Effect of Fertilizing and Irrigation on the Soil Properties and Natural Vegetation of the Danube Plain's Salt Affected Area

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The central problem of our long-term research programme is the economic agricultural utilization and improvement of solonchak and solonchak-solonetz soils covering about 100 000 hectares in the region between the rivers Danube and Tisza. Our main task is to elaborate amelioration methods for the utilization of these soils either as grassland or as arable land [8, 10, 14].

Large-scale complex amelioration is rather expensive, therefore it is more expedient from the economical point of view to use these soils as grassland. This can be achieved with mineral fertilization and irrigation and the results are quite satisfactory.

In Hungary it was A. A. J. DE 'SIGMOND who first experimented with the irrigation of alkali soils [15, 16, 17]. On the basis of his investigations, he called attention to the close relation between the soluble salt and soda content of alkali soils and the quality of their natural vegetation. Thus the amelioration of these soils brings about a change also in their plant cover.

'SIGMOND [18], on the basis of soil investigations performed on more than a hundred sites along the planned Danube—Tisza canal, summarized the properties of alkali soils occurring there and gave practical recommendations for their reclamation and utilization. 'SIGMOND stated that on the salt affected soils in the northern part of the Hungarian Danube Valley (Szúnyogpuszta-basin), considerable grass production could be realized with irrigation (contour-furrow method) and with systematic and regular fertilization. A long-term research programme on the amelioration and utilization of these salt affected soils was initiated by HERKE and continued later by the author.

The results were published in several papers [5, 9, 10, 11]. It has been proved that the hay yield of *Puccinellia limosa* can be multiplied by applying N sometimes together with P, particularly if fertilizing is combined with irrigation. It has been established [3] that irrigation exercises a beneficial effect all the more so as most part of the roots of *Puccinellia limosa* may be found in the 0—5 cm soil layer. Irrigation by the contour-furrow method induces a considerable leaching of salts in grasslands, and it is even more effective in this respect on arable lands. According to the findings of HARMATI and KÓNYA [4] the large protein content of *Puccinellia limosa* is approximately doubled by N-fertilizing. HARMATI [6, 7] summarized the further results and the rentability of fertilization of natural grassland vegetation on salt affected soils. After amelioration, a grassland vegetation of high productivity was established by BODROGKÖZY and HARMATI [1] who carried out

phytocoenological investigations as well. Important data were published by HERKE [12, 13] SZABOLCS [19] and VÁRALLYAY [20] on the influence of the hydrological conditions on soil formation processes. DARAB [2] studied and evaluated the effect of natural conditions on the salt regime of soils and analyzed the factors having an influence on salt balances and soil formation processes.

In the following the results of a long-term (1951–1971) experiment on a solonchak and a solonchak-solonetz soil are presented. The effects of irrigation and fertilizing on the changes in soil properties, in natural grass vegetation as well as in production were studied.

Material and method

The experiment was started by HERKE at the Szúnyog-puszta Experiment Station of our Institute, situated in the northern part of the Hungarian Danuble Plain, in 1951.

The soil of the experimental field was, originally, a typical sodic solonchak, characteristic of this region, and, as a result of the leaching process, it turned into a solonchak-solonetz. The soil is coarse textured and the A horizon is thicker than that of salt affected soils in the southern parts of the Danube Valley. Consequently, it can be leached more easily than those. The water table is controlled under the experimental field, although it fluctuates between 60–100 cm in winter and 100–150 cm in summer.

At the beginning of the experiment, *Puccinellia limosa* represented about 60–70% of the natural grass vegetation while the rest was *Lepidium carthilagineum* and *Camphorosma ovata*.

Annual treatments between 1951–1964 (period I):

1. Untreated control
2. 70 kg N/ha
3. 140 kg N/ha
4. 210 kg N/ha

The treatments were applied in the latter half of March or in the first half of April. The effects of the treatments were investigated under irrigated and non-irrigated conditions.

The size of plots was 560 m^2, and 4–8 replications were used. The irrigation was carried out by the contour-furrow method, with fresh Danube water.

From 1965 on, because of a considerable change in the grass vegetation, the plots were divided into two parts and P fertilizer was also applied to influence favourably the natural plant association. In the irrigated plots we increased the number of irrigations from annual 2 to 6–8, partly for intensifying the leaching of salts, partly for a better water supply of the developing grass vegetation.

Annual treatment between 1965–1970 (period II):

1. Untreated control
2. 70 kg N/ha
3. 140 kg N/ha

4. 210 kg N/ha
5. 60 kg P_2O_5/ha
6. 60 kg P_2O_5/ha + 70 kg N/ha
7. 60 kg P_2O_5/ha + 140 kg N/ha
8. 60 kg P_2O_5/ha + 210 kg N/ha

The soil properties, the composition of grassland biocoenosis, the quantity of roots, hay-yield and its nutrient content as well as their interrelations were studied systematically. Air temperature, precipitation and depth of water table were recorded, as well.

Experimental results and discussion

The *Puccinellia limosa* grassland association responded significantly to N fertilization already in the first year of the experiment (better growth, denser plant community, etc.) The worthless plants like *Camphorosma ovata* and *Lepidium carthilagineum* were — depending on the N-dosage — oppressed within 2 years. Due to the effect of 140 and 210 kg N/ha a good grassland of high productivity with 100 per cent covering developed, consisting mainly of *Puccinellia limosa* (95–98%). On the unfertilized plots the covering was about 65–70% and the yield of the scarce grass vegetation was only 0.3–0.7 t/ha. In the irrigated experiment the favourable changes in grassland association and the increase in hay-yield were more significant.

The hay-yield was multiplied by the annual application of N fertilizer (NH_4NO_3) in early spring (Fig. 1). It can be seen on Fig. 1 that the possible yield level was not achieved even with the dose of 210 kg N/ha. N efficiency was favourable: 15–25 kg surplus hay-yield per 1 kg N, and it decreased but slightly with increasing N dosages. The high efficiency of N fertilizers can be

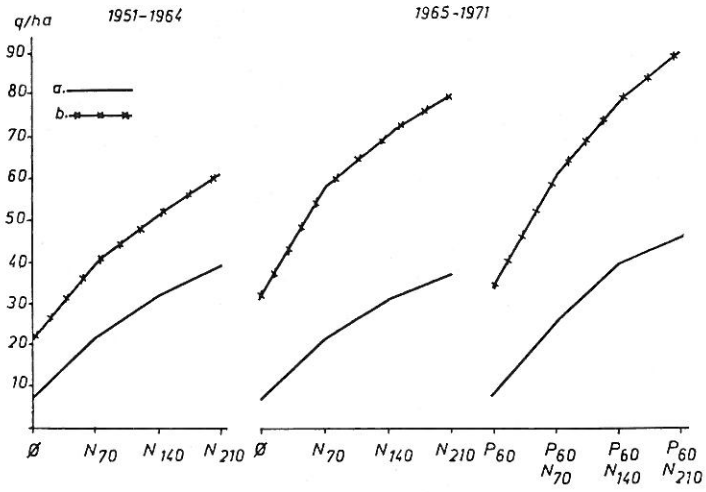

Fig. 1

Average hay-yields in the two periods of the experiments. a. non-irrigated; b. irrigated

explained by the N deficiency of the soil caused by high alkalinity (in the 0—10 cm layer the total N content is less than 0.1%) and by the high N requirement of *Puccinellia limosa*.

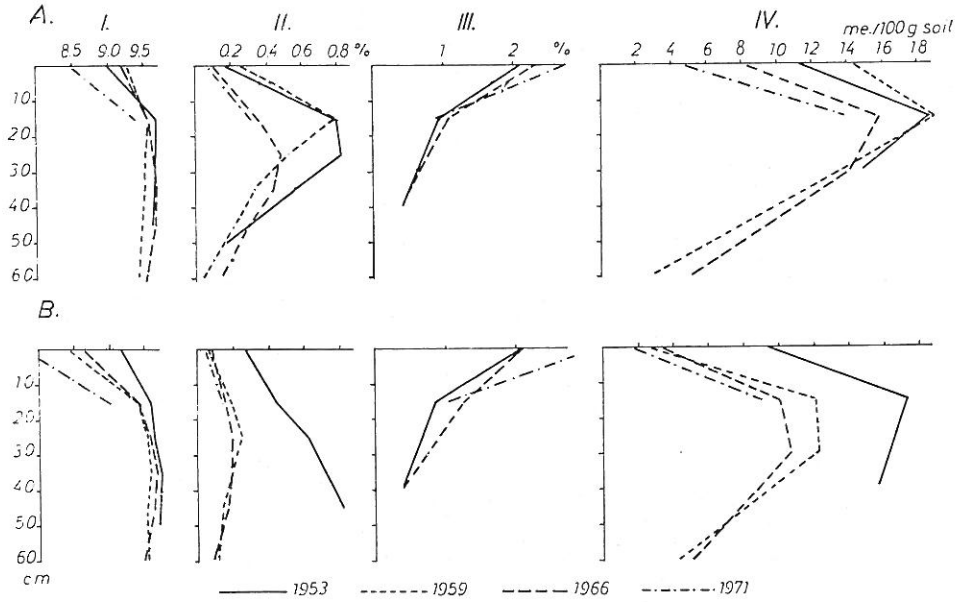

Fig. 2.

Changes in some characteristic properties of the soil under non-irrigated (A) and irrigated (B) conditions. I. pH value; II. total salt content, %; III. organic matter content, %; IV. Mobile Na content, me/100 g soil

In the first period of the experiment P and K were not applied because the soil was well supplied with these nutrients for *Puccinellia limosa*. In the root zone (0—10 cm) the total P_2O_5 and K_2O contents were about 0.11% and about 0.5%, respectively. In accordance with these data PK fertilization applied separately was not effective and did not result in any yield increase.

Irrigated experiment. — A hay-yield increase of about 20 q/ha (60—90%) on the average was obtained by the contour-furrow irrigation, applied at the end of April and at about the middle of May.

In period II it was observed that *Puccinellia limosa* began losing dominance and dicotyledonous weeds (*Rumes stenophillus, Taraxacum officinale*, etc.) appeared in the natural plant association. Because of this, the application of herbicides was necessary to maintain the dominance of the valuable *Puccinellia limosa*. At the same time, however, the hay-yield gradually decreased as a result of the considerable decrease in salinity and in the mobile Na-content of the soil (Figs 2, 3). Regular irrigation resulted in a considerable leaching of the soil. *Puccinellia limosa* — particularly its local varieties, characteristic of salt affected soils in the region between the rivers Danube and Tisza — not only tolerate but even require a certain degree of salinity and alkalinity of the

soil. Consequently, if salinity and alkalinity decrease below a certain limit, then *Puccinellia limosa* loses its absolute dominance in the plant association. Having realized this, we endeavoured to promote the growth of *Agrostis alba* (another valuable grass species) under irrigated conditions. We increased the annual number of irrigations from the previous 2 to 6—8 for intensifying soil leaching and ensuring continuously an adequate water supply for this plant. *Agrostis alba* requires considerably more phosphorus than *Puccinellia limosa* and during the first 14 years of the experiment the original phosphorus

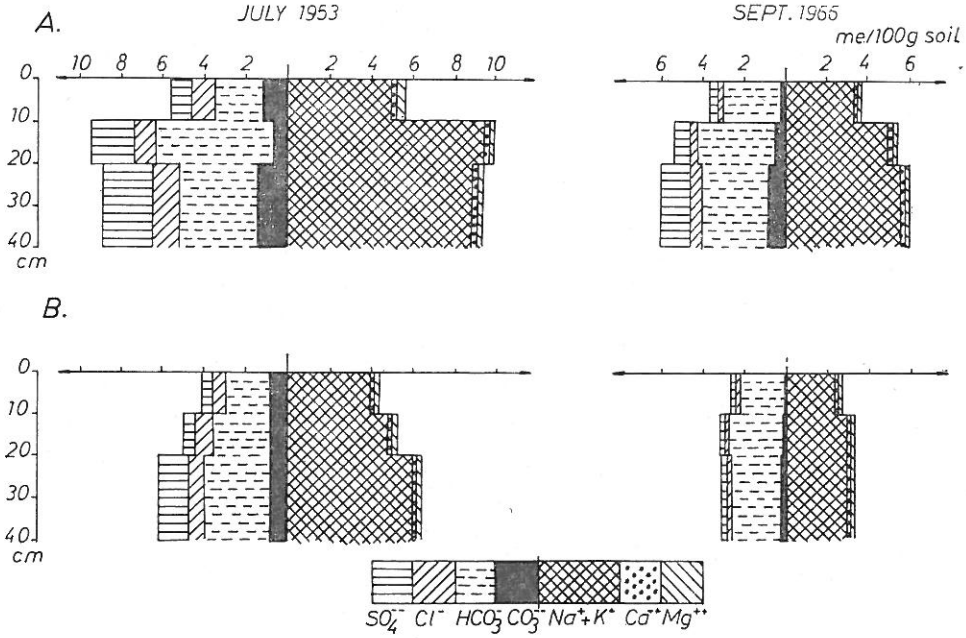

Fig. 3

Changes in the salt profile of the soil (determined by analysing the 1 : 5 aqueous extract) under non-irrigated (A) and irrigated (B) conditions

reserve of the soil decreased considerably. In view of this and also to promote and control the transformation of the grass vegetation and to maintain yields and the quality of hay, P fertilizers were applied. From 1965 (period II) the percentage of *Puccinellia limosa* in the grass cover has steadily decreased.

The changes in grass vegetation are shown on Figs. 4 and 5. In the irrigated experiment the relative occurrence of *Puccinellia limosa* increased with an increase in N dosages while P fertilizing exercised the opposite effect. Its over-all percentage, however, decreased gradually from year to year. In 1970 it was less than 10% even in the treatments with high N doses. In the non-fertilized plots *Puccinellia limosa* completely disappeared.

Later on, parallel with further decrease of the salt content due to continued leaching, *Poa angustifolia* and other even less salt-tolerant species, like *Alopecurus pratensis* appeared as well. Together with *Agrostis alba* they

became the dominant species by 1970. The mass ratios of these species are influenced considerably by the nutrient supply and soil alkalinity.

The average hay-yields in the second period of the experiment — under irrigated conditions (Fig. 1) — are considerably higher than in the first period, particularly if both N and P were applied (the average hay-yield surplus is about 25 q/ha), because the above-mentioned grass species give two or three cuttings. It should be noted, however, that the raw protein content of the latter grass types is about 10 per cent, i.e. considerably lower than that of *Puccinellia limosa*. P fertilizing in itself does not give satisfactory results, but combined NP application brings about increasingly higher yields every year. The efficiency of P fertilizing increases with higher N dosages. Irrigation results in an average hay-yield surplus of 40 q/ha, and provides continuous leaching of the soil (Figs. 2 and 3).

Non-irrigated experiment. — Natural precipitation induced only a moderate leaching of salts during the two decades investigated. Only in the years 1964—1966, when the weather was very rainy, could a more pronounced leaching be observed (Figs. 2 and 3). In general, the resultant of salt movement within the soil profile displayed a definitely downward trend. In the area where water regulation was carried out, a large amount of sodium salts was dissolved from the surface layers of soils and removed into the drainage canals. There the salt balance of soils became negative if the development of salt accumulation processes from the groundwater was prevented by the appropriate control of the water table. The leaching effect of natural precipitation may be considerable, especially in salt affected soils with thinner B horizon.

The changes in the natural plant association in the non-irrigated experiment are shown on Fig. 4. The relative occurrence of *Puccinellia limosa* increased to a great extent due to the effect of N fertilization. This effect, however, lessened considerably with desalinization (leaching) and the mass ratio of *Puccinellia limosa* decreased, though much more slowly than on the irrigated plots. In 1971 *Puccinellia limosa* represented only 26% of the grass vegetation on the plot treated with the highest PN doses ($P_{60}N_{140}$). *Festuca pseudovina*, tolerating quite well the still significant alkalinity and salinity of the soil and not requiring large water supply, became dominant. Under such conditions the growth of *Poa angustifolia* and *Agropyron repens* is limited considerably. Consequently, under non-irrigated conditions the *Puccinellia limosa* association was transformed gradually into *Festuca pseudovina* association even in the case of N fertilization. Because of these coenological changes in the natural vegetation, the potential productivity of the grassland decreased. When higher doses of NP (210 kg N/ha and 60 kg P/ha) were applied, weeds overcame the grass, as may be seen in Fig. 4.

It can be seen in Fig. 1 that the yield increases are similar in the two periods of the experiment and the highest hay surplus was measured in the high dose PN treatments. However, the unfavourable changes in the species composition of the natural grassland make it clear that fertilizer application alone is not enough for establishing an economic and successful grassland-farming on these solonchak, solonchak-solonetz type, highly alkaline salt affected soils.

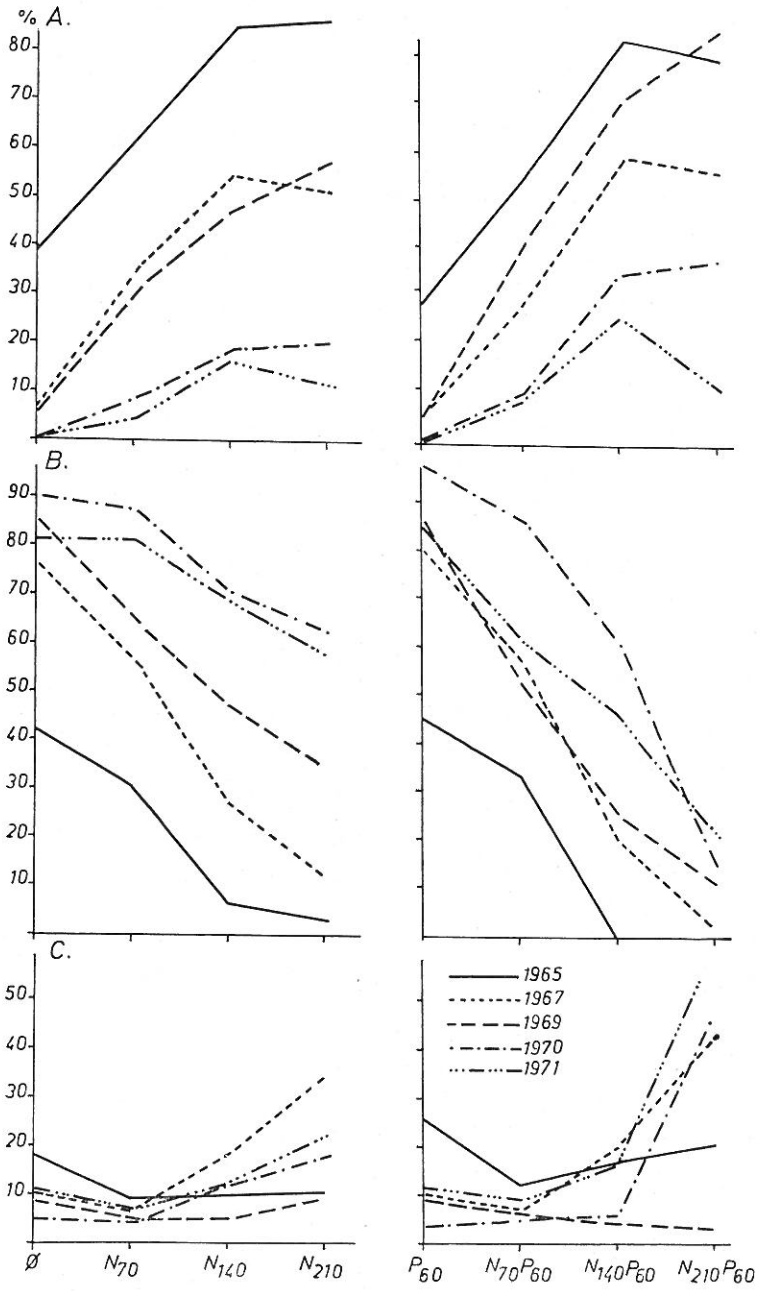

Fig. 4

Changes in the natural grass vegetation on solonchak and solonchak-solonetz soils as affected by fertilizers under non-irrigated conditions. A. *Puccinellia limosa;* B. *Festuca pseudovina;* C. Weed

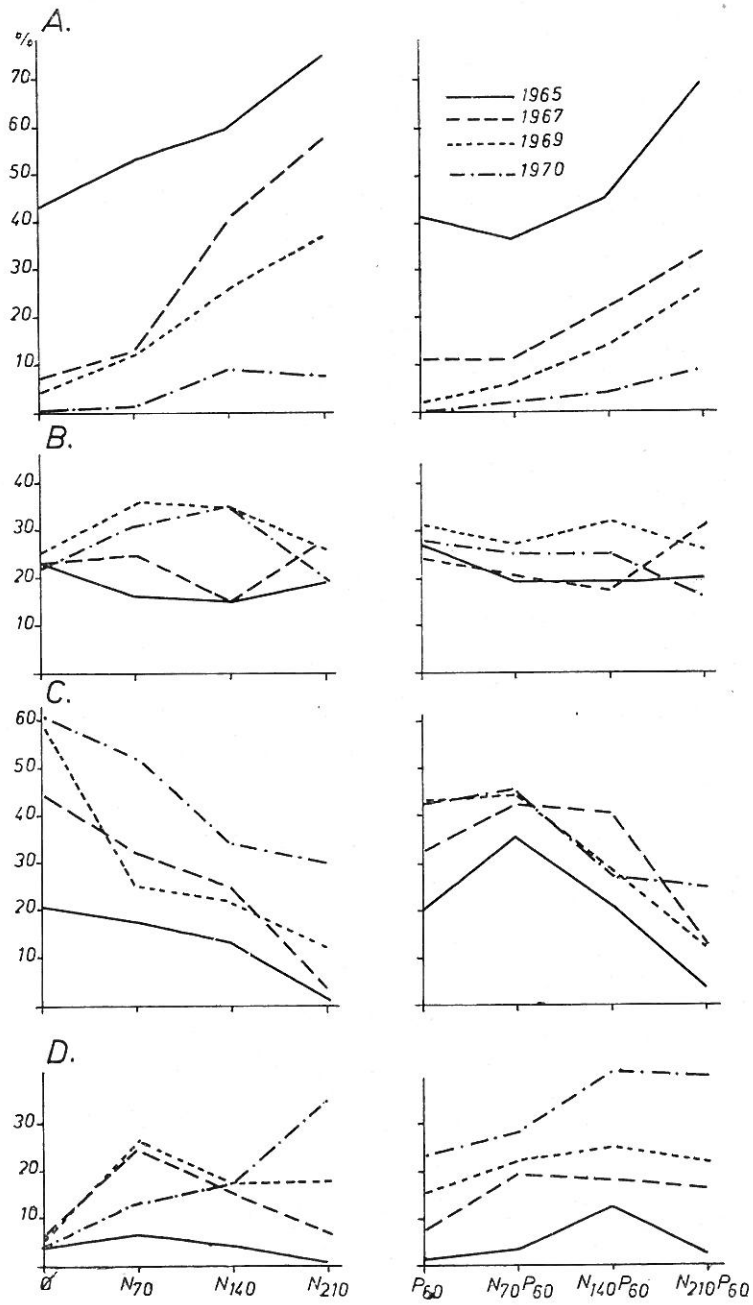

Fig. 5
Changes in the natural grass vegetation on solonchak and solonchak-solonetz soils as affected by fertilizers under irrigated conditions. A. *Puccinellia limosa;* B. *Agrostis alba;* C. *Poa angustifolia;* D. *Alopecurus pratensis*

Conclusions

The coenological composition of the natural grassland vegetation on the salt affected soils in the region between the rivers Danube and Tisza (Hungarian Danube Plain) is determined mainly by the salinity and alkalinity status and the nutrient reserve of the soils as well as by the possibilities of water supply. In the reclaimed areas where water regulation was carried out, a slow leaching of the root zone and, sporadically, of the whole soil profile can be observed. The natural moisture regime of the soil profile becomes gradually drier and the solonchaks are transformed slowly into solonchak-solonetzes. These changes are followed and clearly indicated by the changes in the coenological composition of the natural vegetation. The strongly halophytic plants (*Puccinellia limosa*, *Camphorosma ovata*, *Lepidium carthilagineum*, etc.) are gradually replaced by less halophytic ones. Under dry conditions there appear *Festuca pseudovina*, *Artemisia monogyna*, *Aster pannonicus*, etc. while under irrigated conditions, first *Agrostis alba*, then *Poa angustifolia*, and later *Alopecurus pratensis*.

Summary

At the Experiment Station of our Institute at Szúnyogpuszta (in the northern part of the Hungarian Danube Plain) we studied in long-term (1951 – 1971) field experiments the changes in the soil properties and in the coenological composition of natural grass vegetation, as well as in the hay-yield induced by N, P, and NP fertilizations. The experiments were conducted on solonchak and solonchak-solonetz soils, under irrigated and non-irrigated conditions. The main conclusions can be summarized as follows:

1. In the non-irrigated soils only minor and rather slow leaching process could be observed. During the 21 years of the experiment, in the root zone (0 – 10 cm) pH decreased from 9.33 to 8.77, salinity from 0.36 to 0.14%, the mobile Na content from 13.7 to 7.75 me/100 g soil. The decrease of salinity in the salt accumulation layer (30 – 40 cm) was larger.

Irrigation (with the contour-furrow method, using Danube water) brought about comparatively faster and more considerable leaching in the whole soil profile. In the irrigated soils the leaching process was dominant and its degree increased with more frequent irrigation. In the root zone pH decreased from 9.30 to 8.20, salinity from 0.33 to 0.08%, the mobile Na content from 11.8 to 3.95 me/100 g soil by 1971. The soda solonchak soil gradually turned into a solonchak-solonetz.

2. The coenological composition of the natural grass vegetation – parallel with the leaching of the soil – was transformed, as well. When salinity in the root zone decreased below 0.2% and the pH value below 9, *Puccinellia limosa* gradually lost its dominance. N fertilization moderated this process but could not prevent it completely. Under non-irrigated conditions *Puccinellia limosa* was replaced by *Festuca pseudovina*, under irrigated conditions by *Agrostis alba*, then by *Poa angustifolia* and, still later, by *Alopecurus pratensis*. The ratio of the latter grass species was decisively influenced by the nutrient supply.

3. In the first period of the experiment (1951 – 1965), when *Puccinellia limosa* was dominant, an approximately linear correlation was observed between hay-yields and N-doses. The produced protein content was nearly doubled.

In the second period of the experiment (from 1965) when other grass species were prevailing, the joint application of N and P fertilizers proved to be more efficient, particularly under irrigated conditions. This is quite understandable considering that the natural P-reserve of the soils was decreasing and the P-requirement of the new grass species was higher.

Under non-irrigated conditions relatively high yields of good quality hay can be obtained if the dominance of *Puccinellia limosa* in the plant association is maintained with high N-doses. When it is replaced by *Festuca pseudovina*, an economic yield increase can hardly be achieved by fertilizing. Under irrigated conditions, if a satisfactory nutrient supply is ensured by PN application, the grass species replacing *Puccinellia limosa* give a considerably higher yield but the protein content of hay is lower.

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