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THE IMPACT OF LAND SET-ASIDE ON THE CHEMICAL AND PHYSICAL PROPERTIES OF THE SOIL AND THE COMPOSITION OF VEGETATION SPECIES. CASE STUDY

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Summary

The study aimed to evaluate the effect of soil use in the Młoszowa and Bolęcin villages on the species composition of the overgrown vegetation. Additionally, the study compared the chemical and physical properties of the soils that were not being used for agriculture. The soils of Młoszowa and Bolęcinvillages did not exceed the permissible concentrations of copper, lead, and zinc for agricultural land, as outlined by the national regulations in [Journal of Laws 2016]. In Młoszowa, the concentration of cadmium exceeded the limit values as per national regulations in [Journal of Laws 2016] for agriculturally utilised land (land group II-2) ($<3 \text{ g} \cdot 10^{-3} \cdot \text{kg}^{-1}$ DM). The set-aside of both villages consisted of species typical of ruderal areas, fresh grassland, and thermophilous species. The granulometric composition of the soils, mainly their silt and sand content, were the primary factors that impacted the species composition of the set-aside vegetation. Ruderal and thermophilous species were discovered in the set-aside areas, which are their natural habitats. The occurring ruderal plants typical of post-mining heaps and post-industrial areas, including hemicryptophytes, testify to the long-term process of fallowing and adaptation to the existing ecosystem with a predominance of the most common species.

Keywords

soil • land set-aside • heavy metals • vegetation

1. Introduction

Set-aside land refers to areas of land that have not been cultivated for a significant period of time and have been subjected to natural succession of vegetation. These areas may have become overgrown with weeds and undergone extensive sodding or shrubbery [Janicka 2021, Golonka and Świętochowski 1950, Świętochowski et al. 1996]. Within the European Union, the term 'land set-aside' refers to the temporary exclusion of agricultural land from cultivation [www.cie.gov.pl]. Most authors associate setting aside with the process of soil and agro-environmental degradation. However, it is difficult to identify a regular pattern of its development as its dynamics can be diverse. The nature and extent of development patterns depend on the purpose of the set-aside, the type of conservation system, the level of agrotechnics applied, the genesis of the soil, the soil type, the initial condition of the soil characteristics and agronomic category as well as the diversity of vegetation species covering it [Marks et al. 2000a, Marks et al. 2002a, Podstawska-Chmielewska and Kurus 2007]. The primary effects of set-aside induced degradation include a decrease in both organic carbon content and alkaline cation content within soil sorption complexes [Malicki and Podstawska-Chmielewska 1998, Chudecka and Tomaszewicz 2004]. Some authors hold the opposing stance, claiming that the set-aside does not cause deterioration of the soil environment, but instead raises pH value of the soil, increases the amount of organic compounds and mineral elements present in the soil, and enhances the degree of saturation with alkaline of the sorption complexes, thus enriching the soil condition and quality [Sienkiewicz et al. 2003, Wojnowska et al. 2003]. Without definitively resolving the divergence of researchers' opinions mentioned previously, it should be acknowledged that the undeniable changes in the biological characteristics of soil are highly observable during extended periods of land being set aside. In the early years, the dehydrogenase activity in the soil remains markedly high, particularly in land set-aside compared to agriculturally utilized areas. This could be attributed to the rapid changes in physical and trophic factors of the microenvironment. However, this activity declined in the succeeding years [Martyn et al. 1998, Dzienia 1998]. There is an evident decrease in the values of dynamic balances of organic matter decomposition caused by the reduced supply of building material that is the quantity of aerobic microorganisms due to changes in soil surface relations. This has an impact on the humus content of the soil, specifically the fractional composition of humic acids, and the mobility of microfauna in the soil profile. This process takes place to varying degrees of intensity in heavy and light soils [Malicki and Podstawska-Chmielewska 1998, Marks et al. 2000a, Marks et al. 2002a].

2. The impact of the set-aside on soil physical and chemical properties

The process of set-aside formation typically has a positive impact on the physical properties of the soil, in particular, its air-water properties. These changes are noticeable immediately after the soil is loosened through agrotechnical operations [Krężel 1990, Rola 1993]. A decrease in field air capacity and soil density is visible during this period, while the water capacity and the total porosity increase. The water and humus management of the soil environment remains at a much higher quality level on uncultivated fallows than on those cultivated in the rotation system or black fallows [Kutyna and Niedźwiecki 1996, Ignaczak 1998, Strączyńska and Rola 1998, Słowińska-Jurkiewicz et al. 1999]. However, it is crucial not to disregard other serious risks, such as the reduction of fertility in land set-aside and adjacent areas due to the growth of weeds and trees [Marks et al. 2000a, Marks et al. 2002a]. During the formation of set aside, the chemical properties of the soil are also altered, leading to an increase in soil sorption acidity on the one hand, and a decrease in plant uptake of micro- and macro-nutrients as the supply of nutrients to the soil ceases. Initially, there is an increase in nutrient content, particularly ammonium nitrogen in the lower soil layers, due to the conversion of nitrate to ammonium. This reduces the overall porosity of the soil. Nitrate contaminates deep waters as it can easily migrate between layers and thus increase the leaching process. There is little fluctuation in pH [Koc et al. 1996, Dzienia et al. 1997, Sienkiewicz et al. 1998, Marks et al. 2000a, Marks et al. 2002a].

3. The impact of the set-aside on the phytocenosis

Set-aside is associated with significant changes in the phytocenosis. Although these changes are mostly negative for agriculture, they are not necessarily detrimental to the grassland ecosystems themselves. The extent and direction of these changes are highly dependent on the habitat conditions of the community and the quality and scope of the agrotechnology employed prior to the set-aside. Specifically, these changes mainly affect the orderly progression of the flora corresponding to the habitat type. Scrub communities develop on heavy and poor soils, while boron communities thrive on light soils [Domańska 1997, Malicki et al. 2002, Kryszak et al. 2007]. In addition, these changes could result in the establishment of new syntaxons, woodland-scrub communities, second-growth vegetation, or the reappearance of communities previously lost through agricultural practices in the affected regions [Łabza et al. 2003, Zawieja 2007]. The land set-aside is primarily subject to a process of gradual overgrowth by a variety of weed species, particularly field weeds, often closely related to the species and dependent on the farming technique of the last crop grown on the land, followed by shrubs and trees. Spontaneous and uncontrolled growth of weeds, particularly anemochorous species such as common dandelion (*Taraxacum Officinale*), sow thistles (*Sonchus*), and creeping thistle (*Cirsiumarvense*), poses a substantial threat to the crops of nearby fields. The seeds of these plants, dispersed by the wind, have an advantage over numerous crop species due to their high fertility. Without competition from other crops, weeds can successfully complete their development cycle and effortlessly spread their seeds to adjacent land. In the first three years of land set aside, a wide range of species begin to grow, with annual weed species being the most prevalent [Majda 1997, Hochół et al. 1998]. Eventually, annual species give way to segetal perennial and ruderal species. The number of apophytes and species within the *Poaceae* family begins to rise, demonstrating a clear correlation between the duration of the set-aside and the increase in the number of perennial weed species. The authors also note that crop agrophages can spread through weeds, thus creating an opportunity for weed infestations [Malicki and Podstawska-Chmielewska 1998, Marks et al. 2000a, Marks et al. 2002a]. In consequence of the resumption of agricultural activities, the set-aside land will not only host cultivated crops , but also be plagued by weed invasions associated with the pests typical for a given crop, and in consequence hindering agrotechnical operations. For instance, the sugar beet aphid is a pest of sugar beet that feeds on weed species belonging to the *Chenopodiaceae* species causes significant damage [Rola and Rola 1998, Niedźwiecki et al. 1998, Ziemińska-Smyk 2000, Kostuch et al. 2004].

4. Material and methods of research

The study investigated soils that were excluded from agriculture and hosted diverse species composition. The municipality of Trzebinia was selected for the research site, with two villages, Młoszowa (comprising of 10 study plots) and Bolęcin (comprising of 6 study plots), as the primary focus. A representative, homogeneous sample of vegetation from a given plant community (phytocenosis) was chosen. The plots belonged to the land set aside that used to be arable land in the 1980s. This was determined through the analysis of topographic maps at a scale of 1:10000. The phytosociological photographs were employed to assess the species composition of the plots, using the Braun-Blanquet method [Dzwonko 2007, Wysocki and Sikorski 2002]. Layer C of the plant community, namely the green layer, was examined. This involved identifying all plant species within this layer and estimating vegetation coverage based on the modified Braun-Blanquet scale. Each plot was sampled to collect soil from the depth of 0–40 cm. The soil samples were tested for: granulometric composition using the Casagrande method adapted by Prószyński [applying BN-78/9180-11], pH in 1M KCL and H_2O, electrolytic conductivity applying the conductometric method, soil organic matter content employing the Tiurin method, and soil Cd, Pb, Cu and Zn content using the FAA method.

5. Research results and discussion

In the village of Bolęcin, the mean percentage of organic matter in the soil amounted to 2.77%, compared to 2.30% in Młoszowa. The pH values recorded in both villages indicated slightly acidic soil. The mean soil pH values in Bolęcin (Table 1) and Młoszowa (Table 2), determined in water, were 6.72 and 6.34 respectively. The content of organic matter is the key factor that influences the level of pH in the soil, which in turn impacts the solubility of heavy metals in the soil environment and, consequently, the bioavailability of elements to plants [Mercik and Kubik 1995, Kwapisz and Gworek 2000, Wiater 2008, Józefowska 2009]. An increase in the organic matter content and pH values reduces the transfer of metals in the soil solution to plants. This leads to an increase in their concentration in the soil environment, while decreasing metal accumulation in plants. On the other hand, low humus content and acidic soil reactions enhance the mobility of elements in the soil solution and their phytoavailability to plants [Łabętowicz and Rutkowska 2001, Terelak and Tujaka 2003, Martyn and Niemczuk 2009]. In the granulometric composition of the Bolęcin village soils, loose, loamy, and slightly loamy sandy soils prevail. In only one study plots it was found that the proportion of individual fractions indicated the presence of heavy clay soils. The mean percentage content of the sand fraction was 77.5%, the silt fraction 11.5%, and the clay fraction 11% (Table 1). The soils in Młoszowa consist mainly of sandy, silty, and loamy soil types such as sandy silt, loose loamy sand, loose sand, clayey loam, and light loam. The mean percentage content of the sand fraction was 64.07% (Table 2). The mean electrolytic conductivity of the soil was 153.83 $\mu S \cdot cm^{-1}$ in Bolęcin and

115.04 μS · cm^{-1} in Młoszowa (Table 1 and Table 2). High concentrations of soluble salts significantly inhibit or even prevent plant growth, reducing water and nutrient availability and causing morphological changes such as growth inhibition, shoot dwarfism, and sprout damage [Munnas 2002, Gołda 2005, Koncewicz and Lewak 2007]. The literature indicates that natural soil salinization is rare in the climate of Poland. Soil salt excess is generally associated with the effects of environmental anthropogenisation, especially in areas of furnace and metallurgical waste exploitation, soda industry waste dumps, and lignite and hard coal mining [Siuta 1995, Kozłowski et al. 2004, Zimny 2005].

Table 1. Basic statistics of heavy metal content in soil and selected soil parameters in samples from the Bolęcin village

Parameter		Average	SD (standard deviation)	Median	Max
Organic matter [%]	0–40 cm	2.77	2.17	1.93	6.99
Heavy metal in soil 0–40 cm [mg · kg^{-1}]	Cd	1.65	0.43	1.71	2,11
	Pb	44.20	4.43	44.14	50.03
	Zn	171.25	73.15	176.78	282.72
	Cu	6.42	2.49	5.93	10.40
pH	in water	6.72	0.54	6.60	7.4
	in KCl	6.03	0.74	6.10	6.8
Electrolytic conductivity [μS · cm^{-1}]		153.83	138.62	116.0	409.00
Average share of fraction [%]	sand	77			
	silt	11			
	clay	12			

In the Bolęcin village, the cadmium concentration in the soil from the examined site remained below the permissible concentrations for arable land (land group II-2) according to national regulations [Journal of Laws 2016], with values not exceeding 3 g · 10^{-3} · kg^{-1} DM for this element. The mean lead content in the soil sample collected from the research plot did not exceed the permissible concentrations regulated by the national standards [Journal of Laws 2016] intended for arable land (land group II-2) (<250 mg · 10^{-3} · kg^{-1} DM). Past exploitation of clay in Bolęcin, for chemical and construction raw materials, does not currently lead to toxic cadmium levels in the soils of these villages. The mean cadmium content in soils used for agriculture in the Małopolskie voivodeship is at the level of 0.57 mg · kg^{-1} DM, compared to the 0.21 mg · kg^{-1} DM for Poland [Terelak et al. 2000, Terelak et al. 1998]. The former extraction of clay in Bolęcin, for chemical and construction raw materials, along with the presence of active solid and liquid fuel dumps in the area, currently has no impact on the toxic lead content of the soil in this village. The amount of lead in the geochemical background of agricultural soils in Poland was set at 14 mg · kg^{-1} DM by Terelak et al. [1995], while Czarnowska [1996] determined it to be 9.8 mg · kg^{-1} DM. In the Bolęcin and Młoszowa villages (Table 2), the mean zinc content in the soil in the field sample did not exceed the permissible concentrations of the element based on national regulations [Journal of Laws 2016] for arable land (land group II-2) (<500 mg · 10^{-3} · kg^{-1} DM). Curzydło [1995] asserts that the proximity to the sources of zinc pollution emissions has no influence on the accumulation of the metal in soils. Zinc-contaminated soils may not necessarily be located in the nearest zone of influence from the emitter. According to a study by Gambuś [1993], the mean concentration of the metal in the soils of the former voivo-deship of Krakow amounted to 87.1 mg · kg^{-1} DM. Terelak et al. [1995] identified the geochemical background for zinc in Polish agricultural soils within the range of 7–40 mg · kg^{-1} DM, while Czarnowska [1996] – within the range of 5–59 mg · kg^{-1}. In the soils of Bolęcin and Młoszowa, the mean copper content in soil samples taken from the research plots did not exceed the permissible concentrations of the element according to national regulations [Journal of Laws 2016] for arable land (land group II-2) (<150 g · 10^{-3} · kg^{-1} DM). The mean concentration of the metal in agriculturally used soils in Poland can reach 6.5 mg · kg^{-1} DM [Kabata-Pendias and Pendias 1999]. The copper content in Polish soils was analyzed by Kabata-Pendias and Pendias [2001], with values ranging from 2.2 to 211 mg · kg^{-1} DM. Excessive accumulation of this element in soils mainly concerns areas with high mining and metal smelting dominance, intensive agricultural production, and urban agglomerations affected by atmospheric dust [Wierzbicka 1995, Czamara and Czamara 2008].

In the village of Młoszowa, the cadmium content in the soil from the sample site exceeded the permissible concentration values for arable land (land group II-2) (<3 g · 10^{-3} · kg^{-1} DM) set by national regulations [Journal of Laws 2016]. Węglarz [2007] observed elevated levels of heavy metal content in soils near roads and major transport routes, especially those with heavy traffic. Cadmium concentrations in soil adjacent to motorways can reach levels of up to 10 mg · kg^{-1} DM. Terelak et al. [1995] determined a geochemical baseline for cadmium in agricultural land of Polish soils at 0.5 mg · kg^{-1} DM. Cadmium contamination of soil poses a particularly high risk to plant life as the metal easily leaches into groundwater, and plants have a high absorption capacity. Kabata-Pendias and Pendias [1999] noted that the highest concentrations of cadmium in soil occur mainly in regions with lead, zinc, and copper ore smelters and mines. Consequently, this is linked to the non-ferrous metal production and the combustion of coal. Despite historical evidence of mining for construction materials in Młoszowa, the lead content in the topsoil (0–40 cm) did not exceed the permissible concentration levels. The mean concentration of lead in the soil sample collected from the site did not exceed the permissible concentrations of this element according to the national regulations [Journal of Laws 2016] for arable land (land group II-2) (<250 mg · 10^{-3} · kg^{-1} DM). In research carried out by Gambuś [1993], the mean concentration of lead in soils within the former Krakow voivodeship did not exceed 28.4 mg · kg^{-1} DM.

Table 2. Basic statistics of heavy metal content in soil and selected soil parameters in samples from the Młoszowa village

Parameter		Average	SD (standard deviation)	Median	Max
Organic matter [%]	0–40 cm	2.30	1.2	1.97	4.44
Heavy metal in soil 0–40 cm [mg · kg^{-1}]	Cd	3.60	3.35	2.71	10.99
	Pb	79.25	71.48	59.95	224.32
	Zn	373.49	426.84	204.62	1293.30
	Cu	39.12	45.85	26.15	135.01
pH	in water	6.34	0.70	6.40	7.20
	in KCl	5.87	0.77	5.75	6.90
Electrolytic conductivity [μS · cm^{-1}]		115.04	95.08	79.60	344.00
Average share of fraction [%]	sand	64			
	silt	29			
	clay	7			

Fifty-six vascular plant species were identified in the surveyed plots in the villages. The variation in species composition between plots was considerable. None of the species in the fifth constancy class, which occur in 80–100% of the plots, were recorded. Most species were sporadic, with a frequency of occurrence of up to 20% of the plot. The species that appeared most frequently include yarrow (*Achillea millefolium*), couch grass (*Elymus repens*), false oat-grass (*Arrhenatherum elatius*), and hedgebedstaw (*Galium mollugo*) (Table 3). False oat-grass, couch grass, wood small-reed (*Calamagrostis epigejos*), tall goldenrod (*Solidago Gigantea*), and ground elder (*Aegopodium podagraria*) were the species that almost entirely dominated other species in some study plots (grade 5 on the Braun-Blanquet scale).

The vegetation on land set-aside spontaneously grows on abandoned arable areas, often consisting of expansive species with a high potential for proliferation. The composition of plant communities is influenced by numerous factors, both natural and anthropogenic. The proximity of areas serving as a diaspora source for relevant species is also crucial. Heavy metals, because of their toxicity, can play a key role in determining species distribution [Kwiatkowski et al. 2020]. In a study conducted by Becker and Brandel [2007], no correlation was noted between the species composition of the plant community and the metal concentration in the soil. However, a correlation was observed for the presence of metallophytes. The correlation between the vegetation species composition of the set-aside and the level of metal contamination in soils may be relatively weak for a number of reasons. In the case of land set-aside in the villages of Młoszowa and Bolęcin, the period of vegetation formation lasted a maximum of several decades. Normally, the adaptation of plants to elevated metal levels is a prolonged process, which can be only accelerated by intensive selection pressures such as those resulting from extremely high metal concentrations [Ernst 2006, Janicka et al. 2021]. Several studies on vegetation found in contaminated areas have indicated a significantly higher soil metal content in comparison to those found in the set-aside soils in Trzebinia. Regarding the zinc content of the soil, the results showed 171 790 mg · kg^{-1} [Wójcik et al. 2014], 8361 mg · kg^{-1} [Boularbah et al. 2006, Becker and Dierschke 2008]. The soils in Młoszowa and Bolęcin set-aside areas have higher quality, which allows for the growth of many species and reduces the harmful effects of heavy metals. The granulometric composition of the soil was the main factor influencing the species composition of the vegetation of the set-aside, with a limited selective effect of heavy metals on plants. This is supported by the work of other authors, who found that habitat characteristics typically have a greater effect on species presence than soil metal levels, particularly when contamination is not significant.

Table 3. The most common species among the set-aside plants in the villages of Młoszowa and Bolęcin – species with a constancy exceeding 35%

Species in Latin	Species in English	Stability of occurrence [%]
Achillea millefolium L.	Commonyarrow	77.1
Elymus repens (L.) Gould	Couch grass	71.1
Arrhenatherum elatius (L.) Beauv ex J & C Presl	False oat-grass	63.9
Galium mollugo L.	Hedge bedstraw	60.2
Rumex acetosa L.	Common sorrel	56.6
Dactylis glomerata L.	Orchard grass	54.2
Festuca rubra L.	Red fescue	53.0
Solidago gigantea Aiton	Tall goldenrod	53.0
Vicia tetrasperma (L.) Schreber	Smoothtare	51.8
Convolvulus arvensis L.	Field bindweed	50.6
Melandrium album (Miller) Garcke	White campion	47.0
Crepis biennis L.	Roughhawksbeard	44.6
Equisetum arvense L.	Field horsetail	43.4

Cirsium arvense (L.) Scop	Creepingthistle	43.4
Vicia cracca L.	Tuftedvetch	39.8
Plantago lanceolata L.	English plantain	38.6
Calamagrostis epigeios (L.) Roth	Wood small-reed	38.6
Poa pratensis L.	Kentucky bluegrass	38.6
Knautia arvensis (L.) Coulter	Field scabious	36.1

6. Conclusions

- Considering the results obtained regarding the mean concentrations of copper, lead, and zinc in the soil of Młoszowa and Bolęcin, it can be concluded that they did not exceed the permissible concentration of these elements for agricultural land in accordance with the national regulations [Journal of Laws 2016].
- Analysing the obtained results of the mean content of cadmium in the soils for the village of Młoszowa, it should be concluded that they exceeded the permissible concentration values of the element in accordance with the national regulations [Journal of Laws 2016] for arable land (land group II-2) (<3 g · 10^{-3} · kg^{-1} DM). Therefore, it can be inferred that the soils in the village were contaminated with cadmium.
- Ruderal, fresh meadow and thermophilous species were discovered in the set-aside areas of Młoszowa and Bolęcin. The prevalent plants consisted of typical species found in these habitats. Common yarrow, couch grass, false oat-grass, hedge bedstraw, common sorrel, orchard grass, red fescue, tall goldenrod, smooth tare, field bindweed, white campion, rough hawksbeard, field horsetail, creeping thistle, tufted vetch, English plantain, wood small-reed, Kentucky bluegrass and field scabious were predominant in the vegetation of these set-aside areas. The granulometric composition of the soil, in particular the silt and sand content, was the most important factor influencing species composition.

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