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CHANGES IN SOIL CHARACTERISTICS AS A CONSEQUENCE OF LONG-TERM SOIL IRRIGATION.

Jan VOPRAVIL¹, Petr VRÁBLÍK², Tomáš KHEL¹, Jaroslava VRÁBLÍKOVÁ², Eliška WILDOVÁ²

¹Research Institute for Soil and Water Conservation, Žabovřeská 250, 156 27, Prague, Czech Republic, vopravil@vumop.cz, khel@vumop.cz² J. E. Purkyně University in Ústí nad Labem, Faculty of the Environment, Department of Natural Sciences, Králova výšina 3132/7, 400 96, Ústí nad Labem., Czech Republic, Jaroslava.vrablikova@ujep.cz, petr.vrablik@ujep.cz, eliska.wildova@ujep.cz

Abstract

The objective of this work was to assess the effect of the long-term irrigation of soils (arenic chernozem, modal fluvisol and modal regosol in the model area of Nedomice, Mělník district) on the profile changes in their physical and chemical characteristics. The evaluation was performed on the principle of the retrospective comparison of two sets of analytical data archive results determined in soil samples collected during hydropedological research in the year 1954 (before the realization of irrigation), and the corresponding current results of the analyses of soil samples - collected in the year 2006 - in the same, precisely focused locations, at the same collection depths and using the same analytical methods as half a century ago. The content of selected hazardous elements (As, Cd, Pb and Zn) in these long-term irrigated soils was also monitored, and it demonstrated their increased concentration (particularly cadmium and zinc), but it was not possible to prove that it was caused exclusively by irrigation.

Key words: irrigation, physical/chemical soil characteristics, hazardous elements, Mělník district

Introduction

The contribution is focused primarily on influencing the values of physical soil indicators (porosity P , bulk density p_z , reduced bulk density RBD and maximum capillary water capacity MCWC); of the pedochemical indicators, changes in pH/KCl exchange soil reaction values were compared. The evaluation was performed on the principle of the retrospective comparison of two sets of analytical data: archive results determined in soil samples collected during hydropedological research in the year 1954 (before the realization of irrigation), and the corresponding current results of the analyses of soil samples - collected in the year 2006 - in the same, precisely focused locations, at the same collection depths and using the same analytical methods as half a century ago. The results are processed in the Access database program, and statistically evaluated using a paired t-test at a significance level of $\alpha_{0,05}$ or $\alpha_{0,1}$ in the Unistat program. Even at the time of collection of the samples, significant solidification manifested itself in the topsoil horizon. No demonstrable change occurred in the exchange soil reaction as a result of long-term irrigation in any of the monitored soils. Acidification, which logically comes about as a consequence of calcium loss by leaching, was evidently suppressed or even eliminated by systematic organic and mineral fertilization (including fertilization with calcic manure, or liming) and the decrease in calcium was thereby compensated. On the contrary, in each of the observed soil types, long-term irrigation manifested itself by significant changes in the monitored physical properties: in black earth modal topsoil, a decrease in the maximum capillary water capacity value occurred, while in the subsoil there was a statistically demonstrated reduction in porosity, and at the same time an increase in reduced bulk density. All of these changes indicate solidification of the subsoil, and reduced aeration and permeability of the soil horizon. The rinsing regimen of the irrigated soils brings about the settling of soil particles as a consequence of the disruption of an unstable structure. Technogenic degradation caused by the movement of agricultural machinery enhances the adverse impacts of irrigation on the soil structure. Similar statistically demonstrable changes

in physical characteristics also came about in samples of modal fluvisol: a reduction in the level of porosity and maximum capillary water capacity, and on the contrary an increase in reduced bulk density; in the subsoil, there was a small but demonstrable increase in bulk density and a reduction in the MCWC level. Likewise, in exponents of modal regosol, a demonstrable growth of reduced bulk density and bulk density, and at the same a reduction in the level of porosity and the maximum capillary water capacity values, was recorded. All of these adverse changes in physical characteristics in the topsoil of long-term irrigated regosols document that significant compacting has also affected these soils - in spite of their light texture. In general, the rule applies that light soils resist the compacting process better than soils with a heavier texture.

Irrigation systems have always been constructed primarily for the purpose of a positive effect on moisture conditions in soils, which are one of the main requirements for the growth and development of plants, and the increase of production yield and quality. The moisture requirements of cultivated plants cannot be adequately satisfied, always and everywhere, from natural sources, i.e. by atmospheric precipitation and the capillary rise of water from soil reserves. Jensen and Allen (2016) defines irrigation as an activity during which additional water is applied to the soil, which together with the water which is already naturally present in the soil enables, or at least supports, plant production. This activity has been intrinsic to humankind since times of old; in particular, it was already widespread in ancient Egypt in the 3rd millennium BC (Hillel, 1994). Even in those times, in some parts of the world irrigation not only had a decisive significance for feeding humankind and farm animals, but it also had other impacts, connections and direct and indirect social consequences, and was often also connected with political and cultural-religious aspects. The importance of irrigation is evident from the fact that, at present, almost an entire third of global agricultural production was cultivated on a mere four percent of the global expanse of agricultural soil suitable for harvesting, using intensive irrigation (Jensen and Allen, 2016). According to Bauder et al (2011) an irrigated area produces a 2 - 2.5 x higher average yield; if we also take into consideration the higher quality of production on irrigated soil, then the effectiveness of irrigation is as much as triple that of unirrigated soil. According to FAO materials (2000), we would have to obtain around an extra 250 million hectares of new production areas if we were to do without irrigation (and this is even under the assumption of non-declining, permanently sustainable soil fertility). On the other hand, under certain conditions, the systematic irrigation of soils can mean a significant risk for soil quality (unfortunately quite frequently, and moreover with considerable intensity) and can subsequently reduce its production capability, not only by the significant deterioration of physical soil characteristics (wetting, muddying, loss or damage of soil structure, flushing out of soil particles), but in a number of cases also by salinization and solidification (particularly in the arid localities of the Middle East - in Mesopotamia, large areas of Iraq, Syria etc.), or soil contamination by heavy metals and other, for example organic pollutants from industrial waste and sewage, and last but not least by pesticides and other pollution sources (Kabata-Pendias, 2011). Unfortunately, these and other signs of soil degradation can already be easily identified on enormous expanses of irrigated soils; globally, we are talking about millions, or even tens of millions of hectares (Rengasamy, 2006). In addition to this, erosion and sedimentation in canals and reservoirs in older irrigation systems limits their lifespan (Jensen and Allen, 2016). This however also relates to modern water reservoirs, dams etc. Of course, it is evident that the persistent growth in the world population cannot endure without the further development of irrigation; we can even count on the fact that, in the effort to increase the efficiency of plant production, supplemental irrigation will have to be developed more and more - even in humid conditions (Hoffman, 2007). It will probably be increasingly necessary to use decontaminated and sanitary water from industrial and municipal waste water, because the global irrigation industry is more and more restricted by the limited sources of quality surface water. Of course, the necessary further development of the irrigation industry anticipates the purposeful and adequate intensification of agricultural and water management research - particularly which focused on the increased protection of soil against the probable negative effects of irrigation. Evidently, the systematic monitoring of the expected deterioration of some physical and chemical soil properties will have to be developed. Designers and development workers are expected to strive to accelerate the development of ever more modern technical irrigation equipment - precise, automated, economical, focusing on scientifically managed systems with the most efficient use possible of irrigation water, central pivot irrigation, capillary irrigation and micro

irrigation. In case of doubts regarding efficiency, or when comparing the benefits of irrigation with the costs of the elimination of the consequences of its harmful effects, we should be aware that the existing contamination of surface runoff as a consequence of irrigation would have to be as much as tripled for the costs of its elimination to exceed the effect of irrigation management (Hoffman, 2007). If, therefore, the maintenance of the level and quality of food production is inconceivable without irrigation, then it is all the more necessary to thoroughly utilize the obtained findings, and develop adequate permanently sustainable irrigation system technology, so that the damage to the environment and soil fertility can gradually be annulled or at least minimized.

Materials and methods

The objective of the work is to define, monitor and describe the chemical and physical changes which occur in soils as a consequence of both drainage and irrigation. This contribution is aimed at influencing the values of selected indicators brought about by long-term soil irrigation in the most significant soil exponents of the Nedomice model area, namely in arenic black earth, modal regosol and modal fluvisol. The evaluation was performed on the principle of the retrospective comparison of two sets of data: the results of selected archive physical, and to a lesser extent also chemical analyses (pH /KCl) performed during hydropedological research before the realization of irrigation in the year 1954, and the corresponding paired results of the analyses of soil samples collected in the year 2006 in identical, precisely focused locations, at the same collection depths and using the same determination methods as half a century ago. The results were processed in the Access database program, and statistically evaluated using a paired t-test at a significance level of $\alpha_{0,05}$ or $\alpha_{0,1}$ in the Unistat program.

Of the total 20 excavated probes, 212 soils samples were collected from the upper two to three horizons to monitor changes in the values of the most important indicators in topsoil and subsoil: in the case of arenic black earth, 6 probes were excavated, while 7 probes were excavated from fluvisol and modal regosol.

Nedomice model area

Located in the Mělník district, north-west of Brandýs nad Labem, the area of interest falls climatically within a dry, warm region with mild winters, with average total precipitation of 527 mm and an average annual temperature of 8⁰ C; the duration of the vegetation period was 176 days (from the 19th of April to the 12th of October) with an average temperature of 15⁰ C. Various types of vegetables, early potatoes and other crops have long been cultivated in the area of interest using irrigation. Geologically, this area falls within the middle Polabí [Elbe Lowlands] region (in the Czech table system); it has a flat character with an average altitude of 170 m above sea level, with the terrain broken up by the low peak of Cecemín (height 238 m above sea level). Most of the area of interest is formed by the diluvial and aluvial deposits of the Elbe river; these river terraces date back to from the cool Pleistocene periods. Regosols, and arenic black earths, have developed on them. Soils formed on sandy gravel are typically light, often with a low humus content, and permeable for both air and water, so they are usually dry if the groundwater level is low. The sandy and sandy gravel deposits of diluvial terraces and the soils of flooded valleys spread over both sides of the Cecemín peak, formed by a highly calcic chalk marlite which affects the adjacent areas. Non-carbon alluvial clays with light to medium-heavy textures are usually present on the sandy gravel terraces in the lower positions, while north-west of Nedomice there are alluvial deposits: modal fluvisols have developed on both of these substrates. In the south, the boundary of the area of interest is formed by the regulated flow of the Elbe river, with former meanders and blind shoulders. A higher groundwater level, contingent on the fluctuation of the level of the river, occurs naturally in the areas along the Elbe.

Collection and analysis of samples

The collection of soil samples confirmed the solidification of the soil - often already beginning with the topsoil horizon - manifesting itself by increasing plow resistance, and therefore requiring ever stronger (and unfortunately also heavier) tractors, whose movements solidify the soil even more.

All of the monitored soils were characterized by being not very stable, and with a rather weakly developed structure - primarily board-like, cloddy, and prone to falling apart easily. Essentially, even the irrigation itself has a negative effect on soil structure, as the kinetic energy of the falling drops of water often disrupts soil aggregates. As the hydrological research of the 1950s was focused on researching the possibilities of constructing irrigation systems, it prioritized the determination of the soil texture, and physical indicators before pedochemical ones. In this model area's soils, the determination of chemical properties was limited to the pH / KCl exchange soil reaction (while in the case of soil samples from other model areas, other chemical indicators were also determined as standard). Moreover, in collections from selected probes in the year 2006, the content of hazardous elements (As, Cd, Pb, Zn) in a 2M extract with nitric acid was also monitored.

Of the physical soil characteristics, the following were determined:

- porosity P (amount of pores in soil volume);
- bulk density ρ_z (weight of dried sample without pores to unitary soil volume)
- reduced bulk density RBD (weight of dry sample in natural position - with pores - to unitary soil volume)
- maximum capillary water capacity MCWC (expresses the soil's ability to attract water using capillary forces).

Results and discussion

Soil properties and their changes in individual soils types in the area of interest

1. Chernozem

In the Nedomice model area, it has developed mostly on calcic sands on river terraces at an altitude of around 170 m above seal level; the groundwater level fluctuated at a depth of 110 - 120 cm beneath the terrain. The fields are intensively cultivated; the profile is revived, with a high occurrence of roots. The topsoils have a granularity which is light (sandy to aluminous sandy) but also medium-heavy (sandy aluminous to aluminous), with a medium developed structure which is usually lumpy, cloddy or, in exceptional cases, polyhedral. The consistency is moist and cohesive, in two cases with carbon pseudomycelium; in one probe, solidification was already discovered in the topsoil. Of the chemical properties, only the exchange soil reaction was monitored: it is favorable, fluctuating among neutral to weakly alkaline values - in the case of the carbon-free probe, the increase in pH/KCl is the consequence of the use of calcic fertilizers. The soils mostly have high puffation ability, so they withstand the effects of acidification relatively easily. In the entire data set, no demonstrable change in the exchange soil reaction was discovered in the topsoil or the subsoil (Tab. 1). Only exceptionally, in a sample collected from subsoil in a single probe in the year 2006, was a reduction in the pH value to the level of a weakly acidic reaction discovered: this is a probe whose profile does not contain carbons, and is poorly saturated in terms of sorption. Its subsoil is not affected by liming to the same extent as the topsoil, so the effect of continuing irrigation logically leads to the flushing out of calcium ions and their loss from the sorption complex, or to their replacement by hydrogen ions. In addition to this, irrigation resulted in the reduction of the sorption capacity by the partial depletion of the finest dispersion particles-

Physical properties: of the monitored characteristics, a statistically demonstrable change (reduction in values) was only discovered in black earth topsoils in the case of maximum capillary water capacity MCWC (at a significance level of $\alpha_{0,1}$); compared to the situation before irrigation, a considerable reduction occurred (by approximately 18%). In terms of the soil structure, the cloddy, relatively compact type prevails; it seems therefore that during long-term cultivation, including irrigation, mineral fertilization and intensive mechanization, a more closely packed deposition of particles occurred - creating larger, firmly connected soil aggregates, which cannot be completely pulverized even by fall plowing. From the perspective of granularity, the subsoil did not differ from the topsoil (with the exception of a single probe, which collected lighter, aluminous sandy subsoil. The structure is mainly

medium-developed, predominantly lumpy to indicative of lumps, while in a smaller number of cases it is only weakly developed. The subsoil was mostly revived, with a high occurrence of roots. Over approximately fifty years, a demonstrable change occurred here in the porosity value P ($\alpha_{0.05}$) and simultaneously a demonstrable increase ($\alpha_{0.1}$) in the reduced bulk density (RBD) value. In soils with lighter granularity, this reduction in porosity P attained a proportion of approximately 11% (see table 1). In subsoil, the increase in the RBD value is relatively significant, and attests to the significant compacting of the subsoil horizon of systematically irrigated black earths. Similarly, the increased bulk density values (ρ_z), even when their growth is not statistically demonstrable, also confirm an increase in the compacting of the black earth subsoil horizon.

Table 1: Statistical evaluation of changes in pedophysical and pedochemical indicators in arenic black earth as a consequence of long-term irrigation

CHERNOZEM	topsoil		average	change	subsoil		average	change
	$\alpha_{0.05}$	$\alpha_{0.1}$	old samples	(%)	$\alpha_{0.1}$	$\alpha_{0.05}$	old samples	(%)
significance level								
pH/KCl	±	±			±	±		
P	±	±			>		43.3	11.0
ρ_z	±	±			±	±		
RBD	±	±			±	<	1.5	6.1
MCWC	±	>	35.0	18.0	±	±		

±inconclusive development
 >.....demonstrable reduction
 <.....demonstrable increase

2. Fluvisol

In the area of interest, it has developed on non-calcic alluvial deposits with a lighter to medium-heavy texture, mostly on lowlands, with a groundwater level of under 120 cm. They are intensively cultivated (growing of vegetables before irrigation). They are significantly endangered by wind erosion. In individual probes, the fluvisol topsoils have variously developed structures - from weakly to distinctively developed, according to cloddy, lumpy and polyhedral types (Tab. 2).

Table 2: Statistical evaluation of changes in physical and chemical soil indicators in modal fluvisol as a consequence of long-term irrigation

FLUVISOL	topsoil		average	change	subsoil		average	change
	$\alpha_{0.05}$	$\alpha_{0.1}$	old samples	(%)	$\alpha_{0.05}$	$\alpha_{0.1}$	old samples	(%)
significance level								
pH/KCl	±	±			±	±		
P	>		44.2	26.0	±	±		
ρ_z	±	±			<		2.61	1.2
RBD	<		1.46	21.8	±	±		
MCWC	>		36.7	33.5	±	>	33.3	24.1

±inconclusive development
 >.....demonstrable reduction
 <.....demonstrable increase

Even at a depth of 10-20 cm beneath the surface, the soil in all of the probes was solidified. According to the clay particle content more than half of the fluvisol probes (4 out of 7) fall within the category of light soils. The subsoil has a weakly to medium-developed structure - similarly to the topsoil; it is revived, with a high occurrence of roots. As a consequence of irrigation, a change of texture occurred in about a third of the soil probes - from the heavier granularity category to aluminous sandy granularity, mainly in the subsoil. No statistically significant soil reaction change occurred as a consequence of irrigation (table no. 2) demonstrated in the fluvisol topsoils or subsoils, even though there was in fact a reduction in the pH/KCl level in most probes, to the level of medium to strong acidity; on

the contrary, however, the effect of the use of calcic fertilizers prevailed in one probe, so in fact the opposite trend occurred - in both the topsoil and the subsoil. Unlike the statistically insignificant soil reaction changes, very demonstrable changes were discovered in the values of some of the physical characteristics in the fluvisol soil profile: as a consequence of long-term irrigation, a reduction in the level of porosity P and maximum capillary water capacity MCWC values occurred in the topsoil, while the reduced bulk density RBD values increased (Tab. 2). In all of the fluvisol probes' profiles, it was discovered that compacting began just a few centimeters beneath the surface. The effect of intensive irrigation and the movement of cultivation and harvesting machinery leads to a reduction in porosity and a connected increase in reduced bulk density RBD; similarly, the bulk density values ρ_z also increased, but their growth trend is inconclusive. The decrease in the MCWC level is probably connected with the formation of coarser, non-capillary pores between the soil aggregates, which in fact are larger or smaller lumps created during fall plowing by the disruption of the compact surface solidified by both irrigation and the movement of machinery. It is interesting that, in sandy aluminous fluvisol topsoil, a noticeable change in the proportion of clay particles did not occur, while in the subsoil all of these probes show a considerable loss thereof - on average of as much as a quarter - while, in the third horizon, their proportion actually increased. It is therefore evident that intensive irrigation leads to their shifting within the soil profile. It is interesting that in topsoil - unlike in subsoil - their content did not decrease during irrigation. We can explain this by the fact that, for one, the quantity of clay particles is partially replenished by organic fertilization, and also that some of them are carried to the topsoil directly with irrigation water, in which clay particles are dispersed as opacity. We can also observe a similar profile movement of fine soil particles in aluminous sandy soils, but the reduction in the proportion of clay particles in the subsoil is not as significant as in heavier soils. A statistically demonstrable increase in bulk density ρ_z , ρ at a significance level of $\alpha_{0.05}$, as well as a reduction in the MCWC level at a significance level of $\alpha_{0.1}$ was found in fluvisol subsoil. Here, the changes in the physical indicator values also confirm that solidification processes are taking place in the soil - as a consequence of the rinsing of the soil profile over many years of irrigation.

3. Regosol

In the Nedomice model area, it has developed on sands. With the exception of two probes, which are in sandy aluminous topsoil, these are usually light, aluminous sandy soils, whose upper dark horizon changes quickly to a soil-forming substrate; the groundwater level was not ascertained in any of the excavated probes. Almost half of these probes are endangered by wind erosion. The structure in the topsoil is mostly medium-developed, and very variable - from finely crumbly, cloddy, lumpy or grainy to polyhedral. In the 2nd evaluated horizon, which is formed by the mother substrate itself, no statistically demonstrable changes in soil properties were recorded, which is why we limited ourselves to an evaluation of the topsoil horizon (Tab. 3)

Table 3: Statistical evaluation of time changes in soil characteristics in modal regosol as a consequence of long-term irrigation

REGOSOL	topsoil		average	change	subsoil		average	change
	$\alpha_{0.05}$	$\alpha_{0.1}$	old samples	(%)	$\alpha_{0.05}$	$\alpha_{0.1}$	old samples	(%)
pH/KCl	±	±			±	±		
P	>	±	38.2	16.4	±	±		
ρ_z	±	<	2.65	4.0	±	±		
RBD	<	±			±	±		
MCWC	>		26.6	21.9	±	±		

±inconclusive development

>.....demonstrable reduction

<.....demonstrable increase

With the exception of a single probe, the effect of intensive irrigation led to a reduction in the soil reaction, or more precisely to an increase in acidity; in some cases even below the threshold of strong acidity (pH /KCl <5) - such a significant decrease is probably the consequence of not only systematic irrigation (flushing out of Ca^{2+} ions from the topsoil), but in this case evidently also mineral fertili-

zation inadequately compensated by liming. On the other hand, an inverse shift occurred in one probe (an increase in the pH value) so, overall, we cannot confirm a statistically demonstrable reduction in pH /KCl values (Tab. 3). However, in the topsoil of long-term irrigated regosols, we demonstrated statistically significant changes in some physical characteristics: at a significance level of $\alpha_{0,05}$, it is possible to demonstrate that an appreciable reduction in porosity P and maximum capillary water capacity MCWC occurred (Tab. 3). On the contrary, the reduced bulk density RBD value increased, and bulk density z also rose somewhat p (at a significance level of $\alpha_{0,1}$). From these changes in physical characteristics, it is evident that solidification occurred in the regosol topsoil - mainly due to the effect of the irrigation itself. It is not possible to exclude the adverse effect of the pressure exerted by the movement of machinery, but in soils with such light granularity this reason for the compacting of the soil is usually not as significant as in the case of heavier soils. The reason for the low stability of the structure in the regosol is the very low proportion of the finest soil particles (I. granularity category) and the low proportion of humus (and therefore also a low level of CWC sorption capacity); the insufficiency of both of these cementing components (and moreover a decreasing concentration of calcium ions) adversely affects the formation and stability of the structure of these soils. During irrigation, the soil structure in regosols is very significantly disrupted by the kinetic energy of the falling drops of water; a part is also played by the constant rinsing of the soil profile, and depletion of clay particles together with nutrients - including calcium ions. Apart from this - given the intensive cultivation of vegetables on these irrigated areas - we must expect more frequent cultivation and the movement of machinery. From a pedochemical perspective - given the light texture of these soils - the intensive mineralization of the supplied organic material and its rapid decomposition easily occur, so in this case the effect of organic fertilization does not persist in a longer term. Nevertheless, it applies that organic fertilization is absolutely essential for efficient agricultural production on these soils. Compacting after irrigation is truly also a major problem in these soils, and the afore-mentioned changes in physical indicators are characteristic for them.

To conclude, therefore, we can state that, in the soil profile of chernozem, irrigation led to significant changes in porosity, reduced bulk density and maximum capillary water capacity; in fluvisols, we registered a significant increase in RBD and a reduction in porosity, particularly in the subsoil, while the bulk density value increased significantly in the subsoil - while the MCWC simultaneously decreased. In regosols, essentially similar quantitative shifts occurred, but first and foremost the bulk density increased.

Risky element contents in long-term irrigated soils

Risky elements - namely heavy metals - mainly enter soil via anthropic activity, such as the admixture of industrial fertilizers (e.g. cadmium together with phosphates), from organic waste (cleaning plant waste, manure etc.), from atmospheric industrial pollutants, and last but not least from irrigation water of unsuitable quality (for example from polluted river water). Their mobilization in the soil usually occurs during acidification, but in a number of cases they mobilize, on the contrary, in an alkalic environment. Heavy metals are hazardous in that they often undesirably affect microbial life, mainly respiration, nitrification, mineralization, the activity of certain enzymes etc. (Novák, 2002).

From Table 4, it is evident that in some irrigated soils, namely in modal fluvisol, there is a relatively high concentration of risky elements; mainly cadmium, but also zinc. However, it is difficult to assess whether these high concentrations are the result of irrigation, because we do not have the results of the determination of these values in samples collected in the 1950s at out disposal. In addition to this, it is known that fluvisols (even unirrigated) are often highly burdened by risky elements (Vácha, 2003). Although we can reasonably believe that their high content, or even - in the case of cadmium - the exceeding of the limits of these hazardous substances was truly caused mainly by long-term irrigation, it is not possible to prove it. After all, cadmium can enter soil to a large extent as an undesirable admixture in some lower-quality phosphorus fertilizers.

Table 4: Risky element content in irrigated soils in the Nedomice model area (topsoil)

description of monitored soils			risky element content in 2M HNO ₃ (mg / kg)			
soil type	subtype	granularity	As	Cd	Pb	Zn
black earth	arenic	sandy aluminous	1.5	0.2	12.6	22.1
black earth	arenic	sandy	0.7	0.1	7.6	13.4
black earth	arenic	aluminous sandy	1.4	0.1	10.7	9.2
fluvisol	modal	sandy aluminous	1.4	0.6	21.8	41.5
fluvisol	modal	sandy aluminous	2.5	0.2	14.9	21.2
fluvisol	modal	aluminous sandy	1.5	0.5	16.4	34.7
fluvisol	modal	aluminous sandy	1.4	0.1	18.5	11.8

To assess soil contamination, we have included an abbreviated table (Tab. 5) of admissible values of selected risky elements - arsenic, cadmium, lead and zinc (mg/kg) stipulated in 2M HNO₃. The limit values are listed separately for light soils (a more stricter norm) and for other soils.

Table 5: Maximum admissible risky element concentrations in soil stipulated in 2M HNO₃ (mg / kg) as per Decree no. 13/1994 Coll.

soil type:	As	Cd	Pb	Zn
light soils	4.5	0.4	50.0	50.0
other soils	4.5	1.0	70.0	100.0

Conclusions

The results of our observation have led to the following findings: in the soil profile of arenic black earth, irrigation led to a significant decrease in porosity and maximum capillary water capacity, while in the subsoil it led to an increase in reduced bulk density; in the case of modal fluvisol, we registered a significant increase in the RBD level (in the topsoil) and bulk density (mainly in the subsoil), while the MCWC value in both the topsoil and the subsoil decreased significantly; in the topsoil, porosity also decreased demonstrably. In modal regosol topsoil, a statistically demonstrable reduction in both porosity and MCWC values occurred, with a simultaneous considerably increase in RBD and bulk density values. All of these changes confirm a significant compacting in the profile (including the topsoil) of the monitored soils as a consequence of long-term irrigation. From monitoring the risky element content in soil samples collected in the year 2016, it is evident that their concentration (particularly that of cadmium and zinc) is relatively high; in some cases, it even exceeds the limit values. However, as the paired analyses from the 1950s are not available, it is not possible to prove the extent to which long-term irrigation is responsible for their high content.

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References

- BAUDER, T. A., WASKOM, R. M., SUTHERLAND, P. L. AND DAVIS, J. G. (2011) *Irrigation Water Quality Criteria*. Fact Sheet No. 0.506, Crop Series, Colorado State University, 4 p.
- FAO-Food and Agriculture Organization: FAOSTAT-Agric. Data (2000) *FAO-On Line Database*.
- HILLEL, D. (1994) *Rivers of Eden - The struggle for Water and the Quest for Peace in the Middle East*. Oxford University Press, New York, pg 355;
- HOFFMAN, G.J., EVANS, R. G., JENSEN, M. E., MARTIN, D. L., ELLIOT, R. L. (2007) *Design and Operation of Farm Irrigation Systems*, 2nd edition. American Society of Agricultural and Biological Engineers.
- JENSEN, M. E., ALLEN, R. G. (2016) *Evaporation, Evapotranspiration, and Irrigation Water Requirements*. Task Committee on Revision of Manual 70, American Society of Civil Engineers, Reston.
- KABATA-PENDIAS, A (2011) *Trace elements in soil and plants.*, Fourth edn. CRC Press, Boca Raton, London, New York, Washington
- NOVÁK, P. et al. (2002) *Contemporary state, soil evolution processes and their categorization from the point of view of both production and extraproduction function and vulnerability*. Research Report Nr. MZe-M 07-99-01-02, Prague (in Czech language).
- RENGASAMY, P. (2006) *World salinization with emphasis on Australia*. *Journal of Experimental Botany*, Volume 57, Issue 5. pp. 1017 – 1023.
- VÁCHA, R., POLÁČEK, O., HORVÁTHOVÁ, V. (2003). *The agricultural use of the soils in lowlands from the point of view of soil hygiene*. Pedological days, Brno p. 42-48; (in Czech language).