Summary

Mining for fossil fuels and minerals is a major global economic activity that generates spoil heaps, deep excavations, mine subsidence, and open-cast pits. Despite a growing shift toward renewable energy in the energy mix, spoil heaps still cover over 1% of the Earth's land surface and remain a significant reclamation challenge. Carboniferous rock spoil heaps are widespread in Upper Silesia, forming a dominant feature of the region's coal mining landscape. While these sites pose environmental risks, proper reclamation can transform them into novel ecosystems capable of providing essential services such as carbon sequestration and water retention. The primary objective of this study was to assess the effects of reclamation methods and vegetation types on carbon sequestration and water retention potential in soils of post-mining ecosystems developed on Carboniferous rocks and post-hard coal mine. This was achieved through (i) a critical literature review and (ii) four research studies publish in the international journals. The studies were conducted at the Sośnica hard coal spoil heap in the Upper Silesian Coal Basin, Southern Poland. The review revealed that soil organic carbon (SOC) accumulation in reclaimed mining soils (RMS) was primarily influenced by restoration age, vegetation type, and reclamation technique. Field research demonstrated that topsoil application significantly altered soil properties and organic matter fractions compared to unreclaimed sites. Sites reclaimed with topsoil (RTS) exhibited higher bulk density (BD) and reduced porosity relative to succession on bare-rock (SBR) sites. However, RTS sites achieved substantially higher stocks of SOC and total nitrogen (TN). Furthermore, RTS enhanced the occluded light fraction (C_{oLF}) and mineral-associated carbon fractions (C_{MAF}) in the topsoil (0–10 cm), suggesting improved carbon stabilization in surface layers. In contrast, SBR exhibited higher C_{MAF} in the subsoil (10–20 cm), likely due to the influence of geogenic parent material. Vegetation type further influenced soil properties and SOC dynamics. Grassland and forbland vegetation reduced BD while increasing porosity and capillary water capacity (CWC) in the topsoil compared to woodland. Conversely, woodland displayed lower BD and higher porosity and CWC in the subsoil. Grassland and forbland also enhanced simulated total soil water storage (SWS in mm in 0-20 cm soil layer) relative to woodland. Woodland and forbland communities on reclaimed sites significantly influenced on increasing SOC and TN stocks in the topsoil, although more effectively than natural succession on bare Carboniferous rock. Under woodland, in particular, litter layer accumulated more SOC and TN than soil under grassland and forbland. Additionally, grassland contributed to higher C_{oLF} and C_{MAF} at both soil uppermost layers (depths 0-10 and 10 – 20 cm) compared to forbland and woodland, meanwhile forbland exhibited greater C_{oLF} in 10-20 cm soil layer, than woodland. Therefore, based on the results obtained, it was concluded that grass and forbs vegetation clearly influence carbon stabilization in the developing soil organic matter of the topsoil. Finally, remote sensing and topographic indicators facilitate scalable monitoring of SOC, TN, and SWS, with SOC distribution correlating with the digital terrain model, TN with near-infrared reflectance and NDVI, and SWS with the topographic wetness index and canopy height model, as well. General conclusion demonstrate that grassland and forbland vegetation optimize soil water retention, porosity, and SOC stabilization in uppermost post-mining soils. Moreover, combining topsoil application with woodland cultivation enhances SOC stocks in the litter layer and topsoil, offering a balanced strategy for post-mining soil restoration. The results enable the development of a sustainable reclamation strategy incorporating a mosaic of vegetation types, spontaneous succession, and topsoiling methods. They also permit leaving Carboniferous rocks without mineral soil cover where suitable reclamation substrates are lacking (the so-called soil-less method). In such cases, the additional economic benefits of reclamation could also be significant.

Keywords: coal mining, spoil heap, reclamation, topsoil, succession, soil organic carbon, organic carbon stabilization, water retention, ecosystem services

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