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CONDITION ASSESSMENT OF SUBSURFACE DRAINED AREAS AND INVESTIGATION OF THEIR OPERATIONAL EFFICIENCY BY FIELD INSPECTION AND REMOTE SENSING METHODS

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Abstract

The extreme weather events highlight the need to develop action concepts to maintain agricultural production security in the future. Hydrological extremes can occur within a year in the form of surplus water (i.e. inland excess water), water scarcity or even drought. These adverse effects are influenced, inhibited and also facilitated by human activity. Previously, complex amelioration interventions, including subsurface drainage, aimed to improve the productivity of agricultural areas with unfavourable water management properties. The current efficiency of the subsurface drain networks in the regulation of groundwater level or soil moisture content can be questioned from several aspects. After the end of the socialist era (after 1990s), lack of maintenance and operation tasks have become typical, and are still a problem today in Hungary. Unfortunately, there is no exact national cadastre on the tile drained areas, and data is only available to a limited extent in the original amelioration plan documentations. In the present study, we aimed to reveal the possibilities of delineating the subsurface drained areas, and to develop a new method of condition assessment. Three tile drained study sites were selected on the Great Hungarian Plain in Central Europe. Our field investigations revealed the typical problems of the drained areas: (1) excessive vegetation of the receiving channels; (2) inadequate condition of the receiving main channel bed; (3) soil compaction in multiple layers above the drainage network; and (4) poor condition of outlets of the drain pipes. The developed methodology enabled us to evaluate the soil and the surface/subsurface water of the tile drained areas, and the technical condition of the drains. The necessary action plans or treatments were also outlined to replace the unused drain networks into use. Based on the scientific literature, we also sketched the target conditions and technological solutions that are required for the installation of new drains. The organization of the derived data into a GIS database could serve as a basis for the development of a cadastre of the tile drained areas based on a regional approach.

Keywords: soil moisture regulation, tile drainage, condition assessment, GIS

INTRODUCTION

Human activity in agricultural areas fundamentally influences the structure, the conditions and the water management properties of soils. Typically, subsurface water management is carried out worldwide to improve soil conditions vulnerable to inland excess water or excess salt content. Inland excess water is a temporary inundation mainly on the agricultural fields which mostly arises due to snow melting, heavy rainfall, lack of runoff, upwelling of ground water, insufficient evaporation and low infiltration capacity of the soil (Barta et al., 2013; Van Leeuwen et al., 2013).

The problem of surplus water on agricultural fields could be solved by construction of subsurface drainage networks, which is common used all over the world. Tile drainage is a form of water management that removes excess water from the subsurface of the soil. In 1980, subsurface drained areas covered 1 million ha in Sweden, 2.5 million ha in Finland, 3.8 million ha in the UK, 4 million ha in France, and 6.8 million ha in Germany, 0.7 million ha in the Netherlands, and 0.04 million ha in Hungary (Szinay, 1983). The extent of tile drained areas has expanded greatly in the following decades. However, in Hungary only limited data is available on their extent. Hornyik (1984) stated that ca. 1.3 million ha arable land was in need of subsurface drainage. Babics (1989) referred that ca. 0.15 million ha had subsurface drained until 1989. As a comparison, in the mostly mountainous Slovenia, 72.000 ha of agricultural land have been drained (Maticic and Steinman, 2007), and in the hilly Czech Republic 1.1 million ha land had subsurface drains (Tlapáková et al., 2017). Thus, we can state that the amount of drains installed in Hungary lags far behind the European average.

Tile drainage is studied from two main point of views. The first group of researchers aimed to *identify the abandoned, non-functioning drainage networks*. Tlapláková et al. (2017) managed to detect drain tiles using an aerial thermal camera. The differences in surface temperature caused by the difference in soil moisture described by Tlapákova et al. (2017). They found that the conditions for the identification of the drain networks by remote sensing methods depend on the type of current land cover. Tlapláková et al. (2015) distinguished three basic types of land cover for the best identification which are (a) permanent grasslands, (b) green arable lands, and (c) bare arable lands. The identification method was associated with various agrotechnical, plant developmental (phenophases) and precipitation parameters (Tlapáková et al., 2015). Koganti et al. (2020) applied ground penetrating radar (GPR) to detect subsurface tile drains in agricultural areas. According to their results, the detection of the drain tiles can be particularly successful and accurate using ground penetrating radar, but the results should be interpreted together with the available blueprints of the examined drainage networks. Djurović and Stričević (2004) studied a newly installed drainage system. They concluded that due to inadequate maintenance, the operational efficiency of the drains fell to a minimum level in short period of time.

The other group of researchers *investigated the operational efficiency of tile drainage networks*. They evaluated the role of the drains in crop yields (Bukovinszky et al., 1983; Jiang et al., 2019), examined the environmental effects of agrochemicals in natural watercourses, and the recirculation of effluent drainage waters (Shedekar et al., 2021), evaluated the efficiency of subsurface irrigation through drains (Tolomio and Borin, 2019), simulated and modelled the effects and the transport processes (Singh et al., 2006; Jiang et al., 2019; Luo et al., 2010). Brandyk et al. (1993) found that operation with a drainage-subirrigation system has numerous limits and disadvantages. According to their conclusions, the main problem is that it is not possible to raise the groundwater level above the drains in the summer season, especially in case of periods of drought. Sojka et al. (2020) performed DRAINMOD computer simulations to investigate the effect of climate change on controlled drain systems. Their simulations reflect that by applying controlled drainage and by blocking the outflow of drains in the beginning of the spring season, it is possible to retain water in the soil for later dry periods. A number of publications (Fehér, 1979; Mile, 1986; Bognár and Geredy, 1989; Forgóné, 1996) prove the beneficial effects of tile drainage with proper use and maintenance (groundwater level regulation, prevention of salinization processes, water reclamation etc.) on agricultural production (i.e. better yields, improved soil structure, better air-water-nutrient turnover in soil, reduced and less durable inland excess water cover on surface, increase in the number of days suitable for tillage). Tolomio and Borin (2019) investigated the effect of controlled drainage as well as free drains (non-controlled outflow) on groundwater levels at various crop fields. Their results showed that controlled drainage reduced the amount of effluent water by up to 69% compared to free drains. The practice of controlled drainage (which provides precise regulation of the groundwater level or soil moisture in the area with water level control structures at the outlet of the drainage pipes) is applied in the United States (https://transformingdrainage.org) and in several European countries, but it was not widespread in Hungary.

In addition to its beneficial effects on soil, subsurface drainage can also have a negative impact on the environment, primarily through the multiform agrochemicals that the drains could deliver to the recipient channels. Smith et al. (2015) reported the acceleration of mobility of phosphorus depletion from drained areas. In areas where 50-80% of agricultural land is drained, the excess introduction of agrochemicals taken into the water system can be critical. According to Shedekar et al. (2021), approximately 35% of the excess nitrogen entering U.S. water systems originated from drained areas. Karásek et al. (2015) mentioned that the location of drained areas is not completely known in many areas, and areas that were once drained may also function as grasslands that have now been declared nature reserves due to land use changes. They proposed to restore the drained areas to near-natural hydrological conditions to prevent the areas from drying out.

The first Hungarian studies were conducted to provide professional support for land amelioration interventions. The studies were mainly evaluating the effects of groundwater management on crop yields (Bognár and Geredy, 1989), the role of salt and nutrient movement (Bukovinszky et al., 1983; Lendvai, and Avas, 1983; Forgóné, 1996;), the possibilities of water replenishment by drainage or double-purpose operation of drains (Hornyik, 1984; Mile, 1986), or they analysed the overall effectiveness of the interventions (Bukovinszky, 1983; Fehér and Szalai, 1986). Bukovinszky (1983) emphasized that the comparative assessment of soil conditions before and after the interventions could be realized by continuous data collection and data provision in accordance with a full range of professional criteria. Several experiments were carried out on cultivated areas of state-owned farms and agricultural cooperatives, or on priority experimental sites of individual research institutes and universities. Some experiments were set up on a complex land amelioration model site, which made it possible to determine the rate of deepening of the leached soil layer and the yields that could be achieved in the long run (Nyiri and Fehér, 1977). Bukovinszky et al. (1983) studied the relationship between different plant species and drain scaling (15, 20, 25 m spacing, 0.0-0.1% fall). Their results showed that each plant species responded differently to drainage, thus they concluded that the application of different drainage pipe spacing according to the related tillage may be helpful to increase crop yields (Bukovinszky et al., 1983).

During the second half of the 20th century, researchers also dealt with the issue of dual operation of subsurface drains. The professional application of dual-purpose operation was only possible with a strictly and precisely planned drainage service (operation and maintenance), and only on suitable soils (Fehér and Szalai, 1986). Csaplár (1989) examined the technical conditions of the usability of the drain networks for water replenishment. Based on the applied measurements, the pressure loss of the water led into the drainage pipe from the open channel was significant. In the case of pipelines longer than 100-120 m, the pressure drop was so significant that no substantial water replenishment was possible in the additional sections. Mile (1986) ran an interesting experiment of water replenishment through drains for 4 years. The results were encouraging, as despite of a drought the wheat and maize had reasonable yield on drained plots. Based on the results of their annually repeated spring and autumn soil tests, it was found that Na+ cations had accumulated to a harmful extent in the soil layer close to the surface, which may have been due to inadequate quality of restored irrigation water in the drains. Molnár (1987) formulated his statement, which is still valid today that water surplus and water shortage can occur within one year. In his experiments, water replenishment through the subsurface drain system was carried out on a 1200 ha large test area. Based on Molnár's results (1987) drought damage can be mitigated, if adequate deep tillage is applied (e.g. chisel-ploughing), the drain system (tiles and channels) is emptied in the non-growing season, and good quality irrigation water is used. It was also emphasized that, in practice, water replenishment through drains could only be applied for a short time, otherwise harmful salts could accumulate in the upper layers of the soil.

For almost 40 years, no comprehensive map, written archive or cadastre has been created about the exact location of tile drained areas in Hungary. However, for a future reinterpretation of subsurface drainage, it is required to know the location and condition of the areas that were once treated. The latest edition of the cadastre (Wittmann et al., 1981) contains the description of the tile drained areas of Hungary in tabular form. According to the cadastre, 40,000 ha of agricultural land was tile drained, and the total length of the installed drains was about 16,000 kilometres. The editors of the cadastre suggested regular expansion and further development of the cadastre in every five years, but this was not done. The tile drainage of lowland areas became more extensive in the 1980s and until 1989 the extent of the drained areas reached 150,000 ha (Babics, 1989).

The creation of a "modern" cadastre which contains tile drain lines and the required attribute data can now be solved by creating a GIS database. The database could include a base map, supplemented by point, line or polygon features containing attribute data (basic data from the design documentation and field survey results). A cadastral database containing such data could be suitable for carrying out spatial comparative studies, for example examining the correlations between inland excess water affected areas and subsurface drained areas, or changes in groundwater conditions at the tile drained areas.

The main goals of our research are to (1) explore the conditions of subsurface drains at the study areas, to determine their usability and formulate recommendations; (2) to find out if the tile drains are able to collect the excess water from the soil, and if the drains are able to drive the collected water into the recipient channel. It is also important to (3) evaluate the technical condition of the recipient channel and determine: (a) if the channel is capable to accept the effluent drain water, and (b) if the collector channel is capable to lead away the collected waters to the main channel system. Several field and laboratory tests were performed in tile drained pilot areas at different locations supplementing the traditional methods with more modern ones.

STUDY AREA

Most of Hungary (54.2%) is cultivated, as the large alluvial plains provide favourable topographical conditions and rich soils for crop cultivation. However, due to its low elevation, inland excess water can cause serious problems in wet years, therefore, the deepest areas were tile drained several decades ago. Three low-lying study sites were selected for our investigations on the eastern part of the Great Hungarian Plain.

The eastern part of the Great Hungarian Plain has diverse geomorphology, characterized by the former riverbeds of the Tisza River, the Körös River and its influents, which form depressions on the cultivated fields. These depressions toned to be drained because they are the most affected by the inland excess water inundations due to cohesive meadow and casting soils. The annual precipitation is 500–550 mm. In addition to the frequent droughts, the excess water can develop in the same year. The depth of groundwater varies with seasonal fluctuation. The land use is characterized by very high proportion of arable land, that is well above the national average. Main criteria for the selection of study sites were: (1) being strongly affected by amelioration interventions, (2) the availability of complete and detailed documentation (land amelioration plan), (3) the owner of the plot allowed and supported the field work, and (4) close distance to the home institution (Szarvas) enabling monitoring works. At one of the study site near Mezőtúr, a more complex survey was carried out. On the other two sites (near Zsadány and Csanytelek) less detailed studies were performed, only the general condition of drainage works and their environment were analysed (Fig. 1).

Land amelioration works in the Mezőtúr study site (182 ha) were completed in 1989, but the operating permit was only granted in 1994. Based on the soil database the Mezőtúr study site has hydromorphic meadow soil prone to salinization. During the implementation of the tile

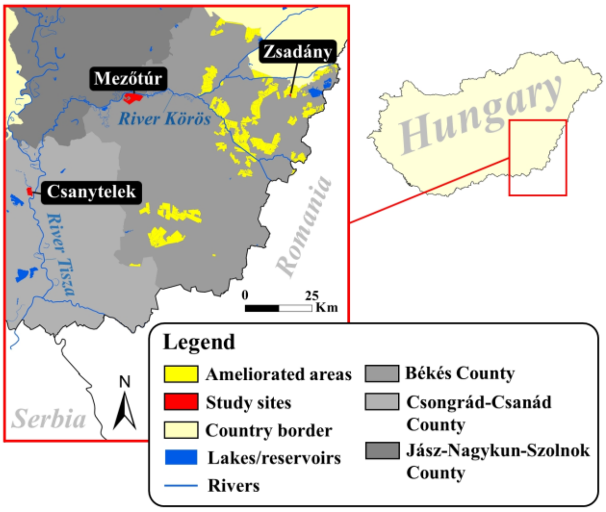


Fig. 1 The location of the pilot areas

drainage interventions, a parallel network of free drains was constructed on both sides of the field, while five targeted drains were established in the inner areas of the field (Fig. 2). In total 137 pipes, with a length of 33.2 km were installed in the area. At the west side of the study area, 46 drainage pipes were installed with uncontrolled outflows to the recipient channel. The installation spacing of the drains is 20 m and their installation depth varies between 85 and 120 cm. Despite these subsurface water management interventions, the area is still endangered by inland excess water inundations, as it is shown on the recent aerial photographs. Every autumn, the farmer of the plot creates ditches to allow inland excess water to run off the field in winter/spring period. Through these small ditches, several cubic meters of valuable topsoil eroded, causing sedimentation and blocked flow of accumulated water in the recipient channel. It is unfortunate, that the new owner, who acquired the land in the 1990s, does not show interest in the previous subsurface water management intervention. During the ordinary recipient channel maintenance (reaping and burning of reeds), the number of intact drainage pipes decreases and they become less usable.

Amelioration and subsurface drainage interventions also took place at the other two study sites before 1990. At Csanytelek pilot site (70 ha) subsurface drainage works were completed in 1987 with 28.8 km installed drains with 20 m of spacing; and Zsadány site (121 ha) has tile drained with 15 km installed drains with 20 m of spacing in 1989. These areas also became privately owned after being part of a large-scale farm, and similar conditions prevail over them. The most typical crops grown are cereals and corn.

METHODS

Considering that on tile drained areas, the agricultural activity is the most relevant, the field and laboratory tests focused on soil and water analyses. Our methodology consists of several related parts and are described below:

Data collection

Amelioration planning documentation for the study sites was obtained from the official archives (regional Water Management Authority). The documentation included permissions from design to operations, maps and blueprints of the subsurface drained areas, site plans, documentation of soil properties, cross sections of the drain recipient channels and roads, groundwater data, etc. After the data collection, paper maps of areas affected by land amelioration including tile drainage, were first identified on a base map and then georeferenced. In addition to the archive plan, documentation of the subsurface drainage interventions of the Mezőtúr study site we also collected remotely sensed data (orthophotos from 2000, 2005, and 2007, high resolution satellite imagery from Google Earth and UAV aerial imagery). In the case of the Mezőtúr study site, we used an updated digital version of the most detailed soil maps of Hungary made before 1945.

Remote sensing methods

UAV aerial photography was applied for identifying and mapping the drain network, as no precisely documented data exists on the location of the tile drain systems. To evaluate moisture conditions of the surface in case of bare soil or vegetation coverage altogether 9 UAV flight campaigns were executed at the Mezőtúr study site. Aerial imagery acquisitions were performed with a fix-winged Trimble UX5 HP, carrying a 36-megapixel (RGB + NIR (red, green, blue + near infrared)) Sony Alpha 7 camera, and a DJI Phantom 4 multicopter (for 12 megapixel RGB + NGB (red, green, blue + near infrared, green, blue) recordings). We studied the visible differences in soil moisture on the surface that could be used to identify the locations of properly functioning drainage pipes. Difference in surface reflectance was detected by 3-channel (RGB; NGB) cameras (Fig. 3). In the case of vegetation, multispectral or thermal images may provide more accurate results, than ours (Tlapáková et al., 2017).

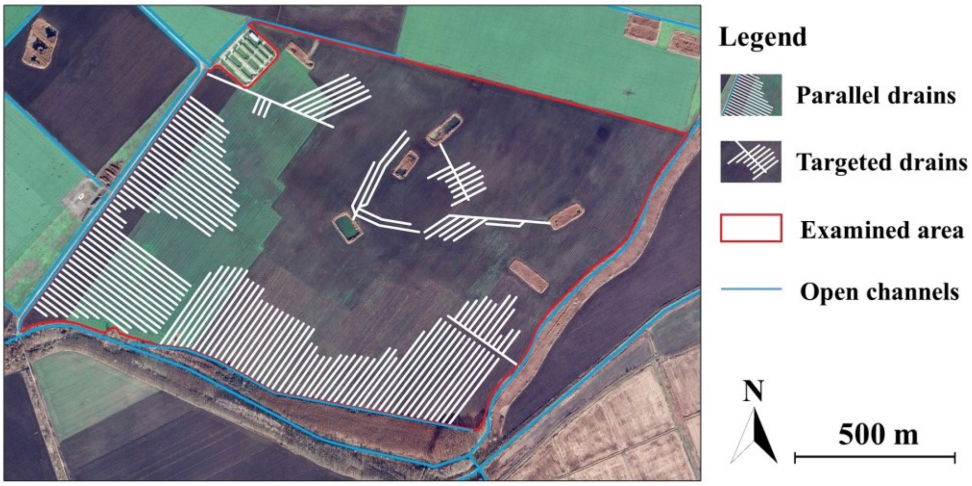


Fig. 2 The study site at Mezőtúr and its tile drain system.
Note, that the drains terminate in artificial canals or in artificial lakes

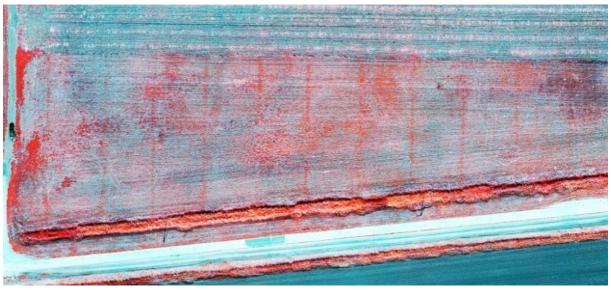


Fig. 3 False coloured composite image of drained alfalfa field made from NIR, green and blue spectral bands. The red colour indicates vegetation, blue colour indicates non-vegetation surfaces

Normalized Difference Vegetation Index (NDVI) and Green Normalized Difference Vegetation Index (GNDVI) maps were calculated, whereupon the differences become quantifiable. One of the campaigns was performed by the Department of Geoinformatics, Physical and Environmental Geography of the University of Szeged. They applied multispectral and thermal sensors (senseFly S.O.D.A / Parrot Sequoia+ / senseFly Deut T camera) on a fix winged eBee senseFly drone to investigate the operational efficiency of tile drain networks which appearance is based on spectral and temperature differences of the surface.

Soil sampling and analysis

During the Mezőtúr field campaign, we *opened soil profile* to describe the soil type of the tile drained area and characterize its mineral precipitations in each soil layer. *Undisturbed soil samples* were taken from the wall of the soil profile (0-130 cm) that we opened above a drainage pipe (2 sample replicates per 7 depths). Undisturbed soil samples were taken to determine the hydraulic conductivity of the soil, and to measure the permeability (k-factor) of the soil layers. A soil layer with a low k-factor can impede the infiltration and migration of water towards to the drains. The determination of the k-factor based on Darcy's law (Gray and Miller, 2004). This allows us to estimate the functionality of drainage in the area as well as to determine the required agrotechnical interventions. The k-factor can also be used to characterize whether the distance of the drainage pipes in the studied area is appropriate for the current soil conditions. The k-factor values of each layer of the studied soil profiles were so low, that their units were expressed in mm/day rather than cm/day.

Open-face Auger sampling was used to determine the soil texture, and the amount of water-soluble salts. Laboratory analysis of auger soil samples was performed to determine the texture of the soil and based on it, the water management properties were evaluated. Open-face Auger soil sampling was carried out above three drains, in-between these drains, and at three non-drained control points (from a depth of 0-100 cm, at every 10 cm) in order to determine the soil texture and salt content. As the auger soil sampling was performed in August 2019, during the evaluation of the data it had to be considered that summers are usually characterized by upward movement of soil moisture content via evaporation. The analysis of soil liquid limit, total dissolved salt content and the adsorbed Ca, K, Mg, Na ions on the surface of soil colloids were performed according to the relevant Hungarian laboratory examination standards (MSZ-08-0205:1978 Determination of physical and hydrophysical properties of soils; MSZ-08-0206-2:1978. Evaluation of some chemical properties of the soil (pH value, phenolphtaleine alkalinity expressed in soda, all water soluble salts, hydrolite and exchanging acidity)). We also followed the standard of MSZ-08-0214-2:1978 Quantitative and qualitative definition of the exchangeable soil cations was made using AAS Flame Photometry. The repetitive measurements on the proportion and ionic composition of salt content accumulated in deep soil layers or near the soil surface refers to the quantity and direction of the movement of salts, which was also monitored in tile drained areas.

Based on the performed *soil penetrometric measurements* the soil moisture conditions and as well as the soil compaction were determined with a custom designed soil penetrometer, to reveal the presumed moisture differences above or between the drain pipes. Soil resistance and moisture were three times sampled in 0-100 cm in 47 points (24 points over drains, 21 points in-between drains, 2 points in control area).

Water sampling and analysis

Water samplings were performed at the Mezőtúr study site from the effluent water of 5 drain outlets and from 3 sections of the recipient channel water. The comparison of the results refers to the discharge of nutrients and agrochemicals from the drains into the recipient water, which might pose risk to the environment.

Discharge measurement of effluent drainage water was also carried out, by measuring the filling time of the sampler with a given volume, thus the discharge data were expressed as liter/hour (l/h). By combining the discharge of the effluent water and its nutrient content, the input of harmful salts or pesticides into the recipient canal was calculated. However, it must be noted, that this calculation reflects the current state, and more repetitions are needed for more accurate estimations. The discharge of the drain water was highly fluctuating at the time of sampling, the highest measured discharge was 18-22 l/h, but there were also drain pipes with lower water discharge (6.5-7.5 l/h), being at the limit of measurability. For comparison, Lendvai and Avas (1983) sampled drains with a flow rate of 1800 l/h during their experiments.

Drain pipes operated just during the winter-spring period at the Mezőtúr study site, so water samples could be collected (and representative) just for this period to understand whether excess salt, nutrients, or suspended solids leave the soil during the winter, emphasising the leaching role of the drains. As the water of the canals usually is used for irrigation during the vegetation period, the water was categorized in terms of suitability as irrigation water (Filep, 1999). Water samples were analysed in the accredited laboratory of the Research Institute for Irrigation and Water Management (ÖVKI). The analysed parameters were pH value, EC (Soil electrical conductivity), bicarbonate, carbonate, ammonium ion, ammonium-nitrogen, nitrate ion, nitrate nitrogen, nitrite, nitrite nitrogen, total nitrogen, orthophosphate ion, orthophosphate phosphorus, total phosphorus, total dry material, total solutes, total suspended solids, chloride, sulphate, calcium, magnesium, potassium and sodium.

Condition assessment of the drains

Technical condition assessment of the recipients, used for the determination of whether the recipient is suitable to (1) provide the operating conditions for the reception, (2) collect effluent drainage water. The actual condition of the drain pipes was surveyed applying an *endoscope camera*. On the photos, we looked for the presence of sediments in drainage pipes and perforations in the drainage pipes. Endoscope camera imagery was collected from the undamaged drain pipes to determine if any groundwater and soil moisture could infiltrate through the perforations of the pipes, or to see whether the drained water can flow through the pipe itself. Following Sojak and Ivarson (1980) observations, an important aspect was to observe the various sediments and mineral precipitates on the inner surface of the drain pipes (e.g. iron ochre or manganese oxide). Endoscope imagery was collected using a waterproof tube camera with adjustable brightness LED lighting, 5 m range, and 800x600 pixel resolution. To validate the filtration of the drainage pipes, a soil profile was also opened above one of the operating drains which we mentioned earlier.

RESULTS

Soil characteristics of Mezőtúr study site

The soil texture determined from the Open-face Auger soil samples (at 97 points) is 88% heavy clay and 12% clay. Soil infiltration rate (k-factor) was determined from undisturbed soil samples above the examined single drain pipe at Mezőtúr site. The soil layers with the highest infiltration rate (1.3-18.8 mm/day) were located directly 20 cm above and below the drain pipe (Table 1).

Several layers of the soil profile above the drain pipe can be considered impermeable for water, as the water did not get through the undisturbed soil samples during the 15-day laboratory test period at all. Based on the evaluation of the total soluble salinity in the soil samples, moderately saline and saline soil levels (total water soluble salinity 0.3-0.74 m/m%) appear both below and above the drains. It limits the growth of roots of most cultivated crops, and thus has a yield-reducing effect (Soni et al., 2021). The results show that soil layers shallower than 50 cm do not contain harmful amounts of salts. The appearance of soil levels with higher salinity showed a large variance under 50 cm. There is no clearly detectable difference in the drained and non-drained fields, but the deep salinity is characteristic at the Mezőtúr study site. Soil resistance and moisture content values are related to each other; i.e. drier soils are more difficult to penetrate. Tests can therefore be performed on nearly saturated soils. In case of high replication rates, the results of soil resistance were used to determine the location of compacted layer (plough pan), which can prevent precipitation or excess water from the surface to infiltrate to deeper layers.

Table 1 The infiltration rates over a single examined drain pipe

Soil depth [cm]	k-factor [mm/day]
0	0.1565
15	0.8
25	0.035
50	1.134
80	0.518
100	1.3
120	18.8

Identification of drain systems

In general, after a precipitation event, the wet and drier parts of the study sites were easily separable in the case of bare soil surface. Contrary to our expectations we could not observe linear traces on UAV images suggesting the presence of drains at Mezőtúr study site. We observed drain lines only on the examined orthophotos (Institute of Geodesy, Cartography and Remote Sensing of Hungary) e.g. around Kunszentmárton, Hungary (Fig. 4).

The Mezőtúr study site was also surveyed during the vegetation period, when NDVI maps were created to entrust the detection of developmental differences in plant

Fig. 4 Appearance of tile drain lines near Kunszentmárton, Hungary. The drawn lines on the bare soil continue on the surface with vegetation too, where the lines still could be observed due to differences in vegetation growth or species composition (source: Institute of Geodesy, Cartography and Remote Sensing of Hungary)

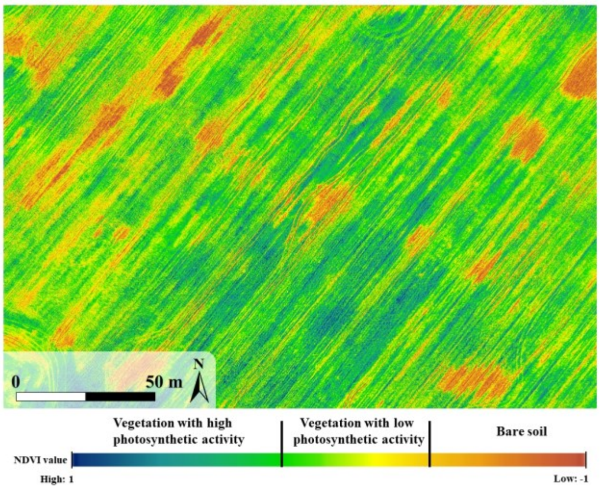


Fig. 5 Detail of the NDVI map of the Mezőtúr study site. The low NDVI values indicate the location of bare soil patches where the vegetation was destroyed by inland excess water

grown and phenophase. In April 2018, the soil moisture modifying effect of the drainage pipes on NDVI values could not be convincingly demonstrated. Due to the shallow roots of wheat grown in the area, the drainage pipes did not directly affect the moisture conditions to the near-surface root zone. At the same time, bare soil patches at the location of dried out inland excess water inundations or saturated soil conditions were very well observed (Fig. 5).

It should be noted that the appearance of inland excess water inundations fundamentally questions the efficiency of the operation of the drains, or the application of the correct agrotechnical treatments. In August 2018, an aerial photograph of a harvested alfalfa field right next to our pilot site was taken. Our experience suggests, that alfalfa had faster growth along the assumed soil drain pipes (Fig. 6). The original blueprint documentation reflects, that the pipes extend from the alfalfa field to the other plot with different land cover and land use, but there is no visible trace of them on that field. The reason for this phenomenon could be explained by the fact that alfalfa roots can penetrate into the deeper soil layers (as “bio-drains”), and thus they get better water supply along the drains. Similar phenomena can be experienced in stubble areas after crop harvest, where various weeds and volunteer crops indicate the location of drainage pipes. The UAV thermal imaging survey that was executed in March 2021 did not yield the expected results at Mezőtúr study site. The surface temperature showed no differences that suggesting the presence of drains.

Condition assessment of drains

During the first field survey (August, 2018) at the Mezőtúr test site, we found that only five drainpipe outlets were visible in the side slope of the channel. In situ inspection of the drain outlets was repeated three times. Finally, the number of identified drainage pipe outlets or their remains increased to 42 out of the 46 we found in the documentation of the area. In our experience, the documentation and the blueprints can only serve as an approximate reference for finding drain outlets. Contrary to the constant distance of 20 m stated in the plan documentation, various distances of 15-25 m between some pipes were found. In some cases, the PVC drain pipe outlets were melted, as the result of inappropriate maintenance of the channel: the farmer eliminated the excess vegetation by periodic burning (Fig. 7A). Despite of the critical injury of the pipelines, some pipes had outflowing drainage water. Other evidence of improper maintenance was a drain outlet (manufactured in 2012) that was found in the non-drained side slope of the channel, suggesting heavy disturbance (Fig. 7B).
Based on the results of the field inspections at Csanytelek and Zsadány sites, we concluded that the drain systems there are characterized by the same conditions and maintenance problems as at Mezőtúr plot. The Mezőtúr study site is unique, since here the outflow of drain pipes was visible, though their condition was unsatisfactory with a few exceptions. In the other two study sites, the drain outflows had already been destroyed and the pipe ends were buried in the side slope of the recipient channel. During the field survey at the Csanytelek site, no pipe outlets were found, but after the dredging of the drainage canal and removing the sludge,

Fig. 6 Phenological differences in alfalfa plants over drains and the intermediate areas: (a) blueprint of the tile drains, (b) vertical aerial photo of the alfalfa field (UAV), (c) oblique aerial photo of the alfalfa field, where denser vegetation indicates the lines of the drain (UAV)

Fig. 7 Typical conditions of the drain pipes at the Mezőtúr study site: (a) melted PVC drain outlet in the channel side slope, (b) a few years old relocated drain pipe outlet, (c) open channel after sludge removal in Csanytelek, (d) ruptured drain pipe in spreaded sludge

some outlets were visible, as the excavator machine cut and teared the last sections of the pipes exposing them (Fig. 7C-D). In the case of the Zsadány study site, after the crop harvest the weeds in the field indicated the linear pattern of the drains. To verify their existence, the buried pipeline was excavated from the side slope of the recipient channel (Fig. 8).

In the Mezőtúr study site, endoscope camera inspections of five drain outlets gave good results. The condition of the inner tube was very good in the examined 4.5 m length (Fig. 9). Precipitates around the pipe perforations were visible, but these did not cause clogging. Most of the inspected drains were found free of dirt, but we also found a tube with sediment in the last 50 cm of the drain, at its outlet. The results suggest that drain pipes are permeable to water, and they can function. Along the recipient channel most of the drain outlets were damaged or buried, and they contained sediment. The causes of perforation clogging and precipitation on the drain pipes were also examined. We opened a soil section and performed a mechanical slope excavation, which proved that the perforations of the 30 years ago installed drain pipe are still permeable to water, i.e. they are free of blockages (Fig. 10).

Water quality of the drain and recipient waters

Compared to the recipient channel's water, nitrate, total nitrogen, total suspended solids, sulphate, calcium, magnesium and sodium appeared in excess in the drained water (Table 2). From the point of view of the Hungarian irrigation water classification (Filep, 1999), the collected inland excess water generated on the Mezőtúr study site had good quality, thus it diluted the water of the recipient channel. The results refer to wide range of parameters (Table 2). However, according to the analysis of the recipient water sample, its water quality was satisfactory

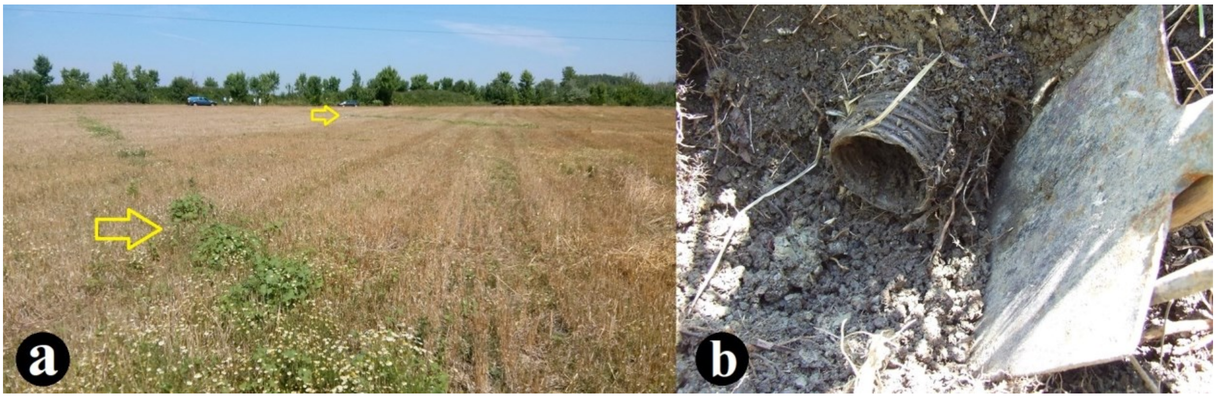


Fig. 8 Weeds indicate the location of the subsurface drain pipes (a) in Zsadány site. The same pipes were found buried in the recipient channel's side slope (b)

Fig. 9 The inspection of drain outlets and inner sections by endoscope camera

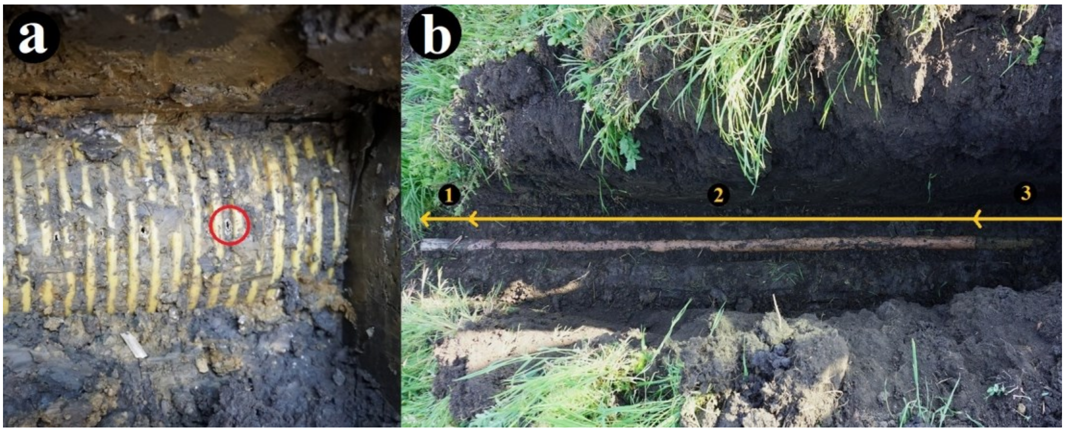


Fig. 10 Open perforations on drain tube (a), and the overview of one excavated pipe (b) with the following sections: (1) drain outlet, (2) intermediate pipe (not always applied), (3) perforated drain tube

to be used for irrigation quality improvement. This raises several environmental issues related to the protection of surface water, as mixed water from surface runoff and drainage effluent water has a direct and indirect impacts on the recipient. According to our results, in February 2018 the electrical conductivity (EC) of the drained water (mean: 2300 μS/cm) was almost three times higher than the values of the channel samples (mean: 780 μS/cm). In the samples from March 2018, in addition to the natural increases of the electrical conductivity values in both examined locations, the difference in mean values had only double (drained water: 3300 μS/cm; channel water: 1630 μS/cm). The increase in conductivity values from February to March can be related to the increase in ambient temperature or the duration of the high groundwater level. In terms of the electrical conductivity, the drainage water has 2-3 times higher values than the recipient water samples, which proves the role of drains in the loss of water-soluble plant nutrients from the soil (leaching)

DISCUSSION

On the selected study sites, various field and remote sensing methods were applied to assess the condition of the drained areas and to determine their future usability (Fig. 11). The evaluation was greatly facilitated by previous Hungarian research reports and results, mostly from the period 1981–1990, which were focused on the maintenance and proper operation of drain networks. Based on the results of our studies, we have drawn the following conclusions:

Babics's (1989) described ca. 150,000 ha of tile drained land in Hungary, however their extent did not change considerably in the last three decades. Tile drainage constructions were uncommon, but in some cases tile drainage was used as an accompanying element of linear irrigation plants. In our investigations, we reviewed a number of amelioration plan documentations and blueprints. However, among the documentations, we found only blueprints and descriptions of drain systems with free outflow (free drains). Unfortunately, the practice of controlled drainage, which is more widely used in other countries (Tolomio and Borin, 2019), has not developed in Hungary, except for at some experimental sites and farms. The favourable effect of tile drainage on crops which was reported by Bukovinszky et al. (1983) was not verifiable in our study sites. The vegetation modifying effect of tile drains was manifested only in the linear patterns experienced during UAV remote sensing data collection. Similar to the results of Tlapákova’s (2015) research report, we found drainage trails on orthophotos which could be validated with the related blueprints. We also applied UAV thermal imagery, as described by Tlapákova (2017) but we did not get the expected results.

According to our results and experiences, we can state that intermittent outflow of inland excess water from the surface is not impeded by drainage pipes, but rather by soil with very poor water permeability. The soil is compacted in several layers, despite the fact that,

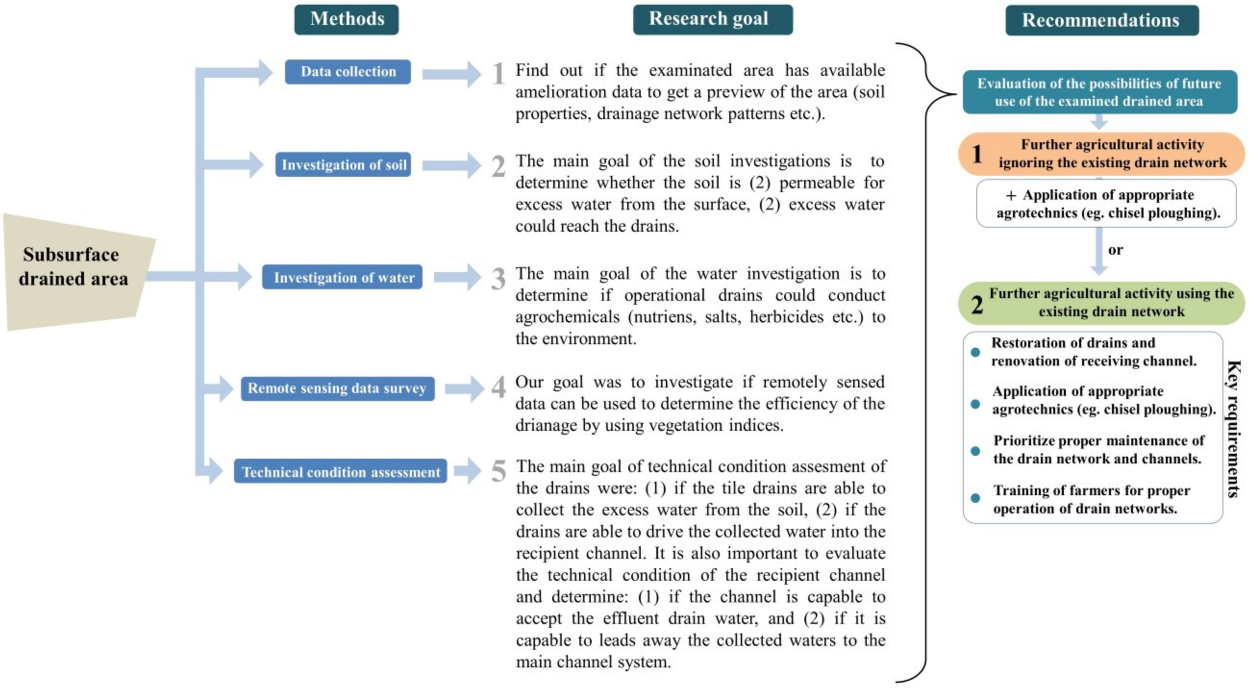
Table 2 Mean values of the analysed parameters of the water samples collected from the drains and from the recipient channel. (Only those parameters are indicated which showed large variations.)

		EC [μS/cm]	Nitrate [mg/l]	Total nitrogen content [mg/l]	Total suspended solids [mg/l]	Sulphate [mg/l]	Ca [mg/l]	Mg [mg/l]	Na [mg/l]
2018 February	drain	2300	130.5	34.5	14.25	1207	144	87.22	296.75
	channel	780	18.4	6.05	38	189	54.33	21.86	80
2018 March	drain	3300	46.1	12.35	88.6	2074	233.2	155.38	442
	channel	1630	6.7	2.85	37.25	569	133.5	52.72	178.5

according to the farmers, they apply chisel-plough in every 2–3 years. Based on these results, it is highly recommended to perform periodic deep cultivation or chisel-ploughing of the plot in order to improve the infiltration properties and the air-water balance of the soil. We agree with Fehér and Szalai's (1986) strict recommendations on the maintenance required for dual-operation of drains. However, we believe that following these recommendations is the basis of single operation drains.

It can be concluded, that nowadays the negligence of subsurface drainage works is common in Hungary, thus we assumed that the drain systems have lost their function in subsurface water management. Karásek et al. (2015) found that abandoned drained areas due to land use change may continue to function. Thus, for example, grasslands may dry out the soil more easily at a dry period. In our opinion, the impact and functionality of abandoned, non-maintained drainage systems is minimal. All these results prove that the subsurface water management interventions could work nowadays, while the beneficial effect of the complex melioration have been eliminated. The justification for the reactivation of drainage networks is unequivocal, but this cannot be generalized. It depends on the characteristics of the soils, actual weather conditions, and applied agro-technics. From the point of view of inland excess water management, the improvement of unfavourable soil infiltration conditions play key role in applying subsurface drainage. In this context, it becomes necessary to use suitable agrotechnical methods that facilitate the infiltration of excess water into the deeper soil layers, and to establish connection with the surface and subsurface drainage network. Another critical point is to ensure the longitudinal impermeability of the drains which typically results from the destruction and clogging of the outlets. Of course, maintenance work on open channel recipient systems cannot be omitted either. Taking these factors into account, the efficiency of the drains and the recipient channel of the studied Mezőtúr study site can be estimated as less than 50%, while the drainage network itself can be considered operational. The improvement of unfavourable infiltration conditions due to heavy textured soils requires a complex approach (agrotechnical interventions, chemical soil conditioning, appropriate surface water management and excess water control etc.). In the absence of these interventions, the regulation of groundwater and soil moisture cannot be realized even after the restoration of drainage systems and their recipient channels. Our water quality test results confirmed the findings of Shedekar et al. (2021) that drains are suitable for removing excess salts and agrochemicals from the tile drained plots, but we did not experience high discharge of drainage water at any of our study sites. The Mezőtúr study site is a typical example of cultivating an agricultural field without considering the possibilities and benefits of using the existing drainage network. We recommend two main treatment options and appropriate practices for using of drain networks in the future (Fig. 11).

The first way of possible application is further agricultural activity ignoring the existing drain network supplemented with the application of appropriate agrotechnics (e.g. chisel ploughing). Our other recommendation is further agricultural activity using the existing drain network, but it requires the following key steps for its success: restoration of drains and renovation of receiving channel; application of appropriate agrotechnics; prioritize proper maintenance of the drain network and channels; and training of farmers for proper operation of drain networks.



1 Find out if the examined area has available amelioration data to get a preview of the area (soil properties, drainage network patterns etc.).

2 The main goal of the soil investigations is to determine whether the soil is (2) permeable for excess water from the surface, (2) excess water could reach the drains.

3 The main goal of the water investigation is to determine if operational drains could conduct agrochemicals (nutriens, salts, herbicides etc.) to the environment.

4 Our goal was to investigate if remotely sensed data can be used to determine the efficiency of the drianage by using vegetation indices.

5 The main goal of technical condition assesment of the drains were: (1) if the tile drains are able to collect the excess water from the soil, (2) if the drains are able to drive the collected water into the recipient channel. It is also important to evaluate the technical condition of the recipient channel and determine: (1) if the channel is capable to accept the effluent drain water, and (2) if it is capable to leads away the collected waters to the main channel system.

- Restoration of drains and renovation of receiving channel.
- Application of appropriate agrotechnics (eg. chisel ploughing).
- Prioritize proper maintenance of the drain network and channels.
- Training of farmers for proper operation of drain networks.

Fig. 11 Flow chart of the applied methods and their research goals to assess subsurface drain systems. The figure also includes our recommendations for the future use of drained areas

CONCLUSIONS

Our aims were to evaluate whether the location of the installed drainage networks can be delineated, whether their operational efficiency can be assessed, and whether they have a role in field-level drainage, water supply, or water retention. The combined methods applied in this survey are recommended to survey the condition of other tile drained areas and they could be adapted for their complex evaluation. Based on these results, interventions that are essential to make a drain system functional can be categorized into (1) reconstruction and (2) construction of new drainage systems of drained areas of any kind have a right to exist only with proper maintenance and operation. Given that 150,000 ha of subsurface drainage has been implemented in Hungary, with about 300,000 ha of buffer area, the reactivation of drained areas combined with the appropriate agro-technics would greatly contribute to maintaining production safety in agriculture.

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