Some Aspects of Substance Transport Processes in Soils Influenced by Soil Moisture Regulation on the Great Hungarian Plain

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Introduction

Most of the factors determining soil fertility are related to the soil moisture regime /VÁRALLYAY, 1986/. This fact is particularly valid in Hungary, especially on the Great Hungarian Plain, where the distribution of the 550 mm annual average precipitation is rather unfavourable /MOLNÁR, 1986; SZABOLCS et al., 1969/. In early spring, after the snow melts, and sometimes in late autumn, considerable excess water is to be found on the heavy clay soils of the Plain. During hot summers, on the other hand, in the middle of the vegetation period of the main crops /winter wheat, maize, sugar beet, sunflower, etc./ a water deficiency of about 100-150 mm occurs in the same regions /SZABOLCS, 1979; VÁRALLYAY, 1986/. Since new sources of water will not be available in the future, the only way to increase crop production is to use the various water sources /groundwater, irrigation water, precipitation/ more rationally and to store as much as possible of the water in the soil, where it is available to the plants, without any harmful secondary side-effects /MOLNÁR and MÉLYVÖLGYI, 1981; SZABOLCS, 1979; VÁRALLYAY, 1986/.

On the Great Hungarian Plain the processes of secondary salinization and alkalization take place mainly in cases where the salt accumulation is the result of an increase in the groundwater table level. As a consequence of this

- the salts from the groundwater will accumulate in the soil horizons above the water table level;
- the rising water table helps to transport the water soluble salts from the deeper layers to the surface or near to the soil surface;
- the changing water table level limits natural drainage and hinders the leaching of salts /SZABOLCS et al., 1969/.

The main causes of this rise in the water table level in the present case are:

- the extension of irrigation to heavy textured soils;
- seepage from irrigation and drainage canals without fixed beds;
- the build-up of water reservoir systems on areas originally having shallow water tables /SZABOLCS et al., 1969/.

It is obvious that a rational regulation of the actual soil moisture /together with the salt balance/ is of prime importance. Consequently, in

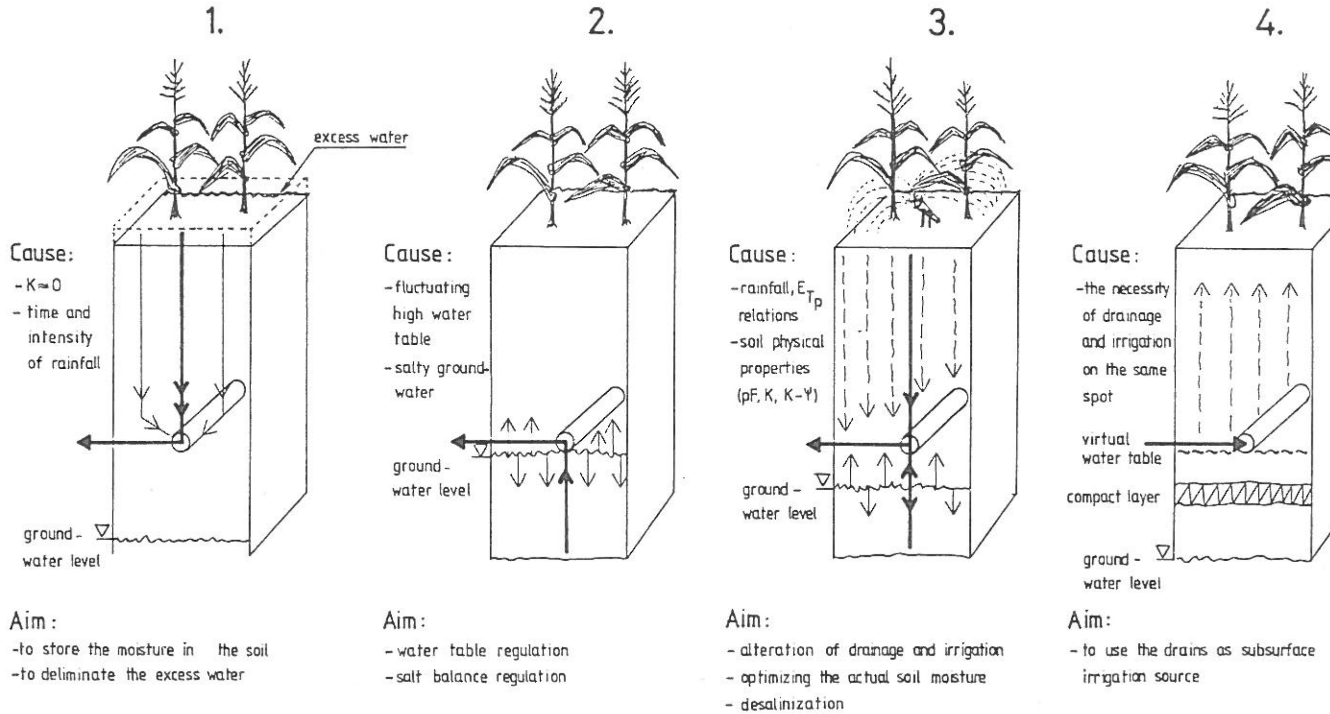

Fig. 1
The main functions of soil moisture regulation on the Great Hungarian Plain

most cases a drainage and irrigation system has been built on such areas, making it possible to change the direction of water flow along the soil profile according to plant needs /MOLNÁR and MÉLYVÖLGYI, 1981/. It is also clear that, to operate this kind of system, permanent control and monitoring is needed /SZABOLCS, 1979/.

The basic functions of the drainage/irrigation systems on the Hungarian Plain are summarized in Fig. 1.

It can be clearly seen that the establishment of a hydro-ameliorative system will very soon influence the substance transport processes, i.e. the different regimes in the soils. From the point of view of both soil-forming processes and agricultural production the most important regimes are:

- the soil moisture regime;
- the salt regime of the soil;
- the nutrient regime of fertilized fields.

In this paper the following questions are studied:

The change in the horizontal and vertical distribution of actual soil moisture due to the effect of soil moisture regulation practice.

The change in soil-forming processes on the area, with particular regard to the salt balance, the salt regime and the hydromorphic features of the soils.

The possibility of aligning fertilization practice with soil moisture regulation practice in order to prevent the nitrate pollution of drainage and groundwater and the loss of N fertilizers.

The possibility of using remote sensing /aerial photos/ to monitor the changes and the efficiency of the system after a soil moisture regulation network has been set up.

Materials and methods

For studying the relationships between soil moisture regulation practice and different substance regimes, an area of 1 200 hectares was selected in the Middle-Tisza Region, near to the Main Irrigation Canal - East. The scheme of the system is demonstrated in Fig. 2. The territory is covered by chernozem, meadow chernozem and meadow soils, and by chernozems solonetzic in the deeper layers, having good potential fertility, high humus content and a deep profile.

The only disadvantages of the area were the shallow, fluctuating water table /Table 1/ and the hazard of secondary salinization from the mineralized /Na^+, HCO_3^-, Cl^-, SO_4^{2-} type/ groundwater.

Over the last 20 years a permanent rise in the water table level has been registered due to seepage from the irrigation canals of the surrounding areas. On these heavy-textured /silty clay - clay/ soils a drainage system was established in 1984 to regulate the water table /to keep it below the "critical depth"/ and to eliminate the temporary waterlogging caused by melting snow and heavy rains. In certain plots the drainage system is combined with surface /sprinkling/ irrigation facilities.

First, a detailed survey was made to ascertain the "initial" soil conditions. The following parameters were studied during this survey:

- groundwater chemistry and season dynamics;
- chemical soil characteristics /pH, carbonate status, humus, salt content and chemistry/;
- physical soil parameters /mechanical composition, pF-curves, K_{sat}, infiltration/.

Some of the results of this study are summarized in Tables 2 and 3.

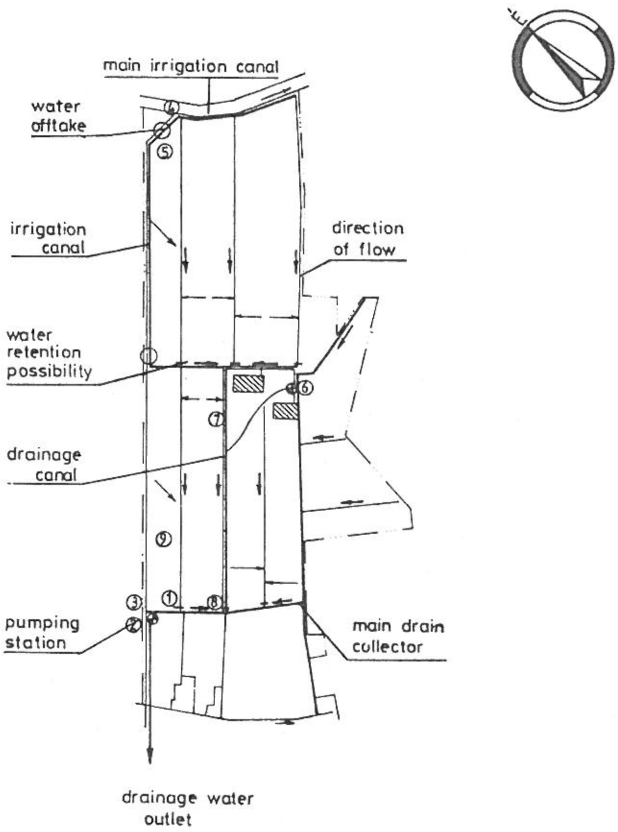

Fig. 2
Scheme of the soil moisture regulation system, and soil sampling sites

Table 1
Change in the water table depth within one hydrological cycle before the construction of the drainage system

Profile No.	Depth of the water table, cm		
	Oct. 1980	May 1981	Sep. 1981
N-1	150	100	210
N-2	110	70	240
NF-1	160	60	150
NF-2	120	150	-
NF-3	160	90	170
NF-5	120	80	-
NF-6	170	120	170
NF-7	160	120	200

Table 2
Certain chemical, physical, water management characteristics of the studied soils

Characteristics	A-horizon	B-horizon	C-horizon
Chemical soil parameters:			
$pH(H_2O)$	6.6-8.1	7.6-8.7	8.3-8.6
Salt content, %	0.02-0.09	0.10-0.35	0.06-0.13
$CaCO_3$, %	0.4-10.0	0.4-16.2	13.4-20.2
Humus, %	2.4-3.7	0.9-1.7	
Soda alkalinity, %	0-0.03	0.02-0.13	0.02-0.16
Physical and water management characteristics:			
K_A /plasticity according to ARANY/	47-54	52-58	47-51
Clay fraction, %	34-36	29-43	27-34
K_{sat}, cm/day	10^{-1}-10^{-2}	10^{-2}-10^{-3}	10^{-2}-10^{0}

Table 3
Chemical characteristics of different water samples

Water samples	pH	Electrical conductivity, mS/cm	Alkalinity	$Ca^{2+}+Mg^{2+}$	Na^+
			meq/l		
1. Main drain collector	8.1	1.65	7.9	10.3	14.7
2. Water at the outlet	8.2	1.60	6.8	11.6	13.7
3. Canal K-IX	8.0	0.57	2.4	3.9	0.6
4. Irrigation Canal East	7.9	0.43	1.7	4.7	2.1
5. Drainwater at site NF_6	8.1	0.91	9.3	6.4	5.9
6. Hamvas Canal	8.2	1.70	7.7	8.3	11.4
7. Drain collector II.	8.3	0.91	8.3	8.7	11.9
8. Drain collector /Pallagi canal/	8.4	1.82	9.2	12.9	12.6
9. Groundwater at site NF_1	7.9	1.50	7.4	9.6	9.9

As a second step, small monitoring /measuring points/ were established at certain locations in the area where the change in the water table level, the salt balance /measuring the actual vertical distribution of water soluble salts by electrical conductivity and the chemical composition of the 11:5 water extract/ and the distribution of the actual soil moisture along the soil profile were studied over a 4-year period. The moisture content of the soil was measured with a soil moisture meter, working on a capacitive basis with 2% relative accuracy, directly measuring the volumetric moisture content /0-50 V %/ of a 200 cm^3 soil sample.

Aerial photographs of the territory were taken twice, first in May 1982, before the amelioration and then in May 1983, when half of the work had been carried out. The scale of the photos was 1:10 000 on Kodak infrared negative films and contact copies on black and white infrared films. Topographical maps, genetic soil maps on the same scale, and physical and chemical soil data were used in the interpretation of the photos.

Results and discussion

The area studied is potentially one of the most productive territories of the region, but at the same time the possibility and real hazard of secondary salinization can also be recognized /Tables 1 and 3/.

It is obvious from the data that a drainage-irrigation system is needed to regulate the vertical distribution of the actual soil moisture and at the same time, to prevent the upward movement of water-soluble salts from the groundwater.

In Figs. 3 and 4 the results of the "in situ" monitoring of the actual soil moisture and the salt distribution are shown. From the results obtained, the following conclusions can be drawn:

- Intensive soil moisture regulation has a considerable influence on mass transport properties along the soil profile due to the alternating use of drainage and irrigation. This effect is clearly seen in the vertical distribution of moisture and in the salt content of the soils.
- The applied drainage system changed the salt balance of the soils. The stabilization of the groundwater at ~ 90 cm from the top resulted in a slight leaching from the soil profile above.
- The vertical distribution of the actual moisture in the soil profile is strongly dependent not only on precipitation but also on the actual groundwater level and sometimes on the effect of the retention of irrigation water in the drain pipes. Naturally it is also influenced by the mechanical composition and layering of the soils /water storage capacity/.
- With the help of permanent monitoring /either with sampling at intervals or with continuous measurement/ the salt balance and the actual soil moisture status can be checked in order to prevent secondary salinization.

The estimation of NO_3-N and NH_4-N in the soil and water samples was carried out using the adapted and partly modified BREMNER method. The results for the water samples are summarized in Table 4 and for the soil samples in Fig. 5.

The application of N fertilizers on various parts of the area was adjusted primarily to the cultivated plants and not to the drainage and irrigation practice. This fact was obvious from the very high amount of NO_3 in the water at the outlet of the drainage plant after top-dressing in April 1987.

The normal practice on this farm was to use about 90-100 kg N/ha for winter wheat. This amount, and especially the distribution of the dosage, explains the losses from fertilizer during the winter period.

For crops sown in spring /maize, sugar beet/ the distribution of N fertilizers is as follows: about 40-60 kg N/ha in autumn, and 60-150 kg N/ha in spring, depending on the planned yield and the needs of the plant. This amount of N fertilizer, partly as NH_4^+ and partly as NO_3^- moves downwards with the precipitation or irrigation water. The movement is illustrated in Fig. 5. It is interesting to compare the results obtained at site NF_1, where maize was the cultivated crop, with those at site NF_6, where winter wheat was grown. In the two cases the schedule of N fertilizer distribution is

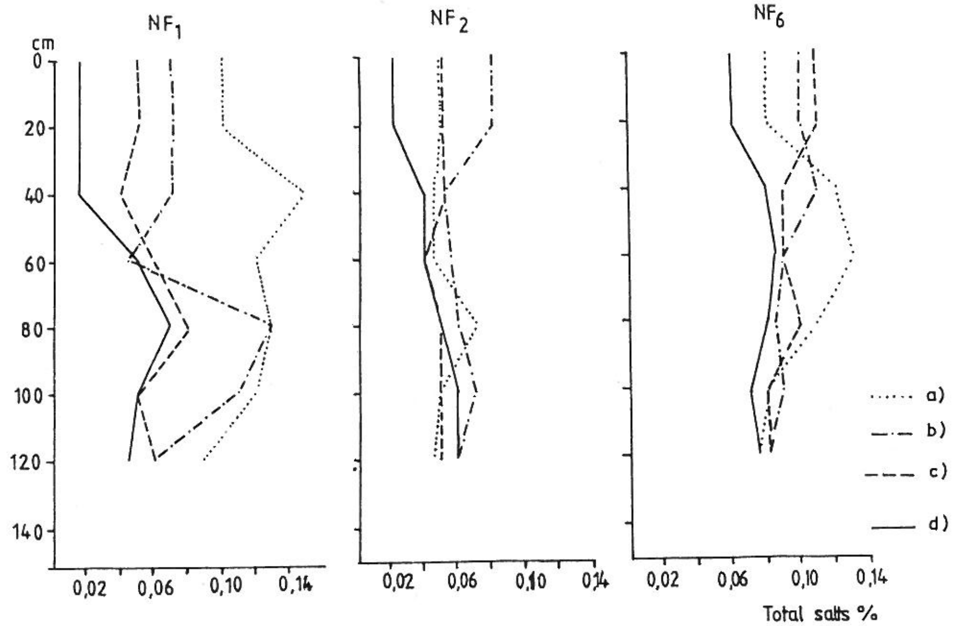

Fig. 3
Changes in the salt profile at certain sites during a hydrological cycle.
a/ March, 1986; b/ May, 1986; c/ October, 1986; d/ April, 1987

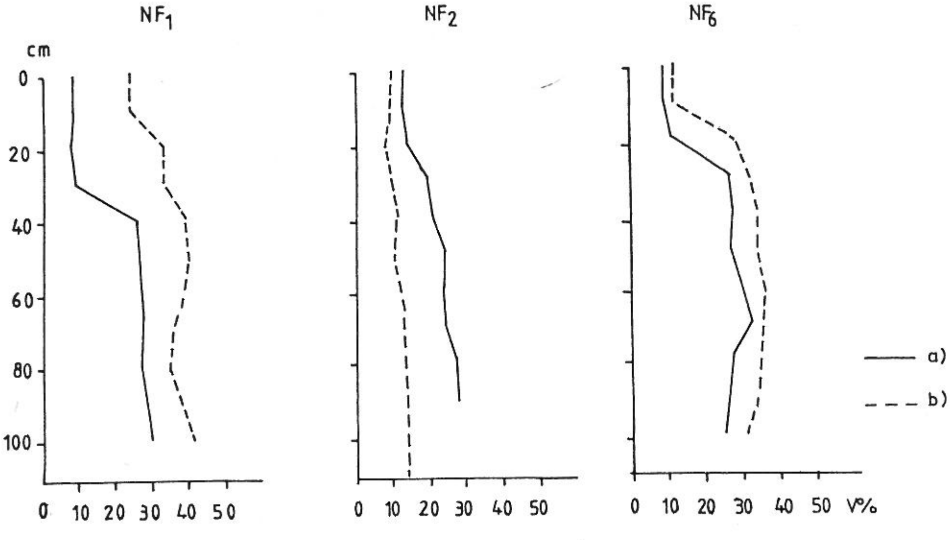

Fig. 4
Distribution of actual soil moisture at certain sites. a/ October, 1986;
b/ April, 1987

Table 4
NH_4-N and NO_3-N content of some of the waters of the area studied

Sample No.	Mar. 1986		May 1986		Oct. 1986		April 1987	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
	mg/l							
1.	0.11	8.05	0.35	0.55	0.56	0.77	6.99	81.74
2.	0.14	15.34	0.37	0.81	0.28	2.46	19.56	156.49
3.	0.35	3.32	0.94	1.24	0.28	0.77	18.86	46.11
4.	0.42	3.11	0.33	0.92	0.14	0.70	13.27	48.20
5.	0.14	6.21	1.22	2.54	0.14	2.11	17.47	40.52
6.	0.21	5.01	0.78	2.18	0.21	0.70	30.74	67.07
7.	0.07	11.54	2.14	6.30	–	–	6.29	62.87
8.	0.11	13.13	0.59	3.76	0.56	0.70	20.96	88.72
9.	0.18	57.12	3.53	43.76	–	–	–	–

For sampling sites see Fig. 2.

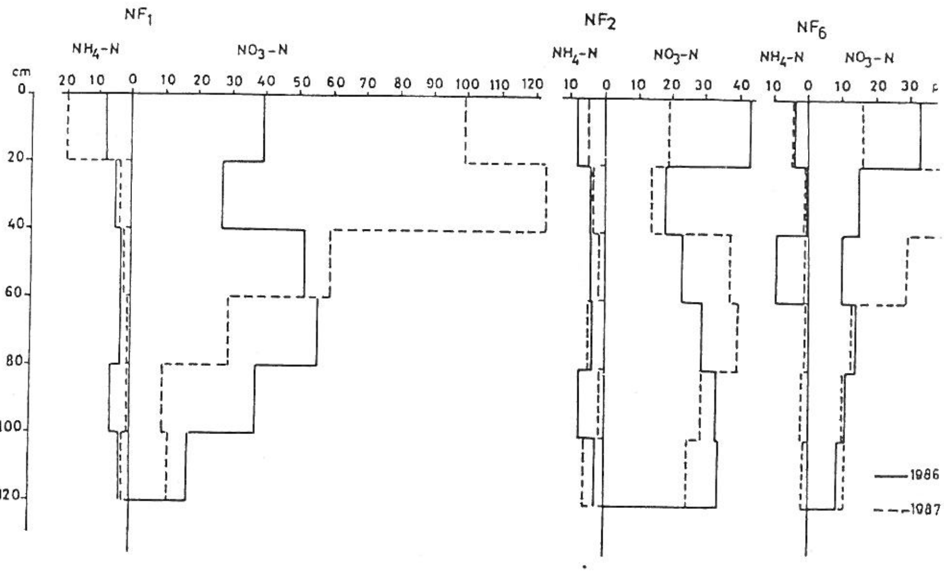

Fig. 5
Changes in NH_4-N and NO_3-N concentrations with depth at certain sites

different. It can be observed that the trend of NO_3^- leaching is similar, while that of NH_4 is completely opposite.

In order to decrease the leaching of N compounds, i.e. N fertilizer losses, it might be rational to apply the fertilizer not in one or two amounts, but in many smaller doses. The schedule of fertilization should be selected according to the desiccation of the soils /opening and closing the drains/ and to the application of surface or subsurface irrigation. In this way the NO_3^- pollution of groundwaters, drain waters and natural water sources could be prevented.

On evaluating the complex information contained in the aerial photographs, a category system was established indicating:

- waterlogged spots;
- places with high actual soil moisture but without submergence;
- eroded spots;
- spots affected by salt accumulation.

After detecting these spots on both aerial photographs, a multitemporal evaluation was also made. From the results it is obvious that, after land levelling, the construction of drains and the use of temporary irrigation facilities, i.e. after the optimization of the actual soil moisture in the root zone, the spots indicating waterlogging and overmoistening disappeared on the ameliorated part of the territory. Finally, it can be concluded that the use of remotely sensed data makes it much easier to decide whether complex hydro-amelioration has achieved its purpose or not. All the results show that a better crop yield was obtained on the experimental field.

Summary

In Hungary most irrigated soils, the best quality soils for cropping, have shallow mineralized groundwater tables involving a certain risk of secondary salinization. Measures aimed at regulating the actual soil moisture and the distribution of water-soluble salts along the soil profile, now have a very important role in Hungarian agriculture. The aim of constructing an irrigation-drainage system is to keep the water table level below the "critical depth" and to optimize the actual soil moisture and salinity status of the root zone for a given crop. To carry out this task, it is necessary to establish a monitoring system not only capable of measuring the soil parameters mentioned above, but also facilitating intervention into the movement /direction and intensity/ of the surface water along the soil profile. In this paper a model-site experiment of this type was described.

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