly methane, but it also contains a small amount of carbon dioxide, nitrogen, and hydrogen (Jamane, Sato 1963). The short-chain carboxylic acids produced via the glycolytic decomposition are used up not only by reduction, but also by methane bacteria. Under Eh_0 0 mV an intensive sulphate reduction process starts for which the energy is partly supplied from hydrogen produced by Clostridia. A source of energy for the sulphate-reducing bacteria could be ethanol, lactic acid, and pyruvic acid, but they cannot use acetic acid.
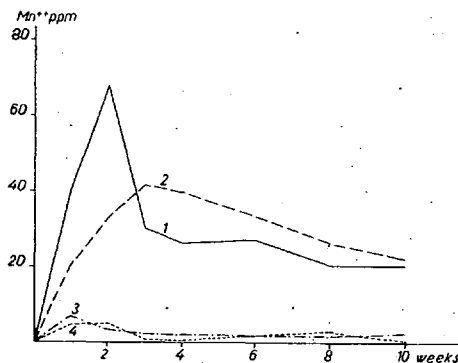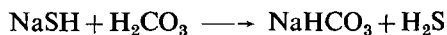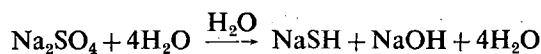

Fig. 5. Kinetics of Mn^{++} in submerged meadow soil meadow-solonetz, and solonchak-solonetz soils.
1,2=meadow-solonetz, 3,4=solonchak-solonetz

Besides utilizing hydrogen, the sulphate-reducing bacteria need carbon in the form of organic compounds (Starkey 1966). The most common equations balanced of sulphate reduction are as follows:

$$Na_2SO_4 + 4H_2O \xrightarrow{\ H_2O\ } NaSH + NaOH + 4H_2O$$

$$NaSH + H_2CO_3 \longrightarrow NaHCO_3 + H_2S$$

As a result of sulphate reduction sodium hydrocarbonate and hydrogen sulphide are produced (Fig. 6.). Due to the above processes the pH
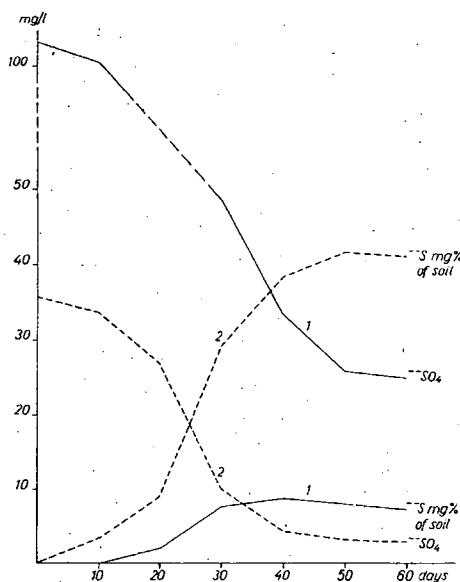

Fig. 6. Kinetics of SO_4—— and S—— in submerged meadow-solonetz and solonchak-solonetz soil

of the water increases, but the mud remains nearly neutral owing to the action of bacteria. H_2S produces FeS by reacting with Fe^{2+} ions and other compounds. The bacterial reduction processes are intensive in the nearly neutral swamps too even if the number of bacteria decreases to a minimum because of the alkalization of the water to a pH higher than 9. The enormous decrease in the number of bacteria is not only a consequence of the increases in the amount of OH ions, but we think it may be due to the toxic effect of free ammonia. The surface of the nearly neutral mud is greenish-brown, due to the presence of iron oxides, which are mostly the oxidation products of iron-sulphides.

The sulphide content in the swamp of acidic soils may reach 40—50 mg/100 g however in the limely soils it remains under 10 mg/100 g. Later the rise of the redox level stops, afterwards it decreases slowly. In those
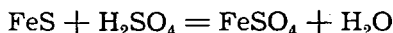
places where the reducing character of the layers has changed to anaerobic one, the FeS will be oxidized.

$$FeS + 2\,O_2 = FeSO_4$$
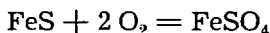
The ferro-sulphate produced hydrolizes and as a consequence ferro-hydroxide arises.

$$FeSO_4 + 2\,H_2O = Fe(OH)_2 + H_2SO_4$$
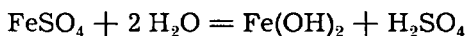
H_2SO_4 releases H_2S from its environment,

$$FeS + H_2SO_4 = FeSO_4 + H_2O$$

this may undergo further oxidation and elementary sulphur is formed.

$$2\,H_2S + O_2 = H_2O + 2\,S$$
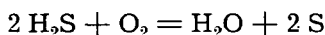
The simplified aquation of sulphur oxidation consisting of several steps may be written as follows.

$$2\,S + 3\,O_2 + H_2O = 2\,H_2SO_4$$
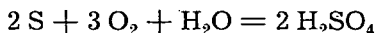
In the microbiological oxidation of elementary sulphur, and thiosulphates to sulphates, members of the genus Thiobacillus are active. This change, i. e. the oxidation of hydrogen sulphide may take place partly during the waterlogging and partly after the evaporation of the water layer. Later the sulphur precipitates; the screenlike picture of that is shoown in Fig 7. Thus, during water-logging reducing processes take place in the swamp, while during the dry period the reduced compounds will be oxidized under aerobic conditions. Oxidation, however, may come into action in a swamps even before draining or desiccation. With a sudden fall of temperature the oxygen content of the water may increase, and therefore the upper surface of the swamp may become oxidized. But in the water of ponds the release of H_2S commences usually at the time of cooling down in autum. It may happen, that this process will go on under the ice sheet because of the sudden onset of winter. Under this condition the H_2S could not pass into the atmosphere, because the water layer is not incontact with the atmosphere, and the oxidation of H_2S is slow, or fails to occur. The H_2S, which may accumulate in this way has caused the complete fish-decay, e. g. in the dead arms of Tisza, in the lake of Palics, and the lakes of Tata.

Consequently, the intermittent waterlogging, that is, the dry and wet periods are a prerequisite of oxidation-reduction processes which will lead to alkalization. 'Sigmond's factors assure the conditions for that. In the swamps and waters of submerged soils these processes occur. Though the processes carry on in the same direction alkali soils of different profiles and properties result. For example under the effect of the same climate alkali soils of completely different profiles have come into being in a relatively small area like the Hungarian Lowland and parts of
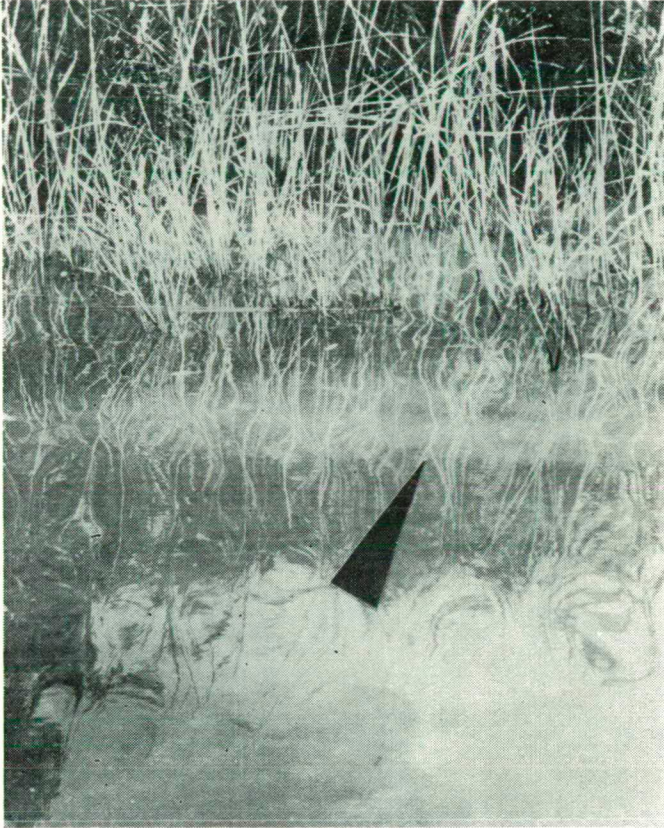
Fig. 7. Veil-like colloidal sulfur in dead-arm on acidic meadow-soil

neighbouring countries. We may thus draw the conclusion, that the mineral composition of the original deposits of the rivers, or their lime content might influence the processes outlined above.

The consequences of redox changes in the lime-containing swamps

During the water-logging in limely and sandy soils the ferrous sulphide is uniformly distributed under the horizontally located redox layer. Together with other gases continuously produced, the H_2S rises in the alkaline water layer, and a part released in the air according to the pH-dependent dissociation. The sulphide left over in the swamp will be oxidized later to H_2SO_4. This can react with a small part of the $NaHCO_3$ and form again Na_2SO_4. So, one part of $NaHCO_3$ will be left over in each year, and its amount will increase as the years go by. Hence the water turns more and more alkaline, and the dissolved $Ca(HCO_3)_2$ precipitates in the form of lime and produces a hard bank underneath the mud. The

formation of lime may be promoted by the interchangeable Na-content, and by the abundance of $NaHCO_3$ and Na_2CO_3 (Janitzky and Whithing 1964).

During the evaporation of the water, that is during desiccation, the bicarbonate comes to the surface, because the CO_2 tension decreases with evaporation, and it turns into soda on the shore. This is the phenomenon of the so called soda-blooming on the uneven, limely-sandy surface (Fig. 8.). Thus, the soda is formed from bicarbonate during desiccation, and

Fig. 8. Soda-blooming on solonchak soil

this is the origin of the Hungarian word: ,,sziksó" (= desiccated salt.). The soda crystals located on the surface cannot be reached by the H_2SO_4 present in deeper wet layers and therefore it cannot transform it to glaubersalt. The H_2SO_4 is neutralized mostly by reacting with lime. It this process takes place deeply, under an impermeable layer, then so called dry carbonic acid can be produced:

$$2\,NaHSO_4 + Ca(HCO_3)_2 = CaSO_4 + Na_2SO_4 + 2\,H_2O + 2\,CO_2$$

This might be the origin of the dry carbonic acid occuring in Répcelak, and in some other newly discovered sources. Under these conditions the soil solution contains a small amount of CO_3 and, one cannot detect large amounts of watersoluble calcium, but as the CO_3^{--} becames neutralized, the amount of Ca ions increases. Figure 9 shows the pH in the surface
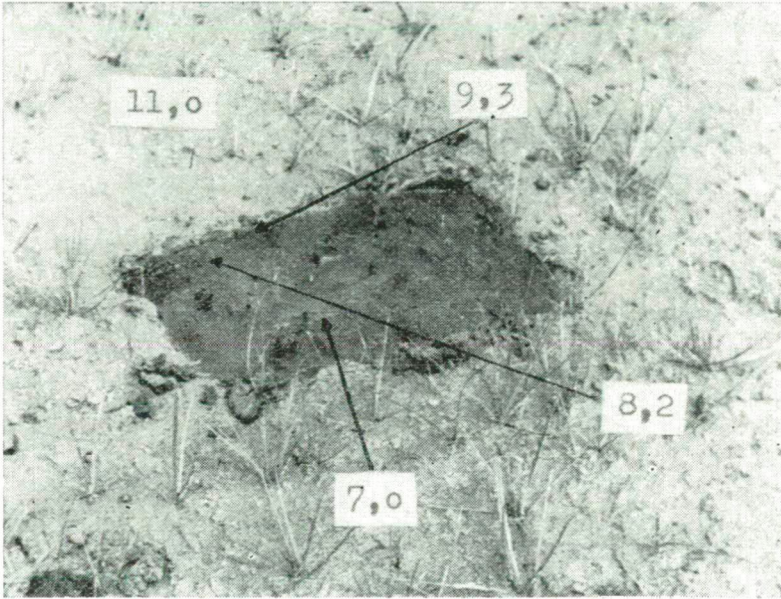

Fig. 9. ph condition at time of desiccation on solonchaks

of desiccating swamps. In the next wet period, due to the hydrolization of soda sodium hydroxide may be formed, and this may react with silicates increasing in that way the soluble silicic acid content of the mud. As a consequence of similar processes the decomposition of sodium containing silicates increases the sodium content of soil solution. In an alkaline environment feldspar will be converted into clay mineral, or into montmorillonite (Székyné, 1959).

$$3\,K_2O \cdot Al_2O_3 \cdot 6SiO_2 \quad — \quad K_2O \cdot 3\,H_2O \cdot 6\,SiO_2 \cdot 2H_2O + 4\,KOH + 12\,SiO_2 \cdot H_2O$$

$$Na_2 \cdot Al_2O_3 \cdot 6\,SiO_2 \quad — \quad Al_2O_3 \cdot 4\,SiO_2 \cdot H_2O \cdot H_2O + 2\,SiO_2 \cdot H_2O + 2\,NaOH$$

These releasing processes prove, that the theory of soda production based on the decomposition of silicates may occur in nature. The precondition for it is, probably however, the soda formed by sulphate reduction and its accumulation as a consequence of stagnant waters.

The weathering processes, the increase of the amounts of dissolved silicic acid involves the proliferation of diatoms (Fig. 10). In our opinion, the diatoms have no particular role in the decomposing of silicates. Their
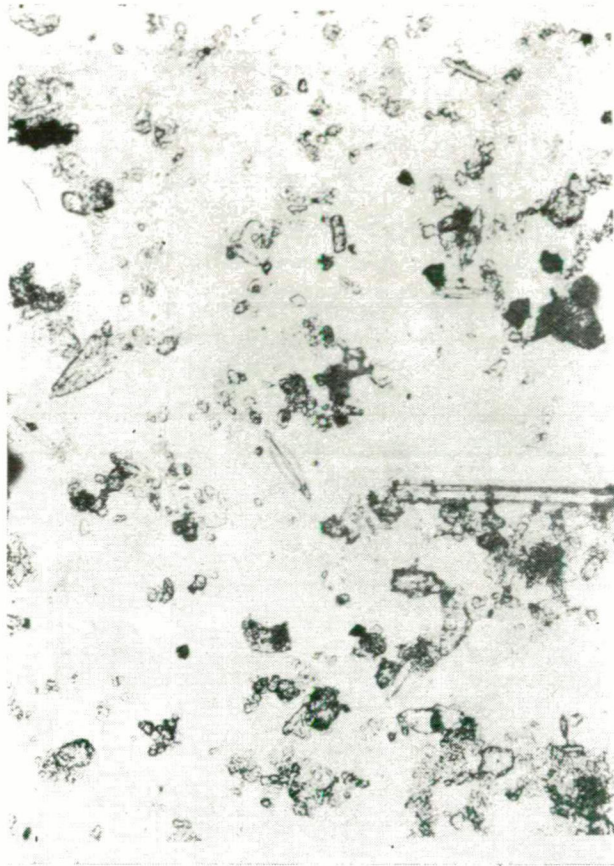
Fig. 10. Microscopic picture of desiccated solonchaks-solonetz

proliferation is not the cause, but the consequence of the increase of dissolved silicic acid.

In the light of the processes outlined above it is reasonable, that for meliorating alkali soils for agricultural cultivation, nearly all compounds of sulphur, and the sulphur-powder or the sulphur containing lignite itself have been widely used. By the application of these compounds the sulphuric acid produced turns the soda back to glaubersalt which is physiologically indifferent.

The effects of redox changes in the lime-free, acidic soil

In the swamp of the soils, due to the layered setting of organic material the gas production brings 3—4 cm deep holes into being. Their walls are coloured shiny black by ferro sulphide. In the period of the waterlogging, mostly under the influence of the climatic factors, i. e.

cooling down and air depression, sometimes large amounts of H_2S are released and cause fish decay or root-rot of rice plants and other bog plants (Amstrong, 1969; Amstrong and Boatman, 1967). At such times there is a smell of hydogen sulphide in the air. There are no such problems in fishponds and paddies on solonchak soils.

The H_2S in the water is oxidized abiotically or microbiologically here too. In connection with this we noticed that in the water of an experimental rice field suffering from root-rot Rhodopseudomonas palustris caused reddish-brown waterblooming. The majority of the sulphide-oxidation takes place in an abiotic way after desiccation. Afterwards the dome-shaped gas-ceilings are bent back and following the desiccation their previous places are indicated in the profile by thin, brick-red limonite layers.

During the desiccation, H_2SO_4 will be produced as a consequence of oxidation of ironsulphide, and this causes an acidic environment. The H_2SO_4 exerts an effect on sulphuric acid soluble feldspars. For instance anortite undergoes a transformation in sulphuric acid containing water as follows:

$$CaAl_2Si_2O_8 + H_2SO_4 + H_2O = Al_2O_3 \cdot 2\,SiO_2 \cdot 2\,H_2O + CaSO_4$$
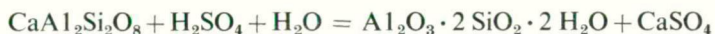
As a result of acidic reactions clay minerals, silicic acid and sulphate occur. The produced silicic acid, however, immediately precipitates in the presence of acids (Fig. 11.). The salts originated on account of releasing effects are mostly sulphates. They will be washed by the autum precipitation. Due to the eluviation, soda and other salts never occur in the surface layer. They are present only in the deeper lime-containing layers where the H_2SO_4 is not effective because it is neutralized already in the upper zones. Therefore the sulphates will accumulate here and in some spots gypsum crystallizes. The weathering of feldspar after the dry period caused by soda is possible here too. This leads to the accumulation of illite and SiO_2. The weathering products make the water-impermeable layer more compact.

In the development of this alkali type of soil the surface layer is leached out mostly by sulphuric acid, and it is acidic. The effect of nitric acid produced by nitrification should not be neglected in the process of leaching, because during the desiccation the remains of bacteria will decompose to ammonia in the surface layer, and this ammonia will be oxidized microbiologically. Consequently nitrate is always detectable in the soils, and what is more it accumulates in places in amounts sufficiently large for blooming. Instead of saltpeter it was frequently soda that effloresced on the saltpeter beds. In those soils in which the redox processes outlined above are intensive, the exchangable acidity is extraordinarily high. This fact is probably connected with the intensive weathering of silicates and clay minerals. The Al^{3+} and Fe^{3+} produced during weathering reacts with KCl. Due to this reaction iron-, and aluminium-chloride

Fig. 11. Surface of a paddy soil on meadow-solonetz

comes into being, and they hydrolize in water by forming hydrochloric acid.

$$Fe(Al)Cl_3 + 3 H_2O = Fe(Al)(OH)_3 + 3 HCl$$
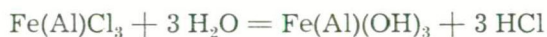
Thus, the originally acidic, and lime free soil turns more and more acidic due to periodical waterlogging, and the sodium ion continually produced incorporates in the adsorbing complexes of the horizon B, but the horizon A of the soil remains acidic.

In the melioration of alkali soils which do not contain lime in their surface layer, liming proved to be a good method. One procedure is to bring up has the deeper limecontaining layer, the so called „yellow-earth", on the surface; or to mix the surface layer with lime containing material of any origin. Samuel Teschedik (1802) was the first to use this method based probably on the experiences of peasants. His efforts were followed by many succesful experiments of scientist up to our time.

Discussion

According to 'Sigmond the fundamental factors of alkalization are as follows: warm, dry climate, periodical waterlogging and water-impermeable layer in the soil. The simultaneous presence of these factors results partly in accumulation of salts and, on the other hand, it makes possible microbiological processes which may lead to soda and sulphuric acid production in the soil because the proliferation of bacteria creates anaerobic conditions in the swamp, and under such conditions sodium hydrocarbonate and hydrogen sulphide will be produced as a result of bacterial sulphate reduction. The sodium-hydrocarbonate remains in the water until desiccation, the H_2S, however, forms FeS with the iron compounds in the soil and this changes later into H_2SO_4 under aerobic conditions. Thus, in the periodically submerged soil under aerobic conditions oxidation and reduction processes alternate. In the reducing process a weak acid (H_2S) and a strong bases (NaOH) are produced. In oxidation, however, a strong acid (H_2SO_4) and a weak bases (FeO—OH) are formed. According to the predominance of these processes alkaline (solonchak) and acidic (solonetz) types of alkali soils may develop. The most important factor in this development — as we have seen is the presence or absence of lime.

The products of these processes do not influence the original properties of limy and lime free soils in the same way. The H_2S produced in limy swamps rises up in the alkaline water and it may change back into sodium sulphate by undergoing oxidation. The soda efflorescing on the desiccated surface avoids the effect of sulphuric acid which is produced later in the deeper wet zones. In the course of time the soda increases in the whole profile. Such is the development of the solonchak type of alkali soils.

On the contrary, in acidic soils the H_2S accumulates mostly in the form of FeS, and later, during desiccation, under aerobic conditions it is oxidized to sulphuric acid and transforms the carbonates into sulphates. The same process weathers the minerals of the environment and carries the diluted salts into deeper layers. This is the essence of the development of solonetz type of soils. There is therefore no genetical relationship between the two types of alkali soils.

The quality of the soil, mostly the presence of lime, or the unsaturatedness of the soil may regulate the effects of the products of processes.

In limy soil, where the environment is weakly alkaline anyway and as a consequence of the loss of part of H_2S, the reduction products predominate, and increasing alkalization could be experienced. Thus, a periodical shallow water-covering may lead to alkalization. Because there are large amounts of salts in the water or in the soil solution, for rice growing and fish breeding and also for soil protection the first and most important task is complete drainage.

Summary

Alkalization takes place in wet and dry periods and is a result of microbiological and abiotic transformation of organogenic elements, mostly of sulphur, nitrogen, and carbon. The preconditions of these transformations are the factors described by 'Sigmond: arid climate, periodical waterlogging and a water-impermeable layer. These factors involve the reduction and oxidation processes which are responsible for the forming of characteristic profiles of alkali soils depending on whether the swamp does or does not contain lime. From the former solonchak, and solonchak-solonetz and from the latter solonetz soils are formed. There is no genetical relationship between the former and the latter groups.

The recognition of the soil-forming role of these processes serves as a bases in explaining the effect of the soil melioration method which has been used already and has proved to be effective.

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