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Podzolic soils – textbook white icons or a black hole in student knowledge?

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Abstract

Podzolic soils, which cover only about 14% of Poland's land area and play a limited role in agricultural production, have attained a disproportionately prominent place in Polish school geography textbooks. Their strong visual distinctiveness, marked by sharp colour contrasts between horizons, may partly explain this emphasis. The present study aimed to assess the representation of podzolic soils in current educational materials (primary and secondary schools) and the level of student knowledge upon completion of primary and secondary education. The research combined a structured content analysis of thirteen widely used geography textbooks (three for primary and ten for secondary school) with a nationwide survey of 569 primary and secondary school students, employing both open-ended and multiple-choice questions to assess conceptual understanding and recognition skills. The textbook review confirmed that podzolic soils are the most frequently referenced soil unit, surpassing chernozems, clay-illuvial, brown soils, and alluvial soils, yet coverage is dominated by visual depictions and general associations (e.g., low fertility, sandy texture, forest use) with minimal attention to formation processes, diagnostic horizons, or chemical properties. Survey results revealed that over one-third of respondents could not provide a single correct association, and only 13.4 % correctly answered all four closed questions. Secondary school students outperformed primary school students across all measures, but even at the higher level, knowledge of diagnostic features and soil profile morphology remained limited. Main misconceptions included overestimating the extent of podzolic soils, misjudging their fertility, and associating them with carbonate parent materials. The findings point to three main shortcomings in soil science education: (1) an overly static presentation of soils, focusing on appearance and distribution rather than genesis and functional implications; (2) limited progression in content depth between primary and secondary levels; and (3) outdated or inconsistent numerical data in textbooks. Addressing these issues does not require wholesale curriculum reform, but rather targeted updates, including accurate distribution maps, concise explanations of podzolization, and the integration of current classification data. Such changes could bridge the gap between name recognition and functional understanding, strengthening soil science literacy among Polish students.

1. Introduction

Podzols occupy barely 3.3 % of the Earth's land surface (Driessen et al. 2001), yet they stand out among far more extensive soil groups. Despite their relatively small area, school textbooks often present these soils as the quintessence of soil. The reason is the podzolization process, which produces a clear, colour-contrasted stratification that even non-specialists can recognise: an ashy white, intensely leached E horizon sharply overlies a rusty reddish B horizon. This striking pattern results from strong leaching under cold, humid conditions and acidic coniferous litter – conditions that dominate the vast boreal belt of Eurasia and North America, as well as many temperate heathlands. Thanks to the combination of clearly visible horizons, a broad geographic extent, and an association with landscapes such as taiga forests, podzols have become one of the most instantly recognisable and most frequently illustrated soil groups in textbooks and field guides worldwide.

Although morphologically distinctive, podzolic soils typically form from nutrient-poor parent materials—sands (e.g., dune sands, fluvioglacial sands) and, in uplands and mountains, the weathering mantles of granites, gneisses, and similar rocks.

They are therefore strongly acidic, low in base cations, and unsuited to conventional agriculture, yet they constitute a vital resource for forestry, particularly in boreal ecosystems. Their ecological and economic importance, combined with their occurrence throughout Northern Hemisphere countries (and their classification systems) where soil science is advanced, has made them one of the favourite objects of soil research. Classic theories of their genesis were advanced in the 19th and 20th centuries by Ramann (1911), Williams (1950), Tomaszewski (1957), Mokma and Buurman (1982), and Farmer (1982). Much of the foundational work was carried out in Russia, where Dokuchaev (1879) first formalised the link between soils and the environmental factors that create them and introduced the very name podzol ("under ash").

Modern studies continue to address the mechanisms of podzolization (e.g. Lundström et al. 2000), the soils' special properties (Kowalkowski, 2002) and their management (Bednarek et al., 2009; Świtoniak et al., 2014). An extensive literature exists on podzols, addressing their complex genesis and diverse properties across globally distributed regions. A significant body of research covers podzols in Poland, spanning environments from the Northern Lowlands to the Carpathians (Czępińska-Kamińska, 1986; Skiba, 2000; Kabała, 2001; Janowska et al., 2002; Kowalczyk and Miechówka, 2001; Konecka-Betley, et al. 2002; Jankowski, 2001, 2014; Kabała and Haase, 2004; Bednarek and Charzyński, 2008; Musielok et al., 2021; Kuligiewicz et al., 2024). Major studies have also been conducted in Finland (Mokma et al., 2004), Scotland (Stevens and Wilson, 1970), Canada (Sanborn, 2011), Brazil (Klinge, 1965; Martinez et al., 2025), and New Zealand (Hewitt, 2021). The scientific recognition of podzols is further evidenced by their designation as "Soil of the Year 2007" in Germany (Sauer, 2007; Medwedski et al., 2025) and twice in Estonia – Podzol in 2017 and Umbric Podzol in 2023 (Kőlli and Tõnutare, 2023).

In Poland, soils formed predominantly through podzolization are classified and referred to as "podzolic soils". The name "podzol" is reserved for a subtype of podzolic soils characterized by a lack of humus in the A horizon due to strong podsolization and leaching of humus substances (Polish Soil Classification, 2019; Kabała et al., 2019). Because they cover well over ten percent of the country's land area and underpin its forestry sector, the Polish Soil Science Society designated them "Soil of the Year 2025." Such selections typically spark scientific interest and yield a burst of new studies and syntheses, as seen previously for Rusty soils (Soil of the Year 2021; Urbańska et al., 2021) and Alluvial soils (Soil of the Year 2022; Urbańska et al., 2022).

Educational research, however, reveals notable gaps in the teaching of soil science. Compared to other environmental topics (hydrosphere, atmosphere), soils receive less curricular attention (Urbańska et al., 2022a). Moreover, coverage is uneven: some soil types are barely mentioned, while podzols are given prominent attention. In a survey of 17 secondary school textbooks (Urbańska et al., 2021), the term podzolic appeared 124 times, while rusty soils, which cover a similar area of Poland, were mentioned only 31 times. Exam papers echo this pattern: questions on podzolic soils recur more often than on any other soil in Poland's matura (secondary school leaving examinations). The popularity of these soils stems not only from the breadth of research devoted to them and their visually striking profiles, but also from their very name: in Polish, podzolic soils are called *gleby bielicowe* ("whitish soils"), a term that naturally evokes their bleached eluvial horizon.

This prominence might suggest that Polish students graduate with a solid grasp of podzols—yet is that really so? Earlier studies (Capra et al., 2017; Urbańska et al., 2021; Charzyński et al., 2022; Urbańska et al., 2022) have highlighted widespread misconceptions and a shallow understanding of soil issues. Hence, this article examines how well upper secondary students actually understand podzolic soils.

The aim of this paper is to evaluate both the representation of podzolic soils in educational materials (textbooks) and the level of student knowledge at the end of elementary and secondary education. Specifically, the study examines the alignment between textbook content and students' actual understanding – assessing both the input (curricular exposure) and the output (environmental literacy). Answering these questions will clarify whether the textbook prominence of podzolic soils translates into genuine ecological literacy among Polish youth – or whether new educational strategies are needed to bridge the gap between name recognition and functional understanding.

2. Methods

Data collection was conducted using the computer-assisted personal interviewing (CAPI) method. Participants were recruited online through a digital form distributed to Polish schools and geography teachers. The survey was disseminated via email invitations to schools whose students regularly participate in the Polish Geographic Olympiad and the annual great test of geographic knowledge organized at Nicolaus Copernicus University in Toruń. Additionally, the questionnaire was shared through the "Nauczyciele Geografii" (Geography Teachers) Facebook group, which facilitated outreach to a broader network of educators. The questionnaire was administered using the Google Forms platform, with data collection taking place between March and May 2025. The main section consisted of five questions: one open-ended and four multiple-choice (A, B, C, D) closed questions, designed to assess both conceptual understanding and applied interpretive skills related to soil genesis and geography, with a specific focus on podzolic soils. These closed-ended questions offered four answer choices each, with only one correct option (indicated below by *).

- What do you associate with podzolic soil? (You may briefly describe its general features, the type of environment or land use it is related to, its fertility, etc. If nothing comes to mind, feel free to leave the answer blank) – open-ended question;
- What is the parent rock of podzolic soils? – Loam, Sand*, Loess, Fluvial deposits;
- With what type of landscape or land use would you associate podzolic soils? – Coniferous forest (pine forest)*, Deciduous forest, Arable field, Meadow or pasture;

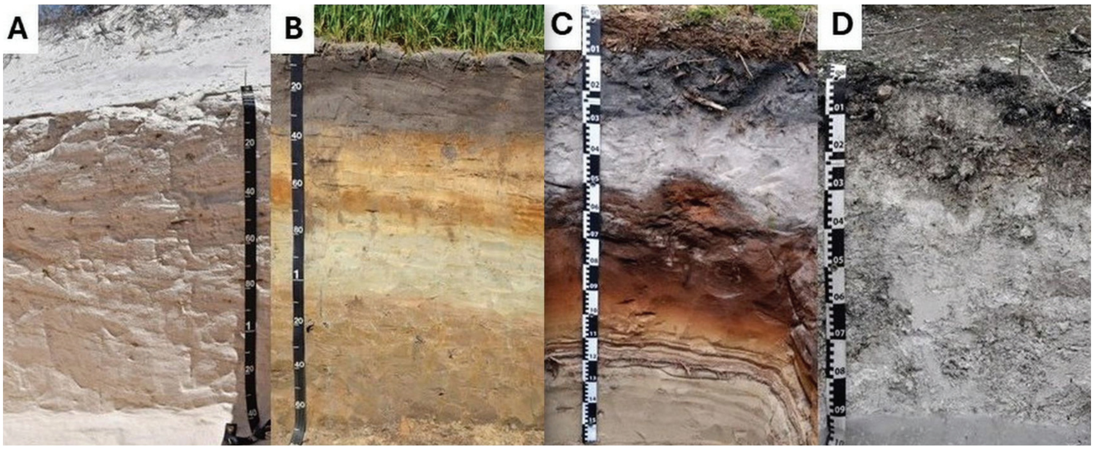

Fig. 1. Soil profiles used in the survey for the visual identification of a podzolic soil

- Select the correct description of podzolic soils? – Low in fertility due to lack of humus and an alkaline reaction, Moderately fertile but become highly crusted after prolonged drought, Potentially fairly fertile but highly prone to erosion, Low in fertility because they have an acidic reaction and often few nutrients*.
- Which of the following photographs shows a podzolic soil? (Fig. 1)

Additionally, the questionnaire collected demographic data on the respondents, including gender, place of residence, voivodeship (province), and current level of education. The study sample consisted of 569 respondents, whose socio-demographic characteristics are summarized in Table 1. representing the final stages of compulsory education in Poland − namely, students near to completing primary (elementary) and high school education. Although the research aimed to compare these two

Table 1
Socio-demographic characteristics of the respondents (n=569)

		Count	%
Sex	Woman	317	55.7
	Man	214	37.6
	Prefer not to say	38	6.7
Place of Residence	Major city (>200k inhabitants)	109	19.16
	Large city (100k–200k inhabitants)	126	22.14
	Medium-sized city (20k–100k inhabitants)	118	20.74
	Small Town (<20k)	107	18.80
	Village / Rural area	109	19.16
Province of residence	Kuyavian-Pomeranian (kujawsko-pomorskie)	256	44.99
	Masovian (mazowieckie)	103	18.10
	Łódź (łódzkie)	55	9.67
	Greater Poland (wielkopolskie)	35	6.15
	Warmian-Masurian (warmińsko-mazurskie)	32	5.62
	Silesian (śląskie)	25	4.39
	Pomeranian (pomorskie)	16	2.81
	Other*[1]	19	3.34
	Unspecified	28	4.92
Current educational enrolment	Elementary	137	24.08
	Secondary	432	75.92

* Includes provinces with fewer than 10 respondents: Holy Cross - świętokrzyskie (1), Lesser Poland – małopolskie (7), Lower Silesian = dolnośląskie (1), Lublin – lubelskie (1), Lubusz – lubuskie (1), Opole – opolskie (1), Podlasie – podlaskie (3), Subcarpathian – podkarpackie (2), West Pomeranian – zachodniopomorskie (2).

educational levels, the sample distribution was skewed toward upper-secondary students. In terms of gender, the sample was female-dominated (55.7%), followed by male respondents (37.6%). The overall distribution remained sufficiently balanced to support comparative analysis.

Respondents were drawn from a broad spectrum of settlement types, ranging from rural areas to major cities. Urban areas, especially medium- and large-sized cities, were slightly more prevalent, yet small towns and rural settings were comparably represented. This variety ensures geographical diversity in terms of urbanization level and allows for the identification of place-based patterns or differences in attitudes.

Individuals from all Polish voivodeships were represented in the sample, albeit often in small numbers. Central Poland was most strongly represented, with the Kuyavian-Pomeranian Voivodeship accounting for 45.0% of all respondents. This was followed by the Masovian with 18.1%, and the Łódź Voivodeship, which contributed 9.7% of the sample. The remaining regions contributed only marginally to the overall sample, with several voivodeships represented by one or two participants. This marked regional concentration reflects the logistical constraints of data collection.

A structured content analysis method, based on categorization grids, was employed to record the presence and scope of Podzol-related content. This method was designed to compare currently available geography textbooks (Table 2) used in Polish schools, encompassing both primary and secondary education levels (basic and extended curricula).

3. Results and discussion

3.1. Textbook content

First and foremost, it is necessary to examine whether podzolic soils are frequently mentioned in school textbooks − especially in comparison to other soil units. Previous studies reviewing textbooks and educational websites (Urbańska et al., 2021) demonstrated that these soils are among the most frequently referenced. It is worth noting that the mentioned study included both relatively recent textbooks (published around 2019) and older editions from the 1960s to the 1990s. A review of thirteen commonly used Polish geography textbooks – three for primary school (7th grade) and ten for high school (1st, 3rd, and 4th grade) – confirms these earlier findings (Table 2). Overall, in all investigated textbooks (Fig. 2), podzolic soils are the most frequently referenced (104 mentions), followed closely by chernozems (95), brown (92), alluvial (85), and clay-illuvial soils (79). These units clearly dominate textbook content, reflecting their importance in either the Polish landscape or the soil classification systems taught in schools. On the other hand, units such as anthropogenic soils (16 mentions), organic/peat/boggy soils (23), and rusty soils (23) are less commonly discussed, indicating either a lower perceived educational relevance. It appears that podzolic soils serve as a core example in soil science education, with basic exposure at the primary level and a more detailed and systematic treatment in secondary education, particularly during the first and third grades in the extended level (Fig. 2).

Table 2
List of analysed textbooks

No.	School level	Grade (B – basic, E – extended)	Publisher	Textbook	Authors	Year
1	Primary school	7	MAC	Geografia 7	Wójtowicz B.,Marszał D., Pruszko G., Figa M., Wiecki W., Mędrzycki Ł.	2022
2			WSIP	Geografia bez tajemnic 7	Głowacz A., Adamczewska M., Dzięcioł – Kurczoba B.	2023
3			Nowa Era	Planeta Nowa 7	Malarz R., Szubert M.,Rachwał T.	2025
4	High school	1B	Operon	Geografia 1; basic level	Zaniewicz Z.	2019
5			Nowa Era	NOWE Oblicza Geografii 1; basic level	Malarz R., Więckowski M.	2024
6		1E	Operon	Geografia 1; extended level	Kurek S.	2021
7			Nowa Era	NOWE Oblicza Geografii 1; extended level	Malarz R., Więckowski M., Kroh P.	2024
8		3B	Operon	Geografia 3; basic level	Zaniewicz Z.	2021
9			Nowa Era	Oblicza Geografii 3; basic level	Adamiak C., Dubownik A., Świtoniak M., Nowak M., Szyda B.	2021
10		3E	Operon	Geografia 3; extended level	Ciesielski P.	2021
11			Nowa Era	Oblicza Geografii 3; extended level	Świtoniak M., Wieczorek T., Malarz R., Karasiewicz T, Więckowski M.	2024
12		4E	Operon	Geografia 4; extended level	Ropel S., Kurek S., Zaniewicz Z.	2022
13			Nowa Era	Oblicza Geografii 4; extended level,	Rachwał T., Adamiak C., Świtoniak M., Kroh P.	2022

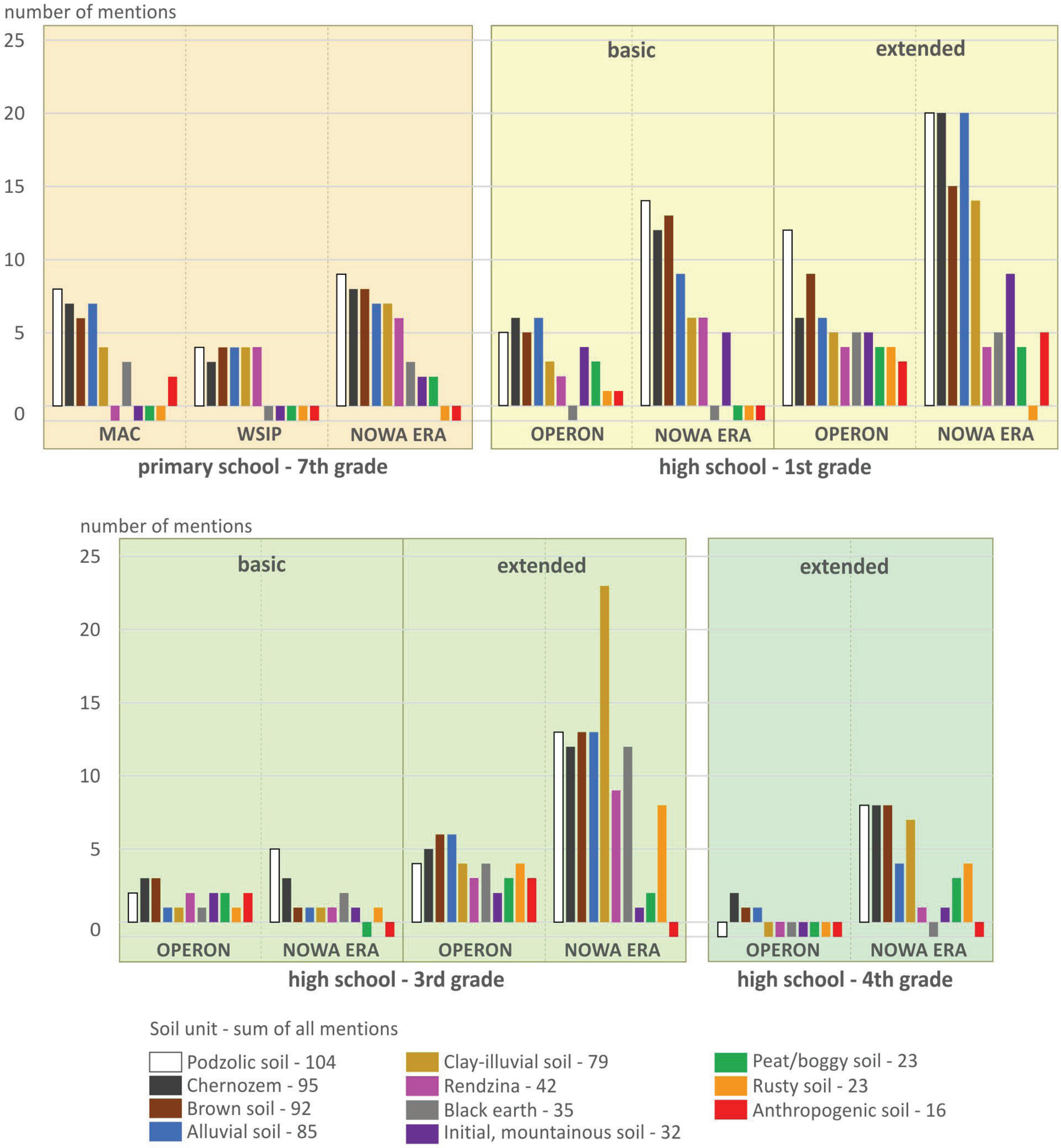

Fig. 2. Mentions of particular soil type names in school textbooks

A question arises as to why podzolic soils, despite accounting for only a modest share of the national territory and not serving as a basis for agricultural production, are so disproportionately represented in school textbooks. The dominance of podzolic soils in textbooks can be partly explained by their striking morphological distinctiveness, with sharp colour contrasts between horizons that make them highly effective in visual materials. Historically, they were also classified together with clay-illuvial soils, called officially as pseudopodzolic until 1974 (Polish Soil Classification, 1959, 1974), which cover nearly half of Poland's territory; the two units were only formally separated in 1974. However, much of the soil science content in current textbooks remains outdated – for example, rusty soils (also distinguished in 1974) are still rarely mentioned, and eroded clay-illuvial soils are often mislabelled as brown soils.

The survey reveals a striking imbalance between descriptive breadth and conceptual depth in the treatment of podzolic soils. Virtually every primary school book offers students a visual entry point. Also, more than half of the secondary texts (all books for the first class) contain at least one photograph or schematic (drawing) cross-section of a podzol (Table 3). Yet this visual emphasis is not matched by a systematic explanation of the soil-forming processes that underlie the images. Only one primary text and four secondary texts discuss podzolization itself – the downward

Table 3
Categories of textbook content concerning podzolic soils

Nr	School level	Year (B – basic, E – extended)	Publisher	Photograph (P) or graph (G) of podzol	Podzolization process	Parent material	Reaction (pH)	Humus horizon	Climate	Typical vegetation	Value for land-use	Soil Map of Poland (P) or World (W)	Share in Poland area
1	Primary school	7	MAC	G	-	+	-	-	+	+	+	P*	25%
2			WSIP	P G	+	+	+	+	-	+	+	P*	-
3			Nowa Era	G	-	+	-	+	-	+	+	P*	-
4	High school	1B	Operon	G	+	+	+	+	+	+	+	P* W	-
5			Nowa Era	G	+	+	-	+	+	+	+	W	-
6		1E	Operon	P Gx2	-	+	+	+	+	+	+	W	-
7			Nowa Era	P G	+	+	-	+	+	+	+	P* W	-
8		3B	Operon	-	-	+	-	-	-	+	-	P*	74%
9			Nowa Era	-	-	+	-	-	-	-	+	-	25%
10		3E	Operon	G	-	+	+	-	-	-	-	P*	26%
11			Nowa Era	-	-	+	-	-	-	+	+	P*	-
12		4E	Operon	-	-	-	-	-	-	-	-	-	-
13			Nowa Era	G	+	+	-	+	+	+	+	W	-

+ yes – no *together with rusty soils

translocation of organo-metal complexes that differentiates the horizons − leaving most students with little sense of how the characteristic eluvial and illuvial horizons evolve. Nevertheless, each student encountered a podzolic soil profile image at least twice (once in primary school and once in secondary school).

Several descriptive elements related to podzolic soils are commonly found in most textbooks. Parent material is mentioned in every primary book and in nine of the ten secondary books. Explicit statements about the land-use value of podzols are included in all primary and seven secondary titles. Likewise, typical vegetation receives relatively thorough coverage: all primary and seven secondary textbooks associate podzols with coniferous or heathland communities, a link that is intuitively accessible and probably benefits from classroom familiarity with boreal landscapes. By contrast, aspects related to chemistry or genesis are marginalized. Soil reaction (pH) is treated in only one primary and three secondary volumes, and the humus horizon characteristics are described in just two primary and five secondary books. Climate—a classical control on podzol formation − receives attention in only one primary text and half of the secondary textbooks. Moreover, podzolization is a rapid process, becoming clearly evident under pine monoculture plantations after only a few decades (Jankowski and Rutkowska, 2024), and it may indicate the process of pinetyzation − the conversion of mixed or broadleaved forest habitats into pine-dominated stands − associated with the degradation of rusty soils (Sewerniak and Jankowski, 2021). Unfortunately, this type of human impact is not mentioned in the textbooks at all.

Spatial context is provided unevenly. Every primary textbook provides a map of Polish podzol distribution, and two of them include a global map. However, only half of the secondary books feature any cartographic material, and only four juxtapose national and world scales. Even where maps are present, the quantitative estimates of the share of Poland covered by podzols range widely, from 25% to 74%, indicating inconsistent use of data sources and infrequent updating. Incorrect information on their share in Poland's soil cover may also stem from the difficulty of distinguishing them − at the national scale − from rusty soils, as highlighted by recent studies (Sykuła et al., 2019). Nevertheless, school textbooks frequently lack up-to-date data on the extent and distribution of the country's main soil units.

3.2. Survey results

The open-ended question about what podzolic soils make students think of was posed first so as not to steer them toward specific lines of thought or hint at the "right" answers. A review of all the answer sheets made it possible to assess the accuracy and sort the individual associations (connotations) proposed by the students.

Across the full cohort, more than one-third of respondents (37.8%) were unable to give any correct association, and another 29.9 % offered only a single correct response. The proportion of students achieving three or more correct associations was limited to 14.3%. Calculated as a weighted average, the

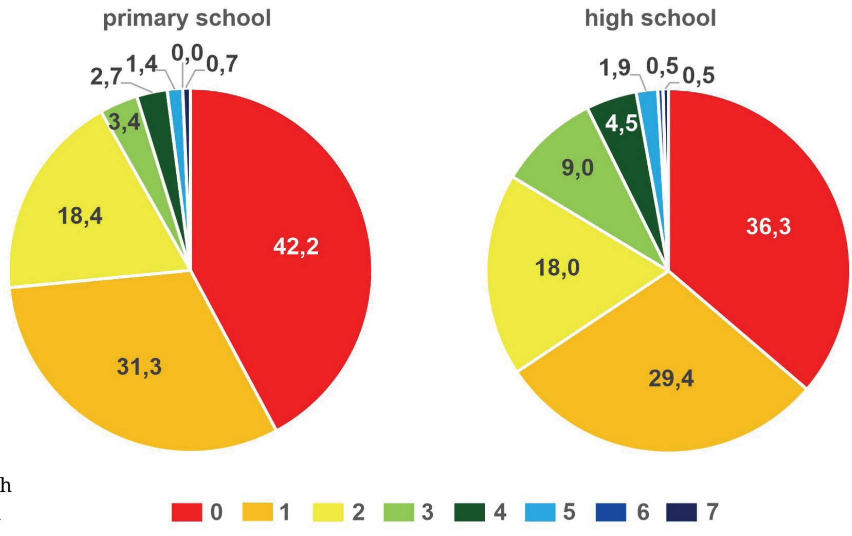

Fig. 3. Number of correct associations (connotations) with Podzolic Soils given by students in an open-ended question

mean number of correct associations per respondent was 1.20. Conceptual knowledge about general connotation with podzolic soils proved weakest in the group of primary school students. A total of 42.2% of them (Fig. 3) failed to produce any accurate association, whereas only 3.4% reached the level of three correct answers and a mere 8.2% achieved three or more. Their mean score was only 1.01 correct associations per student.

High school students displayed a modest but clearly discernible improvement. The share of respondents with zero correct associations decreased to 36.3% (Fig. 3), and 16.4% provided at least three valid associations, which is double the proportion observed in the primary school sample. Their mean score rose to 1.26 correct associations per student. The distributions in both groups are highly right-skewed, reflecting the predominance of low (0–2) scores. Nonetheless, the incremental rise in both the mean number of correct associations and the share of high-scoring individuals from primary to high school levels suggests that formal geography teaching contributes to a gradual, albeit still limited, accumulation of accurate conceptual links with podzolic soils.

A particularly interesting part of the analysis focused on reviewing the most common associations that the surveyed students had with the discussed soils. Across the full sample of surveyed students, the connotation with “low fertility” (43.4%) clearly dominates, followed by the parent material (sandy) context (18.5%) and coniferous vegetation (17.6%). Specific colour of podzolic soils registers only moderate salience (12.0%) while physico-chemical properties such as soil pH (7.0%) and the presence of not very-well developed humus horizon (6.9%) are mentioned far less frequently (Fig. 4). The residual “other” category accounts for 14.2% of responses, indicating a modest but non-negligible diversity of idiosyncratic or highly specific associations – mostly connected with cold and humid climate and dry character of podzolic soils. The obtained results (Fig. 4) accurately reflect the variation in the frequency of specific content presented in textbooks (Table 3). The general land-use value of podzolic soils is frequently mentioned in school geography books, and most students correctly associate these soils with their sandy texture, low agricultural productivity, and common use in forest management – particularly for the cultivation of coniferous forests. However, respondents rarely refer to other characteristics, such as acidic pH, low nutrient content, or the presence of humus, features less frequently presented in textbooks.

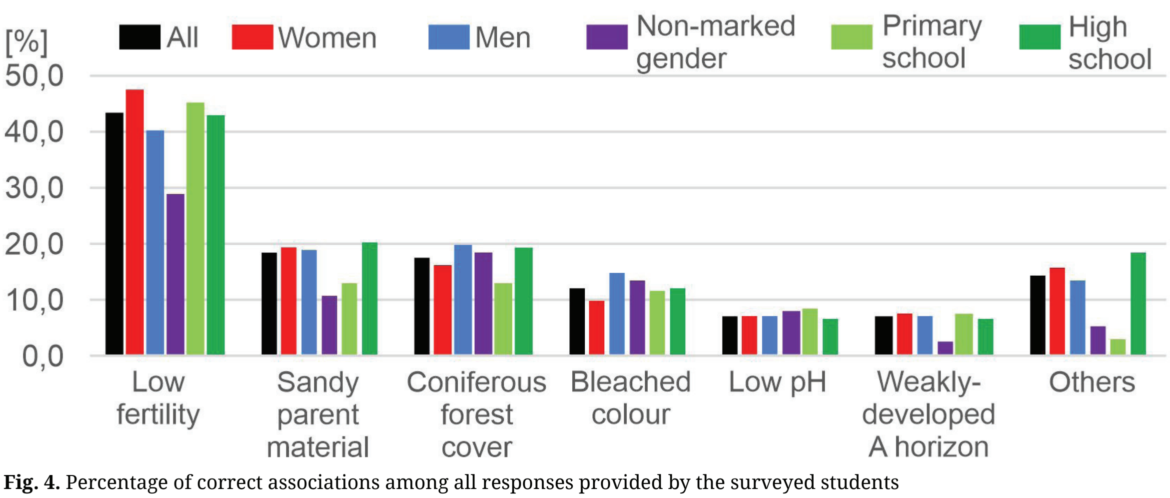

Fig. 4. Percentage of correct associations among all responses provided by the surveyed students

Primary-school students rely most heavily on the broad notion of low fertility (44.9%) and make substantially fewer "other" references (2.7%), suggesting a comparatively narrow conceptual horizon. By contrast, upper-secondary students more often invoke the sandy geological substrate (20.4%) and coniferous vegetation (19.2%), and supply three to four times as many idiosyncratic associations (18.2%), pointing to a richer and more differentiated cognitive schema. In the group of high school students, more frequently given associations were classified as "other" in Fig. 4 – specifically, iron leaching, a cool and humid climate, and the perceived dryness of podzolic soils. These patterns suggest that formal education has a stronger impact on students' understanding of the genesis and properties of podzolic soils.

The presented results also reveal some differences between the two gender groups. Female respondents are the most likely to stress fertility constraints (47.3%), whereas male students mention soil colour (15.0%) and links to coniferous ecosystems (19.6%) more frequently. The prevalence of parent-rock associations is similar in both gendered cohorts (~19%), implying that lithological reasoning is not gender-skewed within the sample. The small "non-marked" subgroup diverges notably from all others: the low fertility concept is invoked by only 28.9% (≈ 15 pp below the overall mean), and humus-horizon references drop to 2.6%. Taken together with a comparatively low share of parent material mentions (10.5%), these figures point to a markedly weaker or less conventional representation of podzolic soils in this residual category, although sampling error cannot be ruled out, given the limited n = 38.

It should be emphasised that the majority of responses (all described above) − i.e., the students' self-reported associations with podzolic soils − were accurate. Among them were several dozen inaccurate answers representing roughly 10–12% of respondents. Two main misconceptions predominated:

- A considerable number (6,7% of the whole group) regarded podzolic soils as relatively fertile and productive, even though they rank among the least productive soils in the country;
- Some students (4,4%) believed that podzolic soils make up a large − if not dominant − proportion of Poland's soil cover, whereas the actual share is only about 14%.

In the first case, this error is not supported by textbook content. The lack of knowledge regarding the share of podzolic soils in Poland's soil cover stems from the absence of such information in textbooks. On soil maps, podzolic soils are often grouped with other sandy soils − particularly rusty soils − which together account for over 25% of the country's surface. One textbook even provides incorrect information, claiming that podzolic soils cover as much as 75% of Poland − equivalent to the total area of all autogenic soils in the country, including rusty, clay-illuvial (lessive), and brown soils.

Moreover, in a few isolated cases, students also linked podzolic soils with carbonate parent materials, despite the fact that these soils are characteristically acidic. This type of information is not included in any of the textbooks; therefore, it is simply an error resulting from a lack of appropriate knowledge.

The results based on the closed-ended items, where students chose one of four response options, display a somewhat different pattern. The distribution of correct responses is presented in Fig. 5. Among all 569 respondents, only 13.4% correctly answered all four questions. However, this proportion varied notably across the analyzed subgroups. The highest proportion of fully correct responses was recorded among secondary school students, with 16.6% achieving a perfect score, exceeding the overall average, which suggests a potentially higher level of subject-specific knowledge or cognitive maturity. In terms of educational level, the contrast between primary and secondary students was particularly pronounced: the share of students with a perfect score was approximately four times higher among secondary school students compared to primary school students, who achieved the lowest score among all subgroups (4.1%). This suggests a possible developmental or curriculum-related effect on the ability to correctly respond to the soil knowledge-based questions posed in the survey. A gender-based analysis revealed that female respondents had a higher rate of full correctness (14.8%) compared to male respondents (12.1%). Interestingly, only 7.9% of respondents who did not specify their gender selected all four correct answers. Interestingly, there was no difference in the maximum number of correct answers across subgroups based on place of residence (Fig. 5). Respondents who provided four correct answers fell within a narrow range of 13.3–14.5%, regardless of whether they were from village, small, large, or major cities. The exception (inexplicable at this stage of the research) is the group of respondents from medium-sized cities – only 9.6% of people gave the maximum number of correct answers. These results also confirm the average scores. Assuming that one correct answer equals one point, this value fluctuates around 2, regardless of the size of the place of residence in each group. The study results, therefore, show that the size of settlement does not significantly affect the level of knowledge about podzolic soils among people from towns of different sizes. This is surprising, as it would seem that in rural communities, where agriculture remains a significant economic activity, soils are not only part of the physical landscape but also carry practical and economic importance. Therefore, a higher share of correct answers could be expected among rural youth. However, it is important to note that residing in a rural area does not necessarily imply a farming background for the respondent. In contemporary Poland, the majority of rural residents are not employed in the agricultural sector. This reflects broader demographic and spatial trends, particularly suburbanization, which has led to the emergence of non-agricultural, residential villages on the fringes of urban centers. In such areas, students may live in a rural landscape while attending schools in nearby towns or cities.

A total of 22.1% of respondents made one mistake and gave three correct answers, with relatively similar results across subgroups: 24.0% for women, 21.5% for men, and 23.0% for secondary school students. Notably lower rates were observed among primary school students (19.7%) and individuals with unmarked gender (10.5%). At the lower end of the performance spectrum, 25.3% of all respondents selected one correct answer. This response category was especially frequent among individuals with unmarked gender (31.6%) and primary school students (30.6%), suggesting either limited knowledge or a higher level

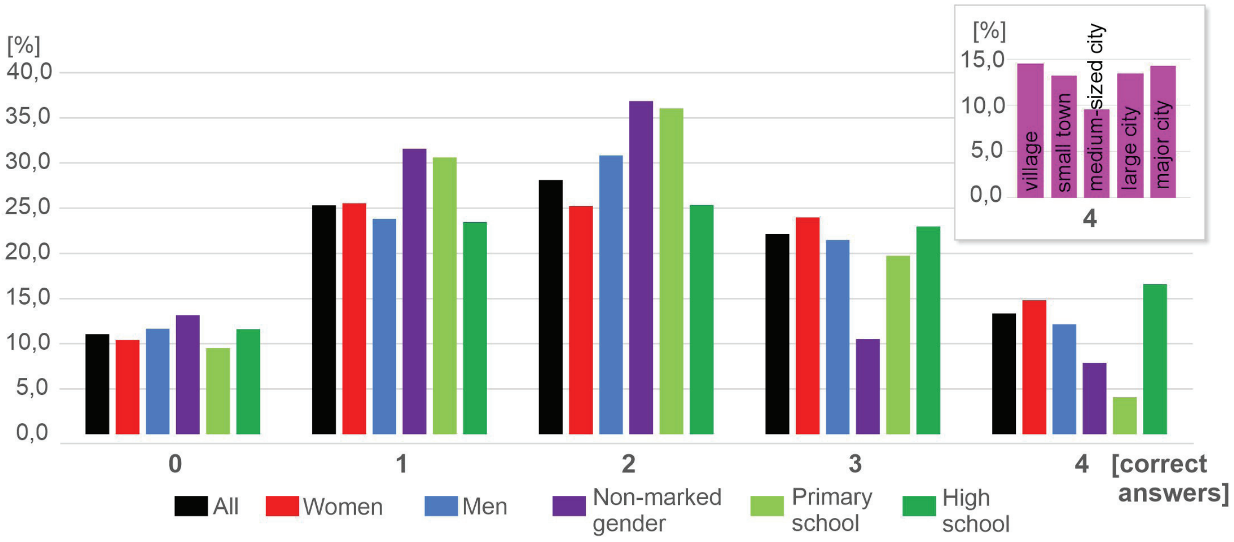

Fig. 5. Distribution of the number of correct answers among the respondent groups

of response uncertainty. Among women and men, the proportions were 25.6% and 23.8%, respectively. Finally, 11.1% of all respondents failed to provide any correct answer. The frequency of this outcome was highest among participants with unspecified gender (13.2%) and lowest among primary school students (9.5%). Both women (10.4%) and men (11.7%) exhibited similar rates of zero correct answers, while secondary school students performed slightly better than the overall average (11.6%). Taken together, these results indicate substantial variation in "podzol-based knowledge" levels across educational and gender-defined subgroups. Respondents affiliated with secondary education consistently outperformed their primary-level peers, particularly in achieving higher numbers of correct responses. Gender-based patterns were less pronounced but suggest slightly better outcomes among female participants in the upper performance categories (3–4 correct answers). These findings support the notion that both gender and educational stage are relevant predictors of knowledge-level outcomes in the podzol-context of this survey.

In terms of correct answers to individual closed multiple-choice questions (Fig. 6), the highest overall accuracy was observed for the question related to **the parent material**, which was correctly answered by 67.3% of all respondents. Female participants demonstrated the highest success rate in this category (71.0%), followed closely by high school students (67.5%), primary school students (66.7%), and male respondents (65.0%). Respondents who did not specify their gender performed markedly lower (50.0% in both cases), but the small size of this group can easily distort the overall results. In the case of **land use**, 63.1% of respondents answered correctly overall. The results across gender groups were relatively consistent (64.0% for both women and men), while students in secondary education scored slightly higher (63,7%) than those in primary education (61,2%). Again, participants with unmarked gender recorded the lowest accuracy (50,0%). Substantially lower correct response rates were noted for the question concerning the **general properties of podzolic soils**. Only 39.7% of all respondents answered this item correctly, with little variation between men (40.7%) and women (39.7%). Primary school students scored lowest in this category (33.3%), while secondary school students showed slightly better understanding (41.9%). The recognition of **soil profiles** proved to be the most challenging: only 31.3% of the total sample identified them correctly. A possible explanation for this may be that the Phaeozem image (37%), due to the presence of an eluvial horizon visible in the image, could have resembled a podzolic soil to less experienced students. Interestingly, despite overall low scores, secondary school students (36.3%) outperformed all other groups, while primary school students performed the worst (17.0%), indicating significant difficulty in recognizing or understanding vertical differentiation in soil horizons of podzolic soils. Gender-related differences were minor in this category, with 32.5% of women and 29.0% of men responding correctly. Comparing the obtained result with the fact that each student encountered a (very characteristic!) podzolic soil profile at least twice in their education, it can be concluded that if there is a lack of understanding of the process and conditions of soil formation, students are not able to easily recognize the soil in question solely on the basis of its morphology. Moreover, the quality of the photos presented in textbooks is sometimes unsatisfactory – in one of the analyzed cases, the podzolic soil appeared almost identical to black earth at first glance, which makes it difficult to understand its typical morphological elements.

The mentioned results indicate a relatively solid understanding of basic soil-forming factors, such as parent material, and the utility value of the discussed soils, which are used in Poland mainly for the cultivation of pine monocultures. However, there is limited knowledge regarding the more diagnostic or conceptual features of podzolic soils, particularly general properties and vertical soil profile morphology. Educational level appears to be a stronger differentiating factor than gender, with secondary school students consistently outperforming primary school students across all thematic areas. The group with unspecified gender tended to score lower across most questions; however, sample size limitations may have influenced this outcome.

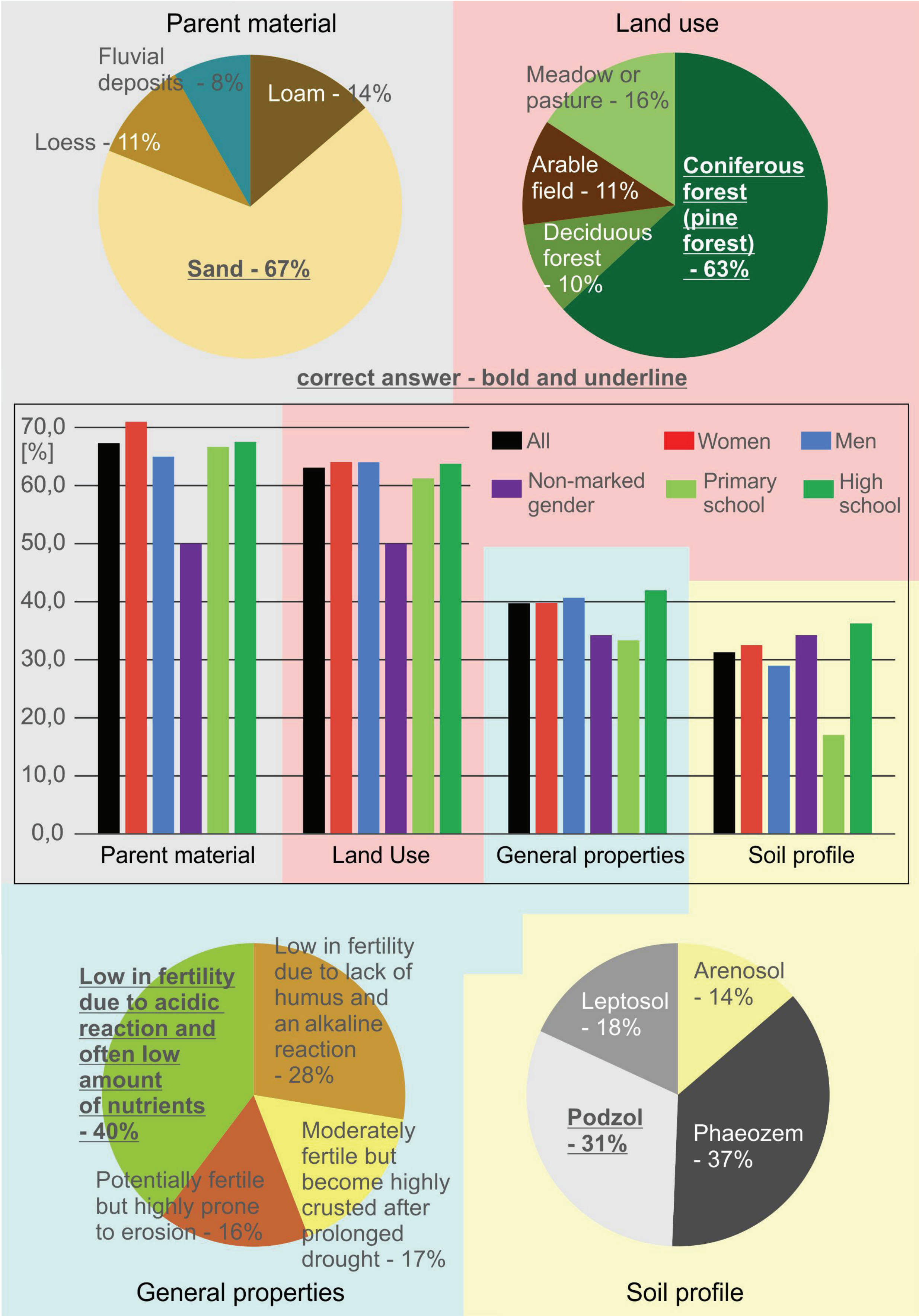

Fig. 6. Percentage of correct answers to closed multiple-choice questions among all respondents (correct answers are underlined)

4. Conclusions and recommendations

Podzolic soils possess substantial didactic value within the context of school-based geography and environmental education. As demonstrated by Urbańska et al. (2021), among the most common and significant soil units in Poland, podzolic soils offer the greatest potential for effective teaching. Their widespread distribution across the country ensures that they can be readily accessed for field-based instruction in almost all regions. Furthermore, their sandy texture facilitates the excavation of soil pits, enabling direct observation of profile characteristics. The genesis of podzolic soils can be clearly articulated, while their pronounced morphological differentiation renders them intuitively recognisable even to individuals without formal soil science training. Rusty soils constitute the only other unit of comparable educational utility; however, coverage of this group in school textbooks is minimal (Fig. 2). The present study sought to assess how podzolic soils are represented in geography textbooks and how well students understand their properties and formation.

The combined analysis of educational materials and survey data leads to the following conclusions:

1. Podzolic soils are overrepresented in textbooks compared to other soil units and relative to their actual share in Poland's soil cover. Their frequent use as illustrative examples results from their striking morphology and association with archetypal landscapes. Moreover, podzolic soils were treated in Polish Soil Classification and cartography until 1974, together with the much more widespread clay-illuvial (lessive soils – then referred to as pseudopodzolic soils). This confirms that textbook-based soil knowledge does not accurately reflect the current state of scientific understanding.
2. Textbook content emphasizes visual aspects (e.g., soil profiles) and basic associations (e.g., low fertility, sandy parent material, forest use), but offers limited explanation of podzolization processes, pH, humus characteristics, or climatic controls.
3. Student knowledge about podzolic soils – assessed through students' ability to generate open-ended associations – remains shallow, particularly at the primary school level. A significant proportion of students (especially in elementary school) cannot provide even one correct association, and only a small fraction of respondents demonstrate a deeper conceptual understanding. Upper secondary students perform better across all categories, indicating that the current geography curriculum does contribute to improved knowledge. However, even at this level, many diagnostic and conceptual aspects of podzolic soils are poorly understood.
4. Closed-question results confirm modest understanding: while most students correctly identify the parent material and land use, fewer can recognize a podzolic soil profile or identify its key diagnostic properties.
5. Educational stage is a more significant differentiator than gender or place of residence. Secondary school students consistently score higher than primary school students, although gender-based differences are present, albeit less pronounced. Surprisingly, rural students − despite potentially greater exposure to soil use − did not perform better than their urban counterparts.
6. There is a clear gap between recognition and understanding. Although students have seen images of podzolic soils during their education, they often fail to interpret them correctly due to insufficient explanation of their formation and characteristics.
7. Improving soil education requires greater emphasis on understanding the causal links between key pedogenic factors, human influence, soil characteristics, their potential for use, and the associated needs for soil conservation. Podzols are furthermore an ideal case study for highlighting the effects of anthropogenic pressure. Afforestation with coniferous species intensifies podzolization – a compelling and powerful example of human-driven changes in pedogenic processes.

The conclusions highlight significant gaps and shortcomings in soil science education at the secondary school level. There may be many reasons for this. Soil science can be intricate, involving physical, chemical, and biological characteristics, which can be tough for students to understand. Conventional teaching methods may not always effectively convey the significance and relevance of soil, leading to a lack of engagement. Soil science is sometimes viewed as solely connected to agriculture, which may not interest all students, particularly those with a keen interest in other environmental disciplines. A substantial number of students lack awareness of the importance of soil health and its connection to various aspects of life, including food security and climate change. This lack of understanding can contribute to disinterest and a deficiency of appreciation for the subject.

Taken together, the findings highlight three shortcomings in soil science education. First, students are offered a largely static portrait of podzols: they see what the soil looks like and where it occurs, but rarely how it forms or engage in causal (cause-and-effect) thinking, why its chemistry constrains land use. Second, progression through the education system does not guarantee deeper coverage, signalling a lack of coordination between curriculum designers and publishers. Third, numerical data are outdated or conflicting, which risks perpetuating misconceptions about the national distribution of podzols. Addressing these gaps would not require wholesale curriculum reform; targeted additions—such as concise diagrams of horizon sequences, short narratives on forest-management challenges, and references to the most recent Polish Soil Map − could furnish students with a more dynamic and accurate understanding of this widespread soil order while also fostering the development of causal (cause-and-effect) thinking as a core cognitive skill in geography and environmental education.

Conflict of interest

The authors declare that they have no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research did not involve human or animal subjects.

Author Contributions

Marcin Świtoniak – Conceptualization, Data curation, Investigation, Methodology, Supervision, Validation, Writing – original draft. **Magdalena Urbańska** – Conceptualization, Data curation, Investigation, Writing – review & editing. **Przemysław Charzyński** – Conceptualization, Data curation, Investigation, Methodology, Supervision, Writing – original draft.

All authors read and approved the final manuscript.

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Gleby bielicowe – czarny koń podręczników czy białe plamy w wiedzy uczniów?

Słowa kluczowe:

Świadomość gleboznawcza
Geografia gleb
Bielicowanie
Podręczniki szkolne
Edukacja środowiskowa
Edukacja geograficzna
Nauczanie STEM

Streszczenie

Gleby bielicowe, choć zajmują jedynie około 14% powierzchni lądowej Polski i odgrywają ograniczoną rolę w produkcji rolnej, bardzo często omawiane są w szkolnych podręcznikach geografii. Ich wyrazista morfologa, charakteryzująca się łatwo rozpoznawalnym kontrastem barwnym pomiędzy poziomami glebowymi, może częściowo tłumaczyć dlaczego tak chętnie gleby te umieszczane są w podręcznikach. Celem badań była ocena zarówno reprezentacji gleb bielicowych w aktualnych materiałach edukacyjnych (w szkołach podstawowych i średnich), jak i poziomu wiedzy uczniów kończących oba etapy kształcenia. Badanie obejmowało analizę treści trzynastu powszechnie używanych podręczników geografii (trzech dla szkoły podstawowej i dziesięciu dla szkoły średniej) z ogólnopolską ankietą wśród 569 uczniów szkół podstawowych i średnich. Wykorzystano zarówno pytania otwarte, jak i zamknięte wielokrotnego wyboru w celu oceny wiedzy dotyczących właściwości i wartości użytkowej oraz umiejętności rozpoznawania omawianych gleb przez ankietowanych uczniów. Analiza aktualnie stosowanych podręczników potwierdziła, że gleby bielicowe są najczęściej wymienianą jednostką glebową, dominując nad czarnoziemami, glebami płowymi, brunatnymi czy madami. Sposób ich prezentacji ogranicza się głównie do ilustracji i ogólnych skojarzeń (np. niska żyzność, piaszczyste uziarnienie, użytkowanie leśne), przy minimalnym uwzględnieniu procesów powstawania, cech diagnostycznych czy właściwości chemicznych. Wyniki ankiety wykazały, że ponad jedna trzecia respondentów nie potrafiła podać ani jednego poprawnego skojarzenia z tymi glebami, a jedynie 13,4% poprawnie odpowiedziało na wszystkie cztery pytania zamknięte. Uczniowie szkół średnich osiągali lepsze wyniki od uczniów szkół podstawowych we wszystkich kategoriach, jednak nawet na wyższym poziomie edukacyjnym wiedza o cechach diagnostycznych i morfologii profilu glebowego pozostawała ograniczona. Do głównych błędnych przekonań należało przeszacowanie zasięgu gleb bielicowych, niewłaściwa ocena ich żyzności oraz wiązanie ich z węglanowym materiałem macierzystym. Uzyskane wyniki wskazują na trzy główne niedociągnięcia w edukacji glebowej: (1) zbyt statyczny sposób prezentacji gleb, koncentrujący się na wyglądzie i rozmieszczeniu zamiast na genezie i funkcjonalnych konsekwencjach; (2) ograniczony postęp w pogłębianiu treści między poziomem podstawowym a średnim; oraz (3) nieaktualne lub niespójne dane liczbowe w podręcznikach. Rozwiązanie tych problemów nie wymaga gruntownej reformy programu nauczania, lecz ukierunkowanego unowocześnienia, obejmującego m.in. aktualne mapy, zwięzłe wyjaśnienia istoty i uwarunkowań procesu bielicowania oraz omówienia omawianych gleb w kontekście użytkowym i ochrony przyrody. Takie zmiany mogłyby zmniejszyć lukę między rozpoznawaniem nazwy a funkcjonalnym zrozumieniem gleb bielicowych, wzmacniając kompetencje „glebowe" uczniów w Polsce.