Agricultural Land Degradation in the Czech Republic

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Contents

Abstract Soil degradation has been identified as a major threat to the productivity of agricultural land. In the Czech Republic, soils are threatened primarily by water and wind erosion, but compaction, loss of organic matter, loss of soil structure stability, pollution and over-fertilization, loss of biodiversity, and soil sealing are also major concerns. Poor soil health results in many off-site effects such as surface water siltation, groundwater pollution, loss of biodiversity in the countryside, and decreasing crop yields. The Czech agricultural landscape is characterized by large fields with a very small number of interrupting elements such as furrows, paths, or balks and the crop structure is rather uniform. The state has a history of land collectivization which first took place during the twentieth century. The ongoing intensive and unsustainable industrial farming, which is often focused more on high yields of certain economically valuable crops rather than the environment, speeds up

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soil degradation. These problems are fortunately recognized by the stakeholders, legal authorities, and the public. There has been significant debate on sustainable landscape management and agricultural practices, and many positive examples already exist in the Czech Republic.

Keywords Land collectivization, Pesticides, Soil compaction, Soil erosion, Soil sealing, Wild fires, Wind erosion

1 Introduction

The Czech Republic is a landlocked country with an area of 78,887 km^2. Its relief is moderately hilly, with most of the area (78.6%) lying at an elevation between 200 and 600 m a. s. l. The climate is classified as warm temperate humid continental Cfb [1], with predominantly western circulation and mean annual precipitation around 600 to 800 mm. The most intensive rainstorms and peak surface runoff events usually occur in the late spring and early summer months. In general, the climate is rather dynamic, and the weather may change quickly. Moreover, several exceptionally wet and dry years have been recorded in the last two decades, resulting in local floods and droughts [2].

In comparison with other EU countries, the Czech Republic has a high percentage of arable land. Agricultural lands cover 42,002 km^2, which is approximately 53% of the total land area (arable land 42.2%), and forests cover 26,773 km^2, which is 34% of the total land area. Most of the agricultural lands are arable and grasslands (Fig. 1). Farmlands are typically found in less favorable soils and climatic conditions from the production perspective, and the conditions are classified as a submontane type of agriculture [3]. The soil profiles are usually deep, i.e. 40% are deeper than 60 cm, and 54% are between 30 and 60 cm, with soil profile depth considered as a soil layer with stoniness below 50% [4]. In some parts of the country, specifically in Southern

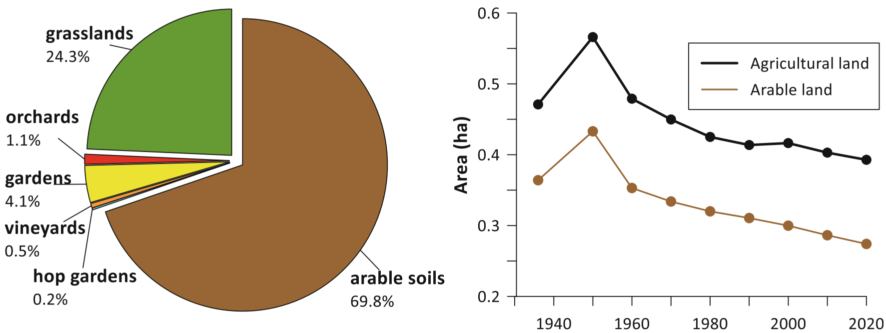

Fig. 1 Ratios of agricultural land use (left), and the temporal evolution of the arable area per capita (right)

Moravia and in Northwestern Bohemia, high-quality (and endangered) Chernosols can be found. The most abundant soil types in the Czech farmlands are Cambisols, followed by Luvisols, Chernosols, Stagnosols, and Fluvisols. The fields are predominantly rainfed, and only 0.6% of the agricultural area is irrigated. Agricultural lands were extensively evaluated during the extensive national mapping campaign of agricultural soils in Czechoslovakia (1961–1971), and in the 1970s and 1980s the lands were classified according to their productive capacity and economic value into Evaluated Soil-Ecological Units (ESEU, in Czech so-called BPEJ) [5]. The Soil-Ecological Units and the official soil prices have been gradually updated [6]. The Soil-Ecological Unit is assessed on the basis of the climatic region in which the parcel is located, the main soil unit, slope, exposure, soil stoniness, and soil profile depth. The State Land Office distributes the soil value map (1:5,000), which is spatially the most detailed resource, e.g., for USLE-based soil erosion modelling [7].

The arable land area decreased significantly between the 1950s and the 1970s, when agricultural fields were transformed to civil infrastructure and mines. In recent years, the area of arable land has decreased slowly and steadily at a rate of approximately 100 km^2 per year, mainly due to the conversion of arable lands to permanent grasslands and to urban uses, especially residential and industrial zones [8]. The farmland area ratio has been declining significantly faster than in the neighboring countries, although the market prices of farmland have been rising [9]. The forests, grasslands, and pasture areas keep increasing slightly [10]. A typical feature of farming in the Czech Republic is that a relatively small number of farms account for a substantial majority of the agricultural area. The average agricultural holding size of a farm is 152 ha [10], which is by far the largest among the EU countries [11]. Farming in the Czech Republic can therefore be characterized, to a considerable extent, as industrial farming.

In the Czech Republic, as in other countries in Central Europe, forestry and agriculture utilize a major portion of the land area, with both positive and negative impacts on the soils and on the environment. Because of the intensive management, the landscape maintains its land use diversity in terms of economical and cultural functions. However, overexploitation causes severe soil degradation resulting in lower soil fertility, soil and water contamination, loss of biodiversity, and changes in land use and in the landscape matrix. Most of the soil-related degradation processes are in line with the general trends in Central Europe. However, there are a few specific issues in the Czech Republic which are related mainly to the abrupt changes in agricultural management in the second half of the twentieth century [12]. Former privately-owned small arable parcels were merged into large soil blocks (through the process of collectivization), balks were ploughed, small landscape features were removed, subsurface tile drainage and systems of surface ditches were introduced into the landscape to extend the arable parcels in occasionally flooded areas (this process had already started at the beginning of the twentieth century), and fertilization and crop production were intensified [13]. As a result, fields have very large size (often over 30 ha), soils are currently threatened mainly by water- and wind-induced soil erosion, the soil organic matter quality has been deteriorating, soils have low hydraulic conductivity, and the subsoil is often compacted [14]. These conditions further lead to unfavorable changes in the physical, chemical, and biological properties of the soil [15].

The effects of past mismanagement of soils have not been eliminated until now, and the long-term trend of unsustainable agricultural land management is still clearly visible on arable soils. The average size of land parcels has not decreased dramatically (although it has been recognized that the extreme size is one of the main reasons of soil degradation and low biodiversity [16]), crops selection and crop rotation are driven by economic rather than by environmental concerns, soil productivity is maintained with the use of mineral fertilizers instead of organic amendments such as manuring, and mostly large agricultural enterprises farm on leased soils, often in an unsustainable manner (only 16% of farmland is owned by farmers who indeed manage the land). In addition, there is an increased pressure on new building plots around the agglomerations. These factors are causing sealing of the most fertile soils in the lowlands [13]. Kozák et al. [17] have identified soil sealing as the main current problem. They have also pointed out the loss of agricultural land due to open-cast mining, though some of this land has already been recultivated.

Acid deposition in the twentieth century and unfavorable forest management based on spruce monocultures have led to forest degradation in some areas in the Czech Republic. There had also been some concerns about the acidification of arable soil, as lower pH could mobilize hazardous trace elements, especially cadmium. Fortunately, however, no extensive acidification has been measured [18]. Salinization of soils is not an extensive problem in the Czech Republic and may occur only locally around roads treated with salt during winter, or in irrigated greenhouses [17]. There is serious concern about soil quality among land managers, academia, and also in the general public. Quantitative assessments are already available such as the study by Šarapatka and Bednář [19] that constructed a PCA (principal component analysis)-based model to estimate the vulnerability of Czech soils to degradation. The results were published in the form of a soil degradation threat map.

2 Soil Erosion

In comparison with the rest of the world, the Czech Republic has relatively low soil erosion potential, as it lacks high mountains and heavy convective rainstorms, and a considerable part of the area is covered by forests [17]. Nevertheless, soil erosion (especially by water) is the most frequently highlighted soil degradation process. A total of 43% of the arable land is on slopes ranging from 3° to 7°, and 10% of the land is on slopes exceeding 7°. Wind erosion occurs mainly, but not exclusively, in the south-eastern part of the Czech Republic, where the climate is warmer and the soils are generally lighter. The estimated annual soil loss from agricultural land for the whole country is estimated to be 21 million tons, which represents an economic loss of up to CZK 4.3 billion [20]. Soil translocation due to tillage operations has also been studied [21, 22]. Up to 16% of arable land is negatively affected by the tillage operations, especially in the most fertile regions of south and northeast

Moravia [23]. Soil erosion has been a prominent topic of national research in the last 20 years. According to the Central Register of Research & Development projects (https://www.isvavai.cz/cep, as of March 2021), 47 out of 116 grant-funded projects related to soils have dealt with the problematics of soil erosion.

2.1 Soil Erosion by Water

More than 55% of agricultural land in the Czech Republic is potentially threatened by surface runoff and subsequent soil erosion by water and out of this percentage, over 17% is extremely threatened [24, 25]. Similar or slightly lower values have been reported during the last 20 years [26], which indicates that the situation has not improved. The permissible soil loss limit on moderately deep to deep soils in the Czech Republic is 4 t ha^{-1} $year^{-1}$, but some argue that the real soil formation processes in the Central European region are even slower (estimated to be 1 cm of soil in approximately 100 years), and that the permissible soil loss limits should be reduced by at least a half. Single erosion events often lead to irreversible topsoil losses of several centimeters locally [14].

The Czech Republic contains densely populated areas where soil erosion is usually accompanied by the off-site negative impacts of considerable economic damage to water structures (e.g., ditches, rivers, and reservoirs affected by siltation and consequently by eutrophication) or to the civil infrastructure (local flash floods, mud flows into villages and gardens) [27–29]. Over 40% of reported erosion cases end up with damage to roads, over 30% with damage to the civil infrastructure, and more than 17% with damage to water bodies [24]. Eroded soils in the Czech Republic produce lower crop yields per hectare. The reported yields are lower by 15–20% on moderately eroded soils and by as much as 75% on heavily eroded soils [24]. Agriculture is the main non-point pollution source of surface waters and groundwater. Surface runoff containing detached soil particles introduces considerable loads of adsorbed pollutants, mainly phosphorus [28, 30] and nitrogen [30]. Soil erosion also has a significant influence on the price of affected parcels [31, 32].

The unsatisfactory present-day situation is connected with mass production in agriculture and with extreme changes in land use (the so-called collectivization process in the 1950s), when large units of arable land were consolidated and the soil degradation process accelerated dramatically in some areas (Fig. 2) [16]. Dostál et al. [33] identified the following dominant factors which have contributed to a dramatic increase in soil erosion:

- Establishment of very large fields (on an average 20 ha, but there are even parcels of 200 ha [34])
- Removal of the dense network of linear features and spot elements in the landscape (such as dirt roads, paths, ridges, grass belts, groves, etc.) which could potentially prevent or terminate surface runoff

Fig. 2 An example of the change in the landscape pattern between 1954 (left) and 2020 (right) due to the collectivization of agriculture (vicinity of the Nučice experimental catchment [35]) (source of the historical orthophotograph CENIA 2010, current situation ČÚZK, available from: http://geoportal.gov.cz)

– Extensive soil amelioration with introduction of dense networks of tile drains, straightening and deepening of streams
– Transformation of grasslands and pastures into arable areas in morphologically unfavorable landscape areas (foothills, slope areas).
– Drainage of inundation areas, leading to more arable land but to lower water retention capacity of the landscape.
– Utilization of heavy machinery, which has resulted in soil compaction and reduced soil infiltration capacity
– Planting of wide row crops (e.g., corn, potatoes)
– A drastic reduction in organic matter inputs, due to reduced livestock production since the 1990s.
– Increased application of mineral fertilizers since the 1970s
– Insufficient use of modern technologies, lack of knowhow, and a lack of political support for soil protective cultivation of the land

Since as early as the 1960s, severe erosion events have been reported, especially in the highlands [36, 37]. The reporting strategy has improved since then. The Research Institute for Soil and Water Conservation and the State Land Office have introduced an online tool for soil erosion event monitoring (accessible from https://me.vumop.cz/app/), which visualizes the spatial and temporal distribution of severe water soil erosion events on agricultural land in the Czech Republic [38]. The increased rates of erosion events, which are observed every year in May and June, are related to a combination of the rainfall pattern and the undeveloped vegetation, which provides insufficient cover for the soil surface at that time of the year (Fig. 3). Erosion events have recently also been recorded in the autumn and increase in the areas where oilseed rape is grown. Most of the erosion events occur on Cambisols (over 40% of the events), which are predominantly located in the hilly regions. Chernozems, which are in general susceptible to water erosion, do not exhibit an extreme number of events in the Czech Republic, as they are located in flatter parts of the country and cover a comparatively small area (7% of the events) [38].

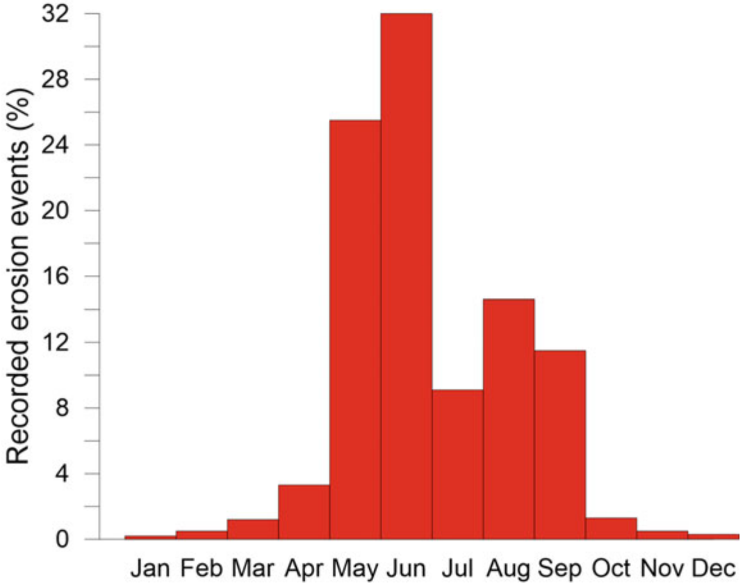

Fig. 3 Ratio of recorded water erosion events in the Czech Republic during a year (based on a monitoring from 2012 to 2015). This figure is based on data retrieved from the soil erosion event monitoring of the Research Institute for Soil and Water Conservation and the State Land Office [24]

Fig. 4 Sheet and rill erosion development near Přestavlky (left), to formation of gullies at Vlkov (right) (photographed in June 2020, courtesy of Josef Krása)

The most widespread crops in the Czech Republic are wheat, barley, and oilseed rape (the sowing areas vary annually between 40% and 65%), followed by fodder crops and maize. The diversity of agricultural crops has decreased in the last 25 years [39]. In the long term, maize has been the most problematic crop from the soil erosion perspective, with approximately one half of significant erosion events occurring on maize fields, followed by winter oilseed rape, winter cereals, and potatoes. By contrast with most other crops, soil erosion events on maize fields have been observed even when the canopy is already closed [38] (Fig. 4).

2.2 Soil Erosion by Wind

Approximately 10% of the area of the Czech Republic (23% of the arable land in Bohemia and 40% of the arable land in Moravia) is threatened by wind erosion, and 5% of the farmland is severely threatened [33]. The most-affected areas are the Elbe plain in Bohemia, the spoil heaps, and the open pit brown coal mines in NW Bohemia, and the southern part of Moravia, where the climate is warmer and the generally dry Chernozem soils are more susceptible to detachment by wind than in the rest of the country [40]. Recent weather extremes, with warm winters with reduced amounts of precipitation and almost no snow, have stimulated the erosion processes, as the bare soil surface dries quickly in spring [41].

Wind erosion events have occurred even in the 1950s, before the arable land collectivization process started [42], but in the long term the disruptive effects did not exceed the limits of natural erosion [43]. However, after small plots were merged into large arable blocks, the semi-natural wind barriers and shelterbelts were destroyed and were later replaced by quickly growing trees and often poorly maintained. The crop diversity was dramatically reduced, and the impact of wind erosion on soil degradation increased. In general, the danger of wind erosion was underestimated. In Southern Moravia, the mean topsoil loss due to wind erosion is currently estimated to be 0.4 mm of the plough layer per year, and locally up to 4–5 mm per year. In the case of severe dust storms, even 20 mm of topsoil loss have been reported [33].

2.3 Soil Erosion Measures and Policy

Effective measures against soil erosion are well known and they have been increasingly applied on a number of fields in the Czech countryside. Unfortunately, effective measures have usually been carried out on a local scale, and either on fields that have already been repeatedly affected by erosion or by a limited number of progressive farmers and land owners. Nevertheless, the ongoing process of land consolidation (aimed at reducing the high ownership fragmentation caused by the restitution of confiscated land in the 1990s) provides a great opportunity to reshape the rural landscape matrix, to introduce stabilizing elements, e.g., pathways, grass strips, alleys, ditches, green vegetation, among others [44], and to improve the resistance of the soil to degradation [45, 46].

The main policy tools implemented by the Ministry of Agriculture are the standards of Good Agricultural and Environmental Condition (GAEC), which support agricultural management in compliance with environmental protection [47]. Farmers and smallholders are motivated to take care of the soil. The Ministry of Agriculture, together with the Research Institute for Soil and Water Conservation, established, among others, a website (http://eagri.cz/public/web/mze/puda) with up-to-date information, guidelines, and interactive tools (an erosion calculator, soil maps, contaminated sites, etc.). In most cases, the goal is to apply a set of erosion measures to protect the soil. The set of anti-erosion measures includes organizational changes, such as proper crop distribution, strip tillage, and complex landscape consolidation. Agrotechnical measures include contour tillage and conservation tillage. Leveling, field balks, and terracing are some of the technical measures. Further measures are aimed at reducing erosion and transport in streams and rivers [48]. The amount of measures required by Cross Compliance is carefully balanced with the available funding (which comes in the form of subsidies to farmers) and the required measures and tolerable limits are therefore in general underestimated, and effective soil conservation would require more effort. However, best management and soil conservation practices, conservation tillage, mulching, direct seeding, and other practices are being implemented on larger and larger areas. Further positive development can be expected with the anticipated ban on glyphosates, which will bring fundamental changes in farming practices [49].

3 Changes in Soil Properties, Soil Compaction

Soils on farmlands are losing their structure, mostly due to intensive tillage and soil compaction. Soil compaction, caused by overuse of heavy machinery, intensive cropping, and inappropriate soil management, has been recognized as one of the major problems of modern agriculture [50]. Compaction results not only in soil aggregates deformation, but also in changes in the conductivity and connectivity of the pores. One can commonly observe the formation of dense soil layers with very low macroporosity and hydraulic conductivity in the shallow soil profile [51]. Consequently, water infiltration is reduced, and in addition this situation causes reduced gas and heat fluxes within the soil profile. In a global perspective, this can influence the global carbon and nitrogen cycles [52, 53].

3.1 Soil Structure Loss

The soil structure of arable land has a significant impact on water and soil air availability, nutrient uptake, and leaching [54]. Thereby, the soil structure indirectly affects the ground and surface water supply and water quality. The aggregation of soil particles and interconnected large pores increase the bypass flow in the soil. Healthy structured soils exhibit increased infiltration rates, reduced surface runoff, water percolating deeper into the soil profile, and usually, but not necessarily, also higher yields.

Agricultural management practices (the tillage system, crop rotation, fertilizers, etc.) can significantly impact the stability of the topsoil aggregates and soil hydraulic properties [55]. Growing crops, tillage, and subsequent reconsolidation due to natural wetting and drying cycles cause changes in the soil bulk density and porosity, the ratio of macropores, the soil hydraulic properties, the surface roughness, or the depression storage of rainwater. The stability of soil aggregates is maintained mainly by the organic matter content, the clay content, iron oxides, and biological activity [56].

A decline in the soil organic matter (SOM) and the microbial biomass in the topsoil has been considered a major agronomic and environmental problem, mainly due to its negative impact on soil properties [17, 57]. Several studies based on long-term monitoring of SOM on various soil types in the Czech Republic indicate a lower current SOM content with worse qualitative parameters than decades ago [58–61]. The SOM decline is attributed mainly to tillage, to the intensification of farming, and to reduced application of manure due to the reduced numbers of livestock (as shown in Fig. 6 in the next section). Bednář and Šarapatka (2018) showed high SOM losses on drained fields and on parcels affected by water erosion [62]. Soil type and the farmer's attitude are also significant factors for loss of SOM, as shown by [63]. Farmers often do not treat soil in a sustainable manner, because they usually do not own the parcels nor have a long tenure contract. As was noted earlier, farming of leased farmland is widespread in the Czech Republic, and a lack of a sense of responsibility for the soil is therefore often a problem.

There have been several research activities related to the soil physical properties of farmed soils in the Czech Republic. The effects of different soil and agricultural management on soil structure and soil hydraulic properties were analyzed by means of long-term monitoring and numerical modelling on Luvisol at the Hněvčeves experimental station (maintained by the Crop Research Institute in Prague) [55]. These studies showed that land use significantly influences the soil hydraulic properties in the upper part of the soil profile (A and Bt1 horizons, down to a depth of approximately 60 cm). Soil water retention and near-saturation hydraulic conductivity were higher in a soil profile with grassland compared to a soil with periodic tillage. Seasonal variability of soil bulk density, saturated water content, and unsaturated hydraulic conductivity were analyzed by Zumr et al. [64] on the Nučice experimental site. The soil water holding capacity generally decreased during the vegetation season as a result of the rainfall kinetic energy, poor soil structure stability, and a compacted shallow plough pan which caused frequent topsoil saturation.

A study by Podrázský et al. [65] proves a positive effect of the minimum tillage system on the soil aggregate stability, especially in the case of maize. A change of land use, such as afforestation or conversion of farmlands to grasslands, is a way to improve the soil water regime of degraded soil. However, the previous land use continues to affect the soil properties for many years, and the imprint of arable soils can prevail even 30 years after a change [44].

A poor soil structure accelerates other soil degradation processes. Agricultural uplands are very susceptible to soil water erosion when they are tilled repeatedly and are left without a protective cover. Erosion tends to preferentially remove low density or light particles, including both clay and soil organic carbon, which are two of the primary bonding agents in the aggregation process [66].

3.2 Soil Compaction

Approximately 38–45% of the Czech farmlands are negatively affected by topsoil and subsoil compaction [67]. This makes compaction, together with soil erosion, loss of organic matter and soil sealing, one of the most prominent soil degradation processes. The consequences of excessive soil compaction are very serious, as the most-affected soils are very fertile [68].

Less than 30% of the threatened soils are vulnerable to the so-called pedogenetic compaction, and more than 70% are vulnerable to the so-called technogenic compaction (VÚMOP 2021). Pedogenetic compaction arises during the formation of whitish illuvial or gley layers and is therefore typical for soil profiles with a comparatively high clay content. Technogenic soil compaction, resulting from mechanical pressure caused by field trafficking by agricultural machines, is dangerous mainly due to the possibility that it can occur in soils of any textural composition [69]. Current over-compaction has been caused mainly by excessively intensive farming in recent decades, mainly disproportionate doses and an incorrect assortment of mineral fertilizers, an insufficient supply of organic matter, and the use of heavy machinery. Conservation and minimum tillage technologies are the main practices in the Czech Republic, while direct seeding is marginal. Livestock trampling causes problems only locally on pastures. Kroulík et al. [70] showed that the ground area percentage that is trafficked at least once in a year is almost 90% for conventional tillage and 72% for conservation tillage [70]. Direct seeding technology requires approximately one half of the trafficked area. Controlled traffic farming with a fixed track system, which has been introduced on many farms, reduces the trafficked area to nearly 30% [71].

In general, soil compaction tends to be a more serious problem for soils with a high clay content [62]. At present, the situation is more complicated, as the long-term degradation has resulted in compaction in subsoil horizons which is very persistent and cannot be removed easily. So far, only minimal attention has been paid to finding an effective solution to this serious issue in agricultural enterprises. Compacted soils exhibit low infiltration capacity and water retention, reduced biological activity due to worse aeration and thermal regimes, higher bulk density, limited effective depth of the soil profile, fast soil drying, fast runoff, and often waterlogging. The direct consequences are increased power consumption during tillage, impaired nutrient utilization by plants, lower quality and a lower amount of yields [68].

A comprehensive study of the compacted subsoil layer and its spatial homogeneity was carried out by Jeřábek et al. [51] at the Nučice experimental catchment. The research was based on a combination of direct soil sampling, mechanical penetration resistance monitoring, geophysical methods (shallow electrical resistivity tomography), and remote sensing (delineation of wheel tracks). The measurements showed that the plough pan was homogeneous in a large part of the catchment, and its mean depth was between 11 and 14 cm (Fig. 5). Zumr et al. [72] showed by means of rainfall runoff monitoring and numerical modelling that the shallow plough

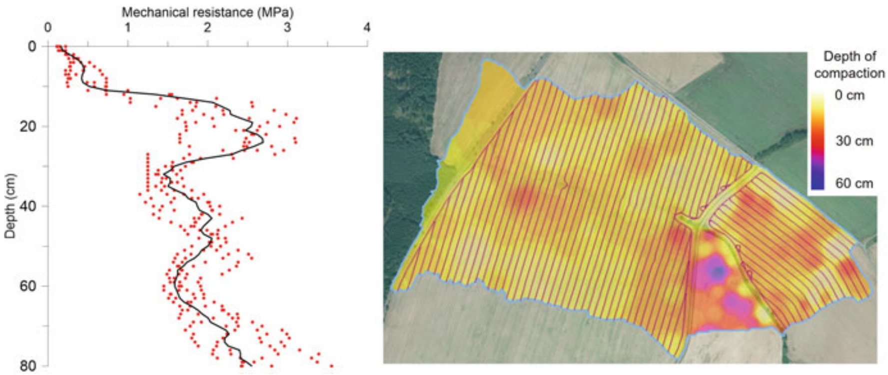

Fig. 5 Mechanical resistance against penetration at one of the observation points in the Nučice catchment. The red dots represent single measured values, and the black line shows the average resistance depth profile (left). The map of the plough pan position was reconstructed on the basis of over 100 measured soil profiles. The lines represent the wheel tracks which are mostly followed during trafficking (right), based on [51]

pan can explain immediate response to intense rainfall and the low soil water retention capacity of the Nučice catchment [73].

4 Soil Contamination

Pollution by various contaminants may cause disturbances in the functioning of the soil ecosystem and presents a risk to humans and to the environment. The main contaminants in the Czech soils are potentially toxic elements (PTASs) and man-made organic chemicals (xenobiotics), such as synthetic pesticides, dissolving agents, hydrocarbons, and drugs. The chemical elements of greatest concern are arsenic, cadmium, nickel, lead, and chromium. In most cases, soil contamination does not cause diffuse pollution, and the contaminated sites are usually small and disconnected. The most-affected areas are those with heavy industry and mining activities (West Bohemia, North Moravia) [17] and areas with high transportation (Prague and its surroundings) [74, 75]. Soils are locally also contaminated in the alluvial plains, due to occasional inundations containing wastewater [76]. Sewage sludge has only rarely been deposited or added to arable soils, as there are strict limits on its chemical composition. Contamination of the surrounding soils from modern landfills has also not been a serious problem [77].

The maximum tolerable values of risk elements and persistent organic pollutants are set in the Czech legislation [17, 78]. Since 1992, arable soils have been regularly tested for agrochemicals and hazardous substances within the Basal Soil Monitoring System organized by the Central Institute for Supervising and Testing in Agriculture (UKZUZ). The results of the monitoring, which has taken place within the area of the whole Czech Republic, show that the limiting values are only rarely (in approximately 1% of the samples) exceeded for cadmium and for arsenic [79], while the remaining tested elements exceed the limits even less often. The limits for the tested organic pollutants (mono and polyaromatic hydrocarbons, PCB, HCB, DDT, styrene, PCDD, and PCDF) were also exceeded only in exceptional cases [18, 78]. Long-term monitoring has not proven any significant temporal trends in soil contamination [66, 80, 81]. Nevertheless, a small number of hotspots remain where soils are strongly contaminated, mainly due to mining activities, industry, or historical landfills [82].

A present-day problem of Czech arable soils is insufficient manuring and unsustainable overdosing of agrochemicals, namely pesticides, herbicides, and mineral fertilizers. The main reason for the manure deficit is a dramatic decrease in livestock production, especially of cattle (Fig. 6). Central Institute for Supervising and Testing in Agriculture of the Czech Republic estimates that due to the lack of organic matter in arable soils, which is being recompensed with fertilizers, the soils will require at least 30 years to recover their function in the ecosystem [83]. In recent years, the average annual fertilizers consumption has been around 130–140 kg ha^{-1} of mineral fertilizers (approximately 75% of which is nitrogen, 15% is phosphorus, and 10% is potassium) and 2 kg ha^{-1} of pesticides (Czech Statistical Office). The statistical data show that the consumption of plant protection products has been declining in recent years, mainly due to lower application of glyphosates [84]. Nevertheless, pesticide residues in arable soils continue to pose an environmental threat,

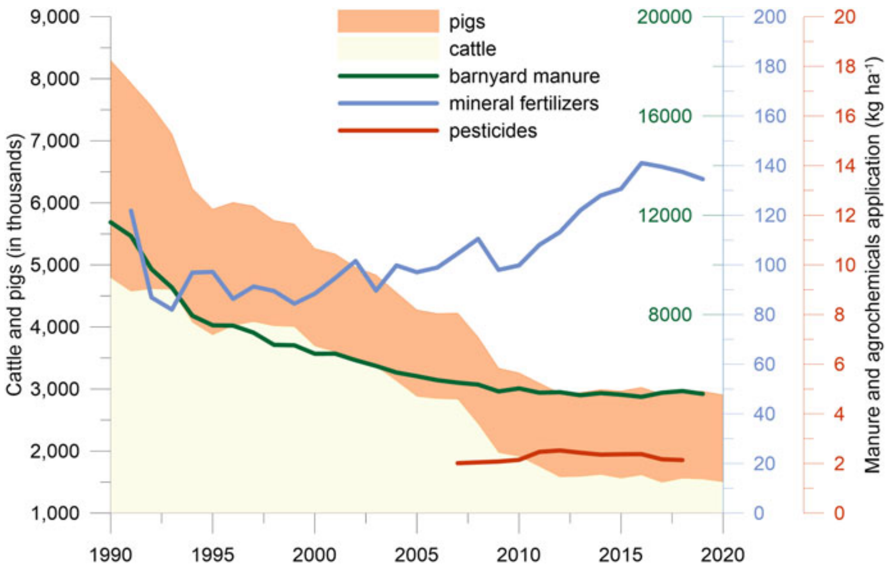

Fig. 6 A decline in numbers of livestock and available barnyard manure has resulted in increased application rates of mineral fertilizers (mainly N, P, K). Data for pesticides is not available for the period before 2006. The consumption of pesticides has decreased slightly in recent years (source of data, Czech Statistical Office, UKZUZ)

especially in the case of triazine and conazole fungicides [85]. In addition, residues of organochlorinated pesticides, which have not been applied since the 1990s, still persisted in the topsoil layers [86]. Pesticides can be transported by infiltrating water into deeper horizons, especially in soils with a heterogeneous structure with the presence of preferential flow [87].

A comprehensive analysis of the current situation and spatial and temporal trends of pesticides in the topsoil has been presented by Kodeš [88]. The study is based on the monitoring period of 2014–2017. Samples from 34 different localities with various soil types were analyzed for 64 currently-used fungicides and insecticides, including conazole and triazines, and recently-banned pesticides (e.g., atrazine, acetochlor, and linuron). The intensive use of protecting agents has resulted in their frequent and widespread occurrence in soils, both for currently-used products and for recently-banned products (and their transformation products). The highest numbers of pesticides have been observed on fields where rapeseed and wheat were cultivated (these are the most widely-grown crops in the Czech Republic). Kodeš [88] pointed out that glyphosate, which is of environmental concern and is applied in large doses, has not been evaluated within this study. In 2014–2019, monitoring performed by the Czech Hydrometeorological Institute detected above-limit concentrations, mostly of metabolites of herbicides, in approximately 30% of groundwater samples. Most of the affected samples were collected in the vicinity of fields with rapeseed planted for biofuels [89–94].

The problematics of veterinary and human pharmaceuticals in soils, their sorption characteristics, degradation rates, leakage to groundwater and root uptake by crops has been studied on Cambisols, Chernozems, and Luvisols [91]. The results show that the pharmaceutical persistence is mostly dependent on the soil type and that the sorption of pharmaceuticals generally decreases with depth [89]. Lower dissipation rates were calculated for soils with a well-developed structure, a high nutrient content, and good biological activity, such as Chernozems [95, 96].

5 Microplastics in Soils

The degree of contamination of soils by microplastics (MPs) is comparable to that in neighboring countries, but there has yet not been any published research that provides a quantitative analysis of the amount of microplastics in the Czech soils. The main sources of plastics on agricultural soils in the Czech Republic are most likely transportation (abrasion of tires) and plastic wastes from agriculture activities (remains of plastic bags, foils, straps, etc.). On some farmlands, where plastic mulching and protection nets are being applied, typically in vegetable or potato production, or in orchards, degraded plastic particles and macroplastics can be found in higher quantities, but this has been evaluated only visually so far.

Microplastics have been found in sludge from wastewater treatment plants and even in treated water. Pivokonsky et al. [97] analyzed water samples of untreated and treated water and showed that the concentration of MPs was approximately 83%

lower in the treated water compared to the raw wastewater [97]. Interestingly, even treated potable water had a rather high MPs concentration of 338 to 628 particles per liter. It should be pointed out that MPs from 1 μm in size were counted, which explains why such a large number of particles were observed. Further relevant research on MPs in the aquatic environment has been carried out by a team from the Institute of Hydrodynamics of the Czech Academy of Sciences. The research has been focused on drinking water and has produced promising results which indicate that the current treatment technology is capable of removing most of the MPs [98, 99]. It can therefore be concluded that a considerable proportion of the trapped MPs (difference between the microplastics amount in the raw and the treated water), which were mostly PET, PP, and PE fibers and fragments below 10 μm in size, most likely ends up in the sludge. Fertilization with sludge is currently not widespread, due to current legislation which sets strict limits on the composition of sludge. However, there is a prospect that sludge will soon be utilized more often as a way to enrich soils with organic matter. Sludge will then become another potential source of microplastics in soils.

Currently, a new research project is starting within the framework of the EU ITN Marie Sklodowska-Curie program entitled “Macro and microplastics in agricultural soil systems.” The Czech Technical University in Prague will be evaluating MP fluxes from arable fields into surface waters.

6 Effects of Fires

Although wildfires are a natural phenomenon, their main cause in populated landscapes is human activity [100–102]. In Europe, 97% of forest fires of known origin within the period from 2006–2015 were directly or indirectly caused by humans. Similarly, the majority of recent wildfires in the Czech Republic were caused by humans [103]. The distribution of wildfires in the landscape is influenced by ignition triggers and also by environmental factors of both anthropogenic and natural origin. The presence of humans in the landscape usually serves as an ignition trigger, while environmental factors influence the probability that a wildfire will occur (Table 1). The environmental factors can be biotic, such as the vegetation cover influencing the fuel type, load and flammability, or abiotic, such as climate, topography, or soil types, which influence the moisture of the fuel and the spread of the fire. Anthropogenic factors influencing fire occurrence can be socio-economic, such as population density or the rate of unemployment, as well as socio-environmental, such as land use [104]. However, the effect of each of these factors on fire incidence varies among habitat types and depends on the temporal and spatial scale, as, for example, climatic variables usually operate on a scale that is broader than regional [105].

In the Czech Republic, the issue of wildfires and their influence on the soil, on human health, and on ecosystems is likely to grow in importance due to the climate change. The Czech Republic has a fragmented terrain and a dense network of forest paths, making it an area where forest fires seldom cause catastrophic damage.

Table 1 Statistics on forest fires in the Czech Republic in the last 10 years, which shows a generally positive correlation between the occurrence of wildfires and the mean temperature [107]

Year	Mean annual temperature (°C)	No. of forest fires	Burned area (ha)	Casualties	Injuries
2010	7.2	732	205	1	21
2011	8.5	1337	337	1	27
2012	8.3	1549	634	2	30
2013	7.9	666	92	0	7
2014	9.4	865	563	2	10
2015	9.4	1748	344	1	33
2016	8.7	892	141	0	6
2017	8.6	966	170	2	9
2018	9.6	2033	492	0	35
2019	9.5	1963	NaN	0	32

Because of this, the role of forest fires in local ecosystems was marginal in Central Europe in the past [106]. However, it has been proved that wildfires have affected the long-term development of forests even in the area of the Czech Republic [100]. The causes of forest fires in the Czech Republic have been analyzed by a small number of authors. The number of forest fires varied between 444 and 1,398 per year in the period from 2006–2018, with an average number of 725 per year. The burned area is usually not large, usually around 0.35 ha, and about 70% of all forest fires affect an area smaller than 0.05 ha. The incidence of forest fires in the Czech Republic is not uniform. In some municipalities no single forest fire was reported within a one-year period, while other municipalities reported more than ten forest fires [107].

Although forest fires are usually emphasized in the scientific literature and in the media, fires on agricultural fields have had a higher economic impact in recent years in the Czech Republic. The fires mostly occur during the hot and dry summer months during the harvest, and the fire is usually caused by contact between the harvester and stones on the soil surface. The fires damage the crops and reduce the yields significantly. In addition, expensive machinery is often damaged beyond repair in the fire. According to the Fire Rescue Service Statistical yearbook, there were over 600 fires in agricultural areas and nearly 2,000 fires in forest areas in 2019. Approximately 60 major fire events were recorded in 2019, which caused damage exceeding 10 million Czech crowns (EUR 400,000). One of the fires broke out on grassland, 11 in forests, and five were related to agricultural activities. 140 cases of self-ignition of agricultural crops occurred in 2019 [108].

Until now, little has been known about the consequences of fires on tilled soils and on the water regime, including the transport characteristics of various chemical components (such as PTEs, pesticides, fertilizers) in Czech conditions. The increased fire risk highlights the need to understand the processes occurring after a fire in terms of the changes to vegetation dynamics, soils, and water. In the Czech Republic, there is no data on post-fire contaminants and little attention has been paid to the long-term effects of fire, especially the effects on solutes and associated pollutants. The effectiveness of post-fire rehabilitation treatments is highly relevant in this context. Research projects funded by the Ministry of Youth and Education and by EU COST Action have recently started to study the effects of wildfires on agriculture soils and grasslands (Fire effects on soils, https://starfos.tacr.cz/cs/project/LTC20001, viewed December 2022).

The risks related to fires in forests, grasslands, shrublands, and croplands are expected to increase due to key factors: (i) the expansion of forests as a result of land abandonment and afforestation; (ii) the increase in fuel load and fuel continuity due to reduced land management; (iii) greater ignition potential due to population growth at the urban/rural interface; (iv) climate change, which will induce higher temperatures, increased wind speeds, an increased probability of prolonged dry periods affecting vegetation flammability [108]; (v) the growth of urban areas located closer to the land; and (vi) intensification of agriculture and harvesting during very dry conditions.

7 Conclusions

Overall, soil degradation is usually a result of more than one degradation process. It is often not possible to assess what degradation factor is the primary cause and what is the consequence, e.g., in the case of soil erosion and low organic matter content. The impacts of unhealthy soils are vast, ranging from biodiversity issues to groundwater quantity and quality. Soil sealing is another important problem for which inappropriate urban and landscape planning is mainly responsible. Soil degradation must therefore be regarded as a complex problem with multiple variables that involve many disciplines (including economics and ecology).

Farmers in the Czech Republic are aware that degraded soils pose a long-term threat to their livelihood. Many farmers have already encountered problems such as reduced yields due to lower amounts of precipitation, and decreased soil water retention capacity, difficult soil tillage and manuring, higher wear of machinery during dry soil cultivation, pests, water and wind erosion, difficulties in estimating the dosage of fertilizers and pesticides in uncertain weather conditions, etc.

The literature review presented here and also many research project reports, guidelines, methodologies, tools, NGO initiatives and politically-oriented activities, which are not fully listed in this chapter, suggest the following specific measures (in line with best management practices), which have a strong potential to slow down soil degradation and result in a more sustainable way for farming in the Czech Republic:

– To increase the soil organic matter (SOM) content in soils. SOM improves the soil structure and the stability of soil aggregates, and therefore reduces the vulnerability of the soil to erosion and improves the soil water regime. The optimal solution is high-quality barnyard manure. Compost, crop residues, and

green manuring are also very beneficial. First and foremost, however, the existing SOM must not be depleted.
– Providing support for small farms with sustainable livestock breeding.
– To change the landscape pattern toward higher spatial fragmentation, with smaller fields and with more small-scale landscape features to increase the ecological stability and the biodiversity of the landscape. A functional landscape will provide ecosystem services such as protection against wind and water erosion, better soil health, rainwater retention and purification, groundwater recharge, and many others.
– Seed catch crops and apply mulching.
– Using soil conservation tillage with a reduced number of passes, controlled trafficking and working soil at the optimal soil moisture. Apply occasional deep soil ripping to at least 40 cm to remove subsoil compaction. Reduce the use of pesticides.
– Providing support for organic farming and agroforestry, which usually results in higher biodiversity and more sustainable agriculture providing beneficial ecological services.
– To ensure sustainable urban growth

Although the current soil status may not look optimistic, there have been many examples of positive practices and trends. The public is aware of the situation and is concerned not only about food quality, but also about the impacts of agriculture on the environment. Organic food and products of local sustainable agriculture are becoming more and more popular. The state legislation follows the European agriculture framework, and stricter limits are expected on pesticide application and on large monoculture fields. We may therefore hope that the trend in the soil quality indicators will follow the air and surface water markers, which have been improving in recent decades.

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