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How Accurately Is Topsoil Texture Shown on Agricultural Soil Maps? A Case Study of Eleven Fields Located in Poland

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Abstract: Agricultural soil maps (ASMs) showing the agricultural land of Poland were prepared at a 1:5000 scale in the 1960s and 1970s. These maps show land suitability groups, soil type, and soil texture (ST) to a depth of 150 cm. Nowadays, these maps are being digitalized and might be a basis for the preparation of modern soil maps at the local, regional, national, and international levels. The agreement between the ST of the topsoil derived from ASMs and the recently evaluated one for eleven fields located in three voivodeships (regions) of Poland was studied. This study considered the examination of soil profiles or augerings and the laboratory analysis of the ST. The agreement between the ST status in the field and that according to the ASMs was field-specific. A complete agreement (purity) within the field was assessed for 5–79% of ST classes and for 23–100% of agronomic categories (ACs), i.e., groupings of similar ST classes. However, the averaged agreement, which treated adjacent ST classes as having a partial agreement, varied from 37 to 88% for ST classes and from 61 to 100% for the ACs among studied fields. These results indicate the variable quality of the information shown on ASMs and the necessity of improving these maps.

Keywords: agricultural soil maps; soil texture class; agronomic category; purity; averaged agreement

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Citation: Stępień, M.; Gozdowski, D.; Samborski, S. How Accurately Is Topsoil Texture Shown on Agricultural Soil Maps? A Case Study of Eleven Fields Located in Poland. *Land* **2024**, *13*, 1852. https://doi.org/10.3390/land13111852

Academic Editor: Alessandro Gimona

Received: 11 September 2024
Revised: 17 October 2024
Accepted: 22 October 2024
Published: 6 November 2024

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1. Introduction

Due to the environmental and ecological roles of soil, it maintains its importance at each level, from local to global, and this implies the need to possess reliable soil maps. For example, at the global level, soil maps are necessary for the preparation of various models, e.g., Earth surface fluxes, soil hydrologic properties, and pedotransfer models [1], and at the local level, soil maps are needed for the proper implementation of precision agriculture techniques, particularly for the variable application of agricultural inputs to increase their efficiency [2].

Polish agricultural soil maps (ASMs) were prepared in the 1960s and 1970s on the basis of soil quality maps (SQMs, 1:5000) and additional terrain studies [3] as support for farms in land management, planning, and soil conservation [4]. Although the ASMs may be considered as land-use maps, their content also includes information on the soil type. For this reason, according to Kabała et al. [5], ASMs will probably be one of the basic sources for the preparation of new and reinterpreted soil maps at medium and small scales, and, then, they will be an indirect source for the preparation of soil maps of Europe.

Soil texture (ST) is one of the most important properties shown on soil maps. This property is relatively stable across time [6], affects the majority of other soil properties, and is important for field management. ST (granulometric) classes (STCs) or soil species according to the Polish Society of Soil Sciences (PSSS, Polish acronym PTG) classification [7] (Figure 1 and Appendix A, Table A1), hereafter referred to as PTG 1956, have been used to show the ST on the ASMs, comprising about 90% of the area of the agricultural land of

Poland. Other soil species, in particular rendzinas, alluvial, and diluvial soils, and those originating from loess, are shown on maps for the remaining 10% of the area of agricultural land according to the digitalized agricultural soil map at a 1:25,000 scale [8]. In 1978, a new professional standard [9] was introduced, which modified the PTG 1956 classification by the further division of some of the STCs. This standard was a base for merging similar ST classes into soil agronomic categories (ACs, Figure 1 and Table A1), which, since 1986, have been used for formulating fertilizer recommendations [10,11] and, with the development of precision agriculture techniques, could be used for site-specific soil management. ACs are not shown on ASMs but may be relatively simply derived from these maps. These days, when digitalized ASMs are available at a low cost for the whole area of agricultural land of Poland, they can be used as a supplementary source of information on soil quality (mainly the drainage capability, strongly related to the ST), which is essential for crop rotation planning. Fertilizer recommendations should be based on the recent results of nutrient availability. However, these recommendations can be more precisely formulated because information about ACs can be derived from ASMs.

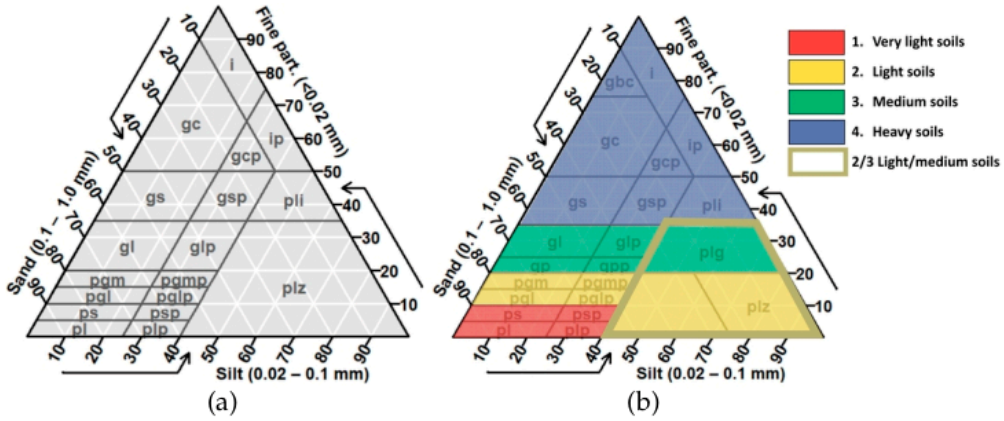


Figure 1. Soil texture triangles showing (**a**) soil texture classes according to PTG 1956, which are shown on agricultural soil maps, and (**b**) soil texture classes according to BN-78/9180-11 and soil agronomic categories. For an explanation of acronyms coding ST classes, see Table A1.

Thus, a question arises: to what extent does the content of the ASMs created in the 1960s and 1970s reflect the current or at least recent soil status of particular fields? Actually, not many studies have explored the agreement of ASMs with the recent soil status of agricultural land in Poland. Koćmit and Podlasiński [12] and Podlasiński [13] studied moraine areas with intensive relief in north-western Poland and concluded that the ASMs from the years of 1966–1974 do not reflect the current soil quality status of these areas, due to map generalization and changes in soil cover due to erosion. For this reason, the authors argued for the updating of ASMs by improving the accuracy of soil delineations, taking into account erosion transformations of the soil [12]. Stępień et al. [14] examined the topsoil texture of four fields in Poland and observed a very variable agreement, from 0 to 100%, between the ST indicated on the ASMs and the recent ST status of these fields. Also, at a global scale, not many studies have been conducted that compare ST derived from soil maps or determined by a laboratory or field method. In Brazil, Van den Berg and Oliveira [15] assessed the quality of soil maps of 33 fields (395 study sites) and they reported a very high map quality regarding ST in the soil layers of 0–20 cm and 60–80 cm, obtaining 80–95% of purity (the portion of points or the area with the correct prediction of a given attribute by the map). In Croatia, Hengl and Husnyak [16] evaluated 6 of a total of 186 sheets of soil maps of this country at a 1:50,000 scale. The contents of sand, silt, and clay were evaluated in 10 soil profiles with 21 samples, and they obtained normalized RMSE of 60–64% depending on the soil. This indicated low accuracy of this soil attribute as the value of the normalized RMSE should be lower than 40%. Radočaj et al. [17] validated the accuracy of ST shown on the SoilGrids2.0 with a resolution of 250 m, using ground truth

data from 686 soil samples taken from the layer of 0–30 cm. Relatively good accuracy of SoilGrids was obtained for clay content (normalized RMSE of 36%) and very poor for silt (normalized RMSE of 46%) and sand (normalized RMSE of 255%) contents, and, in general it was assessed as low. Richer-de-Forges et al. [18] evaluated various digital soil maps (DSMs) for central France to locally predict ST using hand feel ST determination performed for 3263 soil observation points. As a measure of the soil map accuracy, the authors used the shortest distance between the predicted laboratory ST and the observed hand feel ST class. For topsoil texture, this distance was the shortest for the regional the soil map (0.21) and much longer (0.32) for SoilGrids2.0. As a consequence, the authors questioned the local use of global or continental DSM products. In Namibia, Buenemann et al. [19] assessed various DSM products in terms of topsoil texture prediction quality using, in total, 1102 field locations as a reference. The authors obtained an overall accuracy of 0.27 (purity of 27%) for SoilGrids2.0 and up to 0.42 for WISE30sec [20] and concluded that all soil maps were inaccurate. Maynard et al. [21] evaluated the prediction accuracy of various soil maps (DSM products) of Ghana using three datasets of different sizes (from 75 to 6514 study sites) versus the results of field-estimated ST. The overall accuracy (corresponding to purity) of the maps regarding ST class according to the USDA classification varied from 9 to 35% and depended on the soil map and the dataset used. The overall accuracy, including adjacent ST classes, adjacent to the correctly predicted classes was higher, between 39 and 90%. The authors concluded that "...these map products are not accurate enough to inform site-specific soil management". In other studies on the assessment of the quality of soil maps, the topsoil texture was evaluated together with other soil properties. For example, in Mexico, Lleverino González [22] evaluated the quality of the Land Classification Map (Spanish: mapa de Clases de Tierras) as very high, with a purity of 76%. In central Iowa (USA), Brevik et al. [23] tested the accuracy of a soil map at a scale of 1:15,840 for a 25 ha field and obtained a map purity of 60–70% in the identification of two main soil delineations of four shown on the map, although it was lower in some delineations. Despite this good result in comparison to the national standard of map purity of 50%, the map quality was assessed as not adequate for precision agriculture purposes [23].

The aim of this study is a quantitative comparison of the information on topsoil texture shown on Polish ASMs at a scale of 1:5000 with recent ST status determined in a laboratory for eleven fields of a total area of 369 ha.

2. Materials and Methods

The works on the preparation of soil maps of Poland started in 1959 on the basis of very extensive data gathered during the preparation of the SQMs [6,24]. The creation of the SQMs included very extensive terrain studies, frequently based on a grid of 50 m for soil pits, both basic (to a depth of 150 cm) and auxiliary, and augerings. It was required to xamine at least one basic pit (to a depth of 150 cm) per delineation [6]. Most frequently, it resulted in 30–50 basic soil profiles per 100 ha. The preparation of ASMs included, among the others, examination of the existing documentation, mainly, but not only, SQMs, additional terrain studies including soil pits (4–6 per 100 ha), and preparation of final maps with generalization of existing data and smoothing of delineations. According to the assumption of this generalization, the smallest delineation could have an area of 0.5 ha in areas with very variable soils, 1.5 ha in areas with relatively homogeneous soil cover, and 0.1 ha for wastelands (N). More information on the content of SQMs and ASMs was provided by Stępień et. al. [14].

This study explores data obtained during agronomic studies carried out in 2009–2015. This study comprised 11 relatively large fields (19–111 ha) belonging to four commercial farms located in 3 regions (voivodeships) of Poland (Figure 2, Table 1). One of the main crops grown on these farms was winter wheat (*Triticum aestivum* L.), which was actually the main object of these studies. Locations of the farms represent three (northern, central and south-western) important areas of agricultural production belonging to Central European Lowlands, which occupy about 59% of area of Poland [25] and many areas of Germany,

The Netherlands, and Belgium. Soils of studied fields represent the most important soil types of Poland: brown soils (271 soil samples, map codes B and Bw corresponding to Cambisols, but, if not sandy, most frequently they are classified now as Luvisols without E horizon or Retisols), which occupy about 51.5% of the area of Poland [26], pseudopodzolic soils (22 samples, code A, these soils are currently named clay-illuvial soils and correspond mainly to Luvisols and Retisols), occupying 26% of the area, alluvial soils (73 samples, code F, mainly Fluvisols), 5% of the area, and black earths (68 samples, codes D, Dd and Dz, mainly Phaeozems), 1% of the country area [26]. These soil types are well represented in Europe: according to the Soil Atlas of Europe [27], the Retisols (referenced in the source as Albeluvisol) occupy 15% of the area; Cambisols, 12%; Luvisols, 6%; Fluvisols, 5%; and Phaeozems, 3%.

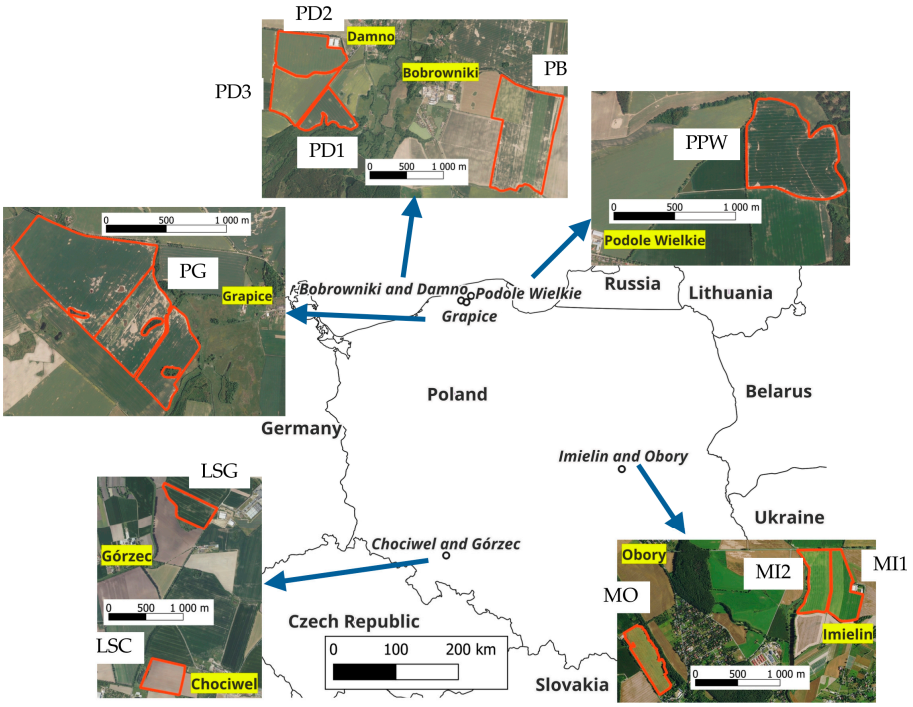


Figure 2. The locations of the study fields in 2009–2015.

In general, between 5 and 12 soil profiles were examined per field to a depth of about 1 m. Additionally, between 16 and 52 samples were collected from the plough layer with a density varying from 0.5 (larger fields) to 2 samples per ha. The location of soil sampling points was arbitrarily designed so that the number of soil samples from one map delineation was proportional to the area of this delineation. Thus, the larger areas delineated on the map were represented by a higher number of soil samples than smaller areas.

Soil sampling points were located in areas not closely situated to boundaries of soil types visible on archival ASMs imported into QGIS software (3.22.4-Białowieża) using the Georeferencer function. Geographical coordinates of soil sampling points were recorded using Topcon GRS-1 and GR-3, GNSS receivers (Livermore, CA, USA) with an accuracy of approximately 0.5 m [28,29]. Therefore, the accuracy of the GNSS receivers used was considered sufficient.

Table 1. Basic information on eleven fields studied in 2009–2015.

Region (Voivodship)	Locality	Latitude Longitude	Field	Area (ha)	Altitude Min.–Max. (m)	Prevailing (Associated) Soil Unit		Prevailing (Associated) Topsoil Texture Class		Soil Examination	
						Soil Type and Subtype (ASM) *	Soil Reference Group WRB 2023 (Recent Studies)	PTG 1956 (ASM)	USDA (Recent Studies)	Number of Topsoil Samples	Years of Soil Sampling
Pomerania	Bobrowniki	54°31′ N 17°21′ E	PB	107	65–74	Bw (B and Dd)	Luvisols (Regosols, Phaeozems, Gleysols)	gl (pgmp)	SL (LS)	61	2015
	Damno	54°32′ N 17°18′ E	PD1	22	54–63	Bw	Luvisols (Regosols, Cambisols)	pgm (glp)	SL (LS)	37	2011–2013
			PD2	44	58–69	Bw	Luvisols (Cambisols, Arenosols, Phaeozems)	glp (pgm)	SL (LS, L)	60	2013–2014
			PD3	40	60–66	Bw	Luvisols (Regosols, Cambisols)	glp (pgm, pgl)	SL (LS)	26	2013–2014
	Grapice	54°31′ N 17°26′ E	PG	111	63–81	Bw (D, Dd, A, B, Emt)	Luvisols (Retisols, Phaeozems, Arenosols)	pgm (pgl, pglp, ps, EmT	SL (LS)	56	2015
	Podole Wielkie	54°35′ N 17°30′ E	PPW	50	62–75	Bw (Dz)	Luvisols (Retisols, Phaeozems)	pgl (pgm, gl)	SL (LS)	26	2015
Mazovia	Imielin	52°05′ N 21°11′ E	MI1	21	88–89	F	Fluvisols	płz (ip)	SiL (L, LS)	33	2013–2014
			MI2	21	87–89	F (N)	Fluvisols	ip (płz, pgl, psp, N)	L (SL, SiL, LS)	41	2013–2014
	Obory	52°04′ N 21°09′ E	MO	19	105–108	A (Dz)	Luvisols (Phaeozems, Arenosols)	pgl (ps, gl)	SL (LS, L)	24	2015
Lower Silesia	Górzec	50°49′ N 17°04′ E	LSG	21	149–155	D (Dz, T)	Phaeozems	gcp and gsp (płi, T)	SiL (L, SL)	38	2013–2014
	Chociwel	50°48′ N 17°06′ E	LSC	20	165–168	B (D)	Luvisols (Phaeozems, Cambisols)	płi (gsp)	SiL (L)	37	2013–2014

*—English names of soil types (upper case letter) and subtypes (lower case letter) shown on ASM based on [24]: A—podzols and pseudopodzols (currently these soils correspond mainly to Luvisols and Retisols) B—brown soils, Bw—leached brown soils and acid brown soils, D—black earths, Dd—black earth (on deluvial material), Dz—degraded black earths and gray soils, F—alluvial soils, E—slimy peat and peaty slime soils (soils developed from limnic sediments on peat), T—peat, N—wastelands.

In total, 439 topsoil samples were collected, air-dried, sieved using a 2 mm mesh, and analyzed using the sieve-hydrometric method of Bouyoucos modified by Casagrande and Prószyński. This method is widely known and used in soil science. In Poland, this method was adapted to mass ST analyses by the use of a hydrometer produced by PTG, regional division in Cracow, Poland, and calibrated for a 40 g soil sample with the scale showing the content of tested soil separates in percent (%), if the measurement was performed at the strictly determined time [30]. This measurement time can be found in tables elaborated for similar STCs (https://www.zgf.uni.wroc.pl/dydaktyka/przedmioty/Gleboznawstwo/areometria_tab.pdf, accessed on 6 October 2024). Since the classification of soil texture PTG 1956 used on ASMs requires soil to be sieved by a 1 mm mesh, and our samples were sieved by 2 mm, so it was necessary to recalculate the results to treat the content of all soil separates smaller than 1 mm as equal to 100% [31,32]. The lack of such recalculation could lead to underestimates of the contents of silt and fine particles and, thus, to classify the soil as a coarser STC.

The agreement between STCs shown on the ASMs and ACs derived from these maps was assessed in soil sampling points. The agreement between STC in point of soil sampling shown on the ASM and determined in this study (STCagr) was evaluated according to Stępień et al. [14], as good (value 1), medium (value 0.5), and poor (value 0.0). This agreement was considered good (1.0) if the STCs determined in a laboratory were exactly the same as shown on the ST triangle. The agreement was assessed as medium (0.5) if the STC determined in our study belonged to a similar STC, i.e., adjacent to a respective group shown on the ST triangle (Table 2 and Figure 3).

Table 2. The criteria used for the agreement evaluation between soil texture class shown on an agricultural soil map and determined by a laboratory method.

STC (Granulometric Group) According to PTG 1956 Classification, Shown on the Map *	STC (Granulometric Group) According to PTG 1956 Classification, Determined in a Laboratory for the Studied Fields	Level of Soil Texture Agreement Between the Map and This Study	
		Kind	Value (STCagr)
ps **	ps	G (good)	1.0
	pl, plp, psp, pgl, pglp	M (medium)	0.5
	any other	P (poor)	0.0
psp	psp	G (good)	1.0
	pl, plp, płz, pgl, pglp	M (medium)	0.5
	any other	P (poor)	0.0
pgl	pgl	G (good)	1.0
	ps, psp, pglp, pgm, pgmp	M (medium)	0.5
	any other	P (poor)	0.0
pglp	pglp	G (good)	1.0
	ps, psp, płz, pgl, pgm, pgmp	M (medium)	0.5
	any other	P (poor)	0.0
pgm	pgm	G (good)	1.0
	pgl, pglp, pgmp, gl, glp	M (medium)	0.5
	any other	P (poor)	0.0
pgmp	pgmp	G (good)	1.0
	pgm, pgl, pglp, płz, gl, glp	M (medium)	0.5
	any other	P (poor)	0.0
płz	płz	G (good)	1.0
	plp, psp, pglp, pgmp, glp, gsp, pli	M (medium)	0.5
	any other	P (poor)	0.0
gl	gl	G (good)	1.0
	pgm, pgmp, glp, gl, gs, gsp	M (medium)	0.5
	any other	P (poor)	0.0
glp	glp	G (good)	1.0
	gl, pgm, pgmp, płz, pli, gsp, gs	M (medium)	0.5
	any other	P (poor)	0.0
gsp	gsp	G (good)	1.0
	gs, gl, glp, płz, pli, ip, gcp, gc	M (medium)	0.5
	any other	P (poor)	0.0
gcp	gcp	G (good)	1.0
	gc, gs, gsp, pli, ip, i	M (medium)	0.5
	any other	P (poor)	0.0
ip	ip	G (good)	1.0
	gc, gcp, gsp, pli, i	M (medium)	0.5
	any other	P (poor)	0.0
pli	pli	G (good)	1.0
	ip, gcp, gsp, glp, płz	M (medium)	0.5
	any other	P (poor)	0.0

*—for explanation of acronyms coding STCs, see Table A1. **—in this table, we considered only ST groups that were shown on the ASMs of the studied fields.

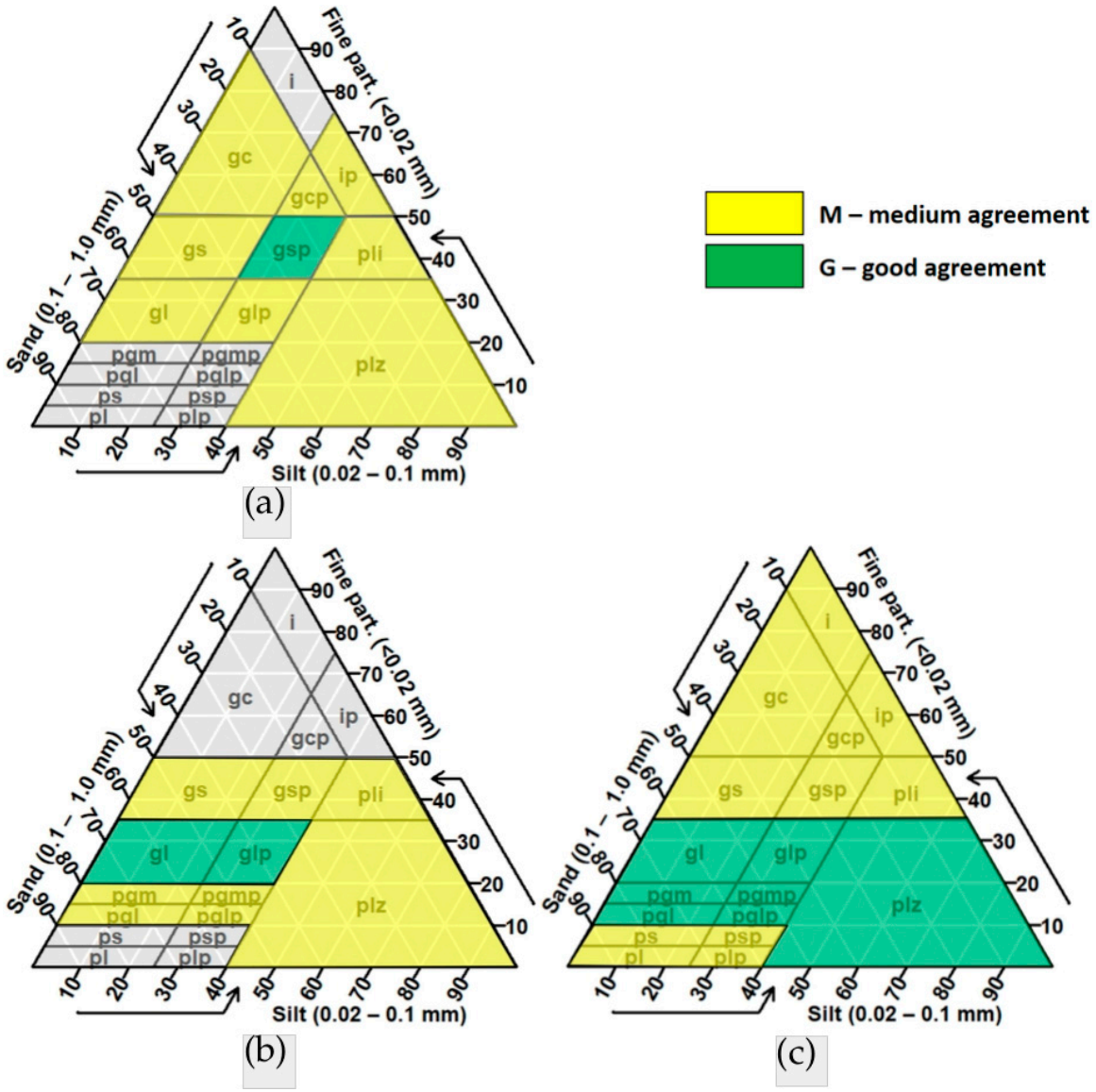


Figure 3. Soil texture (ST) triangles showing: (**a**) STCs used on the agricultural soil maps and an example of the determination of good and medium agreement between the map and recent ST status for gs; (**b**) an example of the determination of good and medium agreement between the map and recent ST status for AC 2. Medium soils; (**c**) an example of the determination of good and medium agreement between the map and recent ST status for AC 2/3—Light/medium (silty) soils.

The division of similar STCs into ACs [10,11] distinguished four categories (1. Very light, 2. Light, 3. Medium and 4. Heavy, Table A1 and Figure 1), which could be most frequently and directly derived from ASMs. The unique exception was ordinary silt (płz), which, in professional standard of ST classification [9] from 1978, was divided into 3 groups of silts: płp (sandy silt), "new" płz, which were then classified into the category of light soils, and płg (loamy silt), which was classified as medium soil (see Figure 1). As a result, the "old" płz shown on the ASMs could be classified as light or medium. For this reason and for the purposes of this study, the AC of 2/3. Light/medium (silty) soils was distinguished (Tables 3 and A1 and Figure 1). As a result, this "old" płz has a medium agreement (0.5) with 7 ST classes. If agreement of ACs between ASM and our studies (ACagr) is considered, it has good agreement with 2 categories (2 and 3), and it was medium with the remaining 2 categories (1 and 4), as shown in Table 3 and Figure 3.

Table 3. The criteria used for the agreement evaluation between the agronomic category (AC) derived from an agricultural soil map and determined by a laboratory method.

AC Derived from Agricultural Soil Map (STCs According to PTG 1956) *	ACs (STCs According to PTG 1956) Determined for the Studied Fields	Level of Agreement Between the Map and This Study	
		Kind	Value (ACagr)
1. Very light soils (ps and psp)	1. (pl, plp, ps, psp)	G (good)	1.0
	2. (pgl, pglp, pgm, pgmp, płz) and 2/3 (płz)	M (medium)	0.5
	any other	P (poor)	0.0
2. Light soils (pgl, pglp, pgm, pgmp)	2. (pgl, pglp, pgm, pgmp)	G (good)	1.0
	1. (pl, plp, ps, psp), 2/3 (płz) and 3 (gl, glp)	M (medium)	0.5
	any other	P (poor)	0.0
2/3. Light/medium (silty) soils (płz)	2. (pgl, pglp, pgm, pgmp), and 3 (gl, glp) and 2/3 (płz)	G (good)	1.0
	1. (pl, plp, ps, psp) and 4 (gs, gsp, płi, gc, gcp, i, ip)	M (medium)	0.5
	-	P (poor)	0.0
3. Medium soils (gl, glp)	3. (gl, glp) and 2/3 (płz)	G (good)	1.0
	2. (pgl, pglp, pgm, pgmp) and 4. (gs, gsp, płi, gc, gcp, i, ip)	M (medium)	0.5
	any other	P (poor)	0.0
4. Heavy soils (gsp, gcp, ip, płi)	4. (gs, gsp, płi, gc, gcp, i, ip)	G (good)	1.0
	3. (gl, glp) and 2/3 (płz)	M (medium)	0.5
	any other	P (poor)	0.0

*—for the explanation of the codes used to denominate each AC (number and name) and ST classes (abbreviations), see Table A1.

For an explanation of the abbreviations coding all ST classes, the content of soil separates, and attribution to the agronomic categories (ACs) see Table A1 and Figure 1.

The agreement between the ST class derived from the ASM and determined using a laboratory method in this study for the particular soil sampling points was calculated using two measures: purity/overall class accuracy (Pur.) and averaged agreement (AA).

The purity of soil map was defined by Bie and Beckett [33] as the "percentage of random sites at which map would have predicted the class to which the soil belongs", and this definition corresponds to overall class accuracy [21], i.e., "the proportion of observation points at which the map predicts the correct soil property class". In our study, soil map purity (Pur.) was calculated according to the following formula:

$$\text{Pur. (\%)} = \text{nG } 100/(\text{nG} + \text{nM} + \text{nP}) \quad (1)$$

where nG is the number of points in the field or other dataset with a good agreement of ST status between the map and this study (STCagr or ACagr, depending on ST classification considered), nM is the number of points with a medium agreement, and nP is the number of points with a poor agreement in the map.

The averaged agreement (AA) was calculated according to the following formula:

$$\text{AA (\%)} = (\text{nG } 1.0 + \text{nM } 0.5)\ 100/(\text{nG} + \text{nM} + \text{nP}) \quad (2)$$

This formula is actually the same as provided by Stępień et al. in 2015 [14], although written in a different way. The purity and AA were calculated regarding STCs shown on ASMs and ACs derived from these maps for each field separately and also for data merged for all fields.

Additionally, example maps of three fields were prepared using QGIS (3.22.4-Białowieża) open software. The preparation of these maps was performed in following steps: (1) Preparation of map background by assigning geographic coordinates to characteristic points (e.g., field corners) of archival ASM (1:5000) scans using the Georeferencer function of QGIS. Exceptionally, for LSG and LSC fields, we used digitalized ASMs. (2) Overlay of field

boundaries and soil sampling locations on the ASM raster with point style and etiquettes showing STCs and ACs according to both the map and our studies. (3) Manual delineation of the areas of estimated disagreement of the ACs derived according to ASMs and this study. Such an area was designated if there were at least two adjacent soil sampling points with respective disagreement and the boundaries were adjusted to the boundaries of the existing map delineations. Therefore, the boundaries of disagreement areas and their size have only illustrative value, since the method adopted in this study to assess the agreement between maps and our soil study is based on values measured at soil sampling points.

Finally, the effect of chosen factors on the agreement between ST shown on the ASM and ST, according to our study, was tested within the whole dataset. The effect of soil type shown on ASMs was checked using the Kruskal–Wallis test, which is equivalent to one-way ANOVA for the data without a normal distribution. The effect of the simplest topographic features was related to altitude derived from the European Digital Elevation Model (EU-DEM) with an approximate resolution of 30 m. The following topographic features were selected: DeltaHfld (m), which we defined as a difference between DEM maximum and minimum altitude observed within the field; DeltaHfldperarea (m/ha), which is Deltahfld divided by field area, HRel_point (m), which is the difference between DEM altitude in a particular point and minimum DEM altitude in a field. To check the strength and direction of the relationship between studied agreements and mentioned topographic features within the whole dataset, the Spearman's rank correlation coefficients were calculated. All statistical analyses were carried out with Statistica (data analysis software system, TIBCO software), version 13 (https://www.statistica.com, accessed on 29 October 2024).

3. Results

3.1. Expectations: The Soil Texture Classes and Agronomic Categories According to the Maps (ASMs) and Their Representativeness

The representativeness of the STCs and the AAs, derived from these STCs, was very variable. Five STCs were not shown on the maps of the studied fields, and the number of topsoil samples of the remaining STCs, according to the PTG 1956, varied between 4 and 111. Table 4 presents the number of soil samples in ST classes shown on the agricultural soil maps of fields considered in this study and the approximated area of these delineations based on digital ASMs prepared at a 1:25,000 scale. The most represented delineation of ST class (according to the map) was pgm (strong loamy sand, 111 samples, almost 150 ha of five fields, located in one region), then gl (light loam, 64 samples, 117 ha, three fields, two regions), glp (silty light loam, 59 samples, 57 ha, four fields, one region) and pgl (light loamy sand, 45 samples, 55 ha, five fields, two regions). Less represented were the delineations of the ST class, such as płz (ordinary silt, 34 samples, 21 ha from two fields, and one region), gsp (silty medium loam, 33 samples, 16 ha from 2 fields, and 1 region), ip (silty clay, 28 samples, two fields, and one region), płi (clayey silt, 26 samples, two fields, and one region) and gcp (silty heavy loam, 13 samples, one field). According to the ASMs, very small representations of ps (weakly loamy sand), pgmp (silty strong loamy sand), pglp (silty light loamy sand) and psp (silty weakly loamy sand) 4–7 samples, 0.5–7.0 ha from one or two fields and regions) was found. Additionally, five samples were collected from very small areas delineated as organic soils (Emt or T) and wastelands (N). In this study, there was no representation of pl (loose sand), plp (silty loose sand, both belong to very light soils), gs (medium loam), gc (heavy loam) and i (clay, all three STCs belonging to heavy soils, Table A1) of STCs.

Table 4. The number of soil samples in ST classes (the upper line for each field) and their approximated areas ** in hectares (the lower line for each field) shown on the agricultural soil map and the ACs derived from these classes for fields considered in this study.

Region	Locality	Field	ACs, STCs *, and Other Mapping Units ** According to the Agricultural Soil Maps															
			1. Very Light			2. Light			2/3. Light/Medium	3. Medium		4. Heavy				Emt	N	T
			ps	psp	pgl	pglp	pgm	pgmp	płz	gl	glp	gsp	gcp	ip	pli			
Pomerania	Bobrowniki	PB						6 7.0		55 99.9								
	Damno	PD1					34 19.2				3 2.7							
		PD2					16 12.4				44 31.4							
		PD3			2 0.9		12 15.8				12 23.1							
	Grapice	PG	2 2.7		7 16.5	4 3.8	42 86.7									1 0.9		
	Podole Wielkie	PPW			13 21.2		7 14.5			6 13.9								
Mazovia	Imielin	MI1							22 14.2					11 7.4				
		MI2		4 0.5	7 3.6				12 6.4					17 10.1			1 0.4	
	Obory	MO	5 2.4		16 12.9					3 3.1								
Lower Silesia	Górzec	LSG										20 8.6	13 8.8		2 1.9			3 0.9
	Chociwel	LSC										13 7.8			24 12.5			
Sum within	ST class		7 5.1	4 0.5	45 55.1	4 3.8	111 149.0	6 7.0	34 20.6	64 116.9	59 57.2	33 16.0	13 8.8	28 17.5	26 14.4	1 0.9	1 0.4	3 0.9
	AC		11 5.6			166 214.9			34 20.6	123 174.1				100 56.7		1 0.9	1 0.4	3 0.9

*—for an explanation of acronyms coding ST classes, see Table A1. **—the other mapping units are the areas that were present during the preparation of the agricultural soil map, but currently are cropped with annual crops. The code Emt shown on the map of field PG denominates a kind of Histosol (in Polish: gleby mułowo-torfowe, i.e., soils developed from limnic sediments on peat), the code N shown on the map of field MI2 is used for waste lands and the code T shown on the map of this field LSG denominates peat (in Polish: torf) [3]. Please note that approximated areas were derived from digitalized agricultural soil maps 1:25,000 (except fields LSG and LSC, 1:5000 digitalized maps), and thus hey do not reflect exactly the areas of particular delineations according to all 1:5000 maps.

In terms of the ACs which might be derived from the ASMs, the light soils were most represented (165 samples collected from 215 ha of nine fields, and two regions), followed by medium soils (123 samples, 174 ha from six fields, and two regions) and heavy soils (100 samples, 57 ha, four fields, and two regions). Much smaller was the representation of an intermediate category of light/medium (silty) soil, płz (34 samples, 2 fields, one region), and the very light soils (ps and psp, 11 samples and 6 ha from three fields, and two regions).

3.2. Reality: Agreement of the Topsoil Texture Classes According to the Agricultural Soil Maps of the Fields with the Topsoil Texture Determined in This Study

Our studies revealed great differences between recent STCs determined by laboratory analyses and STCs shown on ASMs, both within and between particular fields. A comparison of the presence of particular STCs in the fields according to our recent studies and the ASMs is shown in Table 5. When entire fields were considered, the purity of the delineation of ST classes varied between 5 and 79%, and the AA was between 36 and 88%, with the highest values obtained for only one field PB (Table 5). On the other hand, very low purity of the ASM in comparison to the recent ST status was obtained for fields PD2 (5%), MI1 (9.1%) and MI2 (9.8%), and the map purity of remaining fields was between 10 and 50%. The AA of ST classes according to the ASMs and recent ST status on the fields was higher, and it exceeded 50%, not only for the PB field but also for the other five fields: PD1, PD2, PD2, LSG, and LSC.

If particular delineations within fields were considered, the agreement between ST shown on the ASMs and recent ST status was more variable, as both the purity and the AA varied between 0 and 100%, even within one field (Table 5). The null purity (0%) of the ASMs was found in 13 delineations of eight fields and perfect purity (100%) in one delineation of one field.

In this study, examples of the ASMs of three fields are discussed in more detail. In the PB field (Table 6, Figure 4), with apparently the best agreement of the ST class obtained from the ASM and a recent laboratory analysis, two STCs were shown on the map. The smaller delineation of pgmp (located in the north-western corner of the field) showed 0% map purity but 50% of the AA, as all topsoil samples belonged to a similar gl STC. The delineation of gl, shown on the map for most of the field, had a purity of 87% and AA of 92%, but some samples from this delineation (close to the middle of the southern part of the field) belonged to other ST classes, such as pgm, pgl, pgmp and gs. In other words, the PB field is actually loamy (gl), both according to the ASM and recent ST evaluation, but some more sandy areas (pgl and pgmp) were present in other places than indicated on the original ASM.

The PPW field was characterized by map purity of 31% and an AA of 44.2% between the map and the recent ST status (Table 5, Figure 5). The most extensive delineations of pgl on the ASM (south-eastern part) of this field had very poor agreement between the map and recent soil status, with a purity of 0% and AA of 8%, as, actually, gl prevailed in this area (11 samples out of 13). Smaller delineation of pgm showed much better agreement between the map and recent ST evaluation, 29% of purity and 64% of the AA, although it was also mainly loamy (gl) for five samples out of seven. The last and slightly smaller delineation of gl according to the map was also gl according to this study (six samples), and it resulted in a perfect evaluation of both the purity and AA. In other words, according to the ASM, the significant part of this field should be predominantly sandy (pgl and pgm, 20 samples out of 26), but, according to a recent study, it is loamy, as sandy loam (gl) predominates in this field (21 samples out of 26).

Table 5. Comparison of soil texture classes (STCs) within the studied fields according to the agricultural soil maps and recent laboratory evaluation.

Region	Locality	Field	Delineations on the Map		Map Agreement with Recent ST Status			
			STC * (Number of Samples)		Within Delineation		Within the Field	
			According to the Map	According to Recent Studies	Pur. (%)	AA (%)	Pur. (%)	AA (%)
Pomerania	Bobrowniki	PB	pgmp (6)	gl (6)	0.0	50.0	78.7	87.7
			gl (55)	gl (48), pgm (4), pgl (2), gs (1)	87.3	91.8		
	Damno	PD1	pgm (34)	gl (23), pgm (7), pgl (2), pgmp (1), gs (1)	20.6	58.8	21.6	59.5
			glp (3)	gl (2), glp (3)	33.3	66.7		
		PD2	pgm (16)	gl (13), pgm (2), gs (1)	12.5	53.1	5.0	51.7
			glp (44)	gl (39), glp (1), gs (2), pgm (2)	2.2	51.1		
		PD3	pgl (2)	gl (2)	0.0	0.0	11.5	50.0
			pgm (12)	gl (7), pgm (3), pgl (1), gs (1)	25.0	58.3		
			glp (12)	gl (11), gs (1)	0.0	50.0		
			ps (2)	pgm (1), pgmp (1)	0.0	0.0		
	Grapice	PG	pgl (7)	gl (3), pgmp (2), pgm (1), pgl (1)	14.3	35.7	10.7	46.4
			pglp (4)	gl (4)	0.0	0.0		
			pgm (42)	gl (29), pgm (5), glp (4), pgmp (2), pgl (2)	11.9	56.0		
			Emt ** (1)	pgm (1)	0.0	0.0		
	Podole Wielkie	PPW	pgl (13)	gl (11), pgm (2)	0.0	7.7	30.8	44.2
			pgm (7)	gl (5), pgm (2)	28.6	64.3		
			gl (6)	gl (6)	100.0	100.0		
Mazovia	Imielin	MI1	ip (11)	gsp (7), płz (2), pli (2)	0.0	40.9	9.1	47.0
			płz (22)	gsp (6), glp (6), płz (3), pli (3), gs (2), gl (1), pgmp (1)	12.0	50.0		
		MI2	psp (4)	gl (3), pgl (1)	0.0	12.5	9.8	36.6
			pgl (7)	pgl (3), pgm (3), gl(1)	42.9	64.3		
			płz (12)	gl (4), glp (4), gsp (2), pli (1), gcp (1)	0.0	29.2		
			ip (17)	gsp (6), glp (4), gcp (3), ip (1), pli (1), gc (1), pgm (1)	5.9	38.2		
			N *** (1)	pgmp (1)	0.0	0.0		
	Obory	MO	ps (5)	pgm (2), pgl (1), gs (1), gsp (1)	0.0	10.0	29.2	47.9
			pgl (16)	pgm (6), pgl (5), gl (3), pgmp (1), glp (1)	31.3	53.1		
			gl (3)	gl (2), gs (1)	66.7	83.3		
Lower Silesia	Górzec	LSG	gsp (20)	gsp (8), gcp (4), gl (4), glp (3), płz (1)	40.0	70.0	31.6	61.8
			gcp (13)	gsp (6), pli (4), gcp (3)	23.1	61.5		
			pli (2)	pli (1), gsp (1)	50.0	75.0		
			T **** (3)	płz (1)	0.0	0.0		
	Chociwel	LSC	gsp (13)	gcp (9), gsp (4)	30.8	65.4	13.5	56.8
			pli (24)	gsp (18), gcp (5), pli (1)	4.2	52.1		

*—for explanation of acronyms coding ST classes see Table A1. **—Emt is a kind of organic soil ("gleby mułowo-torfowe" in Polish). ***—N is a wasteland. ****—T is a peat

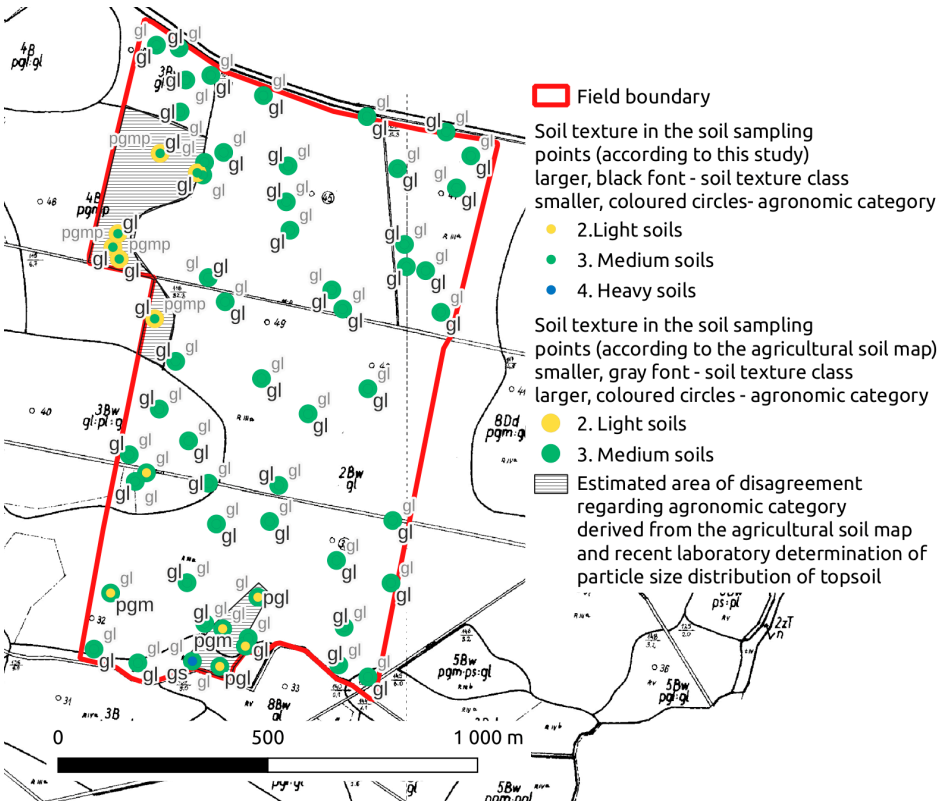


Figure 4. Field PB: soil sampling points with soil texture classes and agronomic categories according to this study and the agricultural soil map, superimposed on the scan of the original ASM. For an explanation of acronyms coding ST classes, see Table A1.

Table 6. Comparison of agronomic categories (ACs) of the studied fields derived from agricultural soil maps and from recent ST evaluation.

Region	Locality	Field	Delineations on the Map		Map Agreement with Recent ST Status			
			AC * (Number of Samples)		Within Delineation		Within the Field	
			According to the Map	According to Recent Studies	Pur. (%)	AA (%)	Pur. (%)	AA (%)
Pomerania	Bobrowniki	PB	Light (6)	Medium (6)	0.0	50.0	78.7	93.6
			Medium (55)	Medium (48), light (6), heavy (1)	87.3	93.6		
	Damno	PD1	Light (34)	Medium (23), light (10), heavy (1)	29.4	63.2	38.2	66.2
			Medium (3)	Medium (3)	33.3	66.7		
		PD2	Light (15)	Medium (12), light (2), heavy (1)	12.5	56.3	70.0	84.2
			Medium (45)	Medium (42), heavy (2), light (2)	90/9	95.5		
		PD3	Light (14)	Medium (9), light (4), heavy (1)	28.6	60.7	57.7	76.9
			Medium (12)	Medium(11), heavy (1)	91.7	95.8		
	Grapice	PG	Very light (2)	Light (2)	0.0	50.0	23.2	60.7
			Light (53)	Medium (40), light (13)	24.5	62.3		
			Emt ** (1)	Light (1)	0.0	0.0		
	Podole Wielkie	PPW	Light (20)	Medium (16), light (4)	20.0	60.0	38.5	69.2
			Medium (6)	Medium (6)	100.0	100.0		
Mazovia	Imielin	MI1	Heavy (11)	Heavy (9), light/medium (2)	81.8	90.9	60.6	80.3
			Light/medium (22)	Heavy (11), medium (7), light/medium (3), light (1)	50.0	75.0		
		MI2	Very light (4)	Medium (3), light (1)	0.0	12.5	63.4	75.6
			Light (7)	Light (7), medium (1)	85.7	92.9		
			Light/medium (12)	Medium (8), heavy (4)	66.7	83.3		
			Heavy (17)	Heavy (12, medium (4), light (1)	70.6	82.4		
			N *** (1)	Light (1)	0.0	0.0		
	Obory	MO	Very light (5)	Light (3), heavy (2)	0.0	30.0	50.0	75.0
			Light (16)	Light (12), medium (4)	75.0	87.5		
			Medium (3)	Medium (2), heavy (1)	66.7	83.3		
Lower Silesia		LSG	Heavy (35)	Heavy (27), medium (7), light/medium (1)	77.1	88.6	71.0	81.6
			T **** (3)	Light/medium (1)	0.0	0.0		
	Chociwel	LSC	Heavy (37)	Heavy (37)	100.0	100.0	100.0	100.0

*—for explanation of codes and names of ACs see Table A1 and Figure 1. **—Emt is a kind of organic soil ("gleby mułowo-torfowe" in Polish). ***—N is a wasteland. ****—T is a peat

The ASM of field MI2 was characterized by very poor purity (9.8%, Table 5) and the lowest AA (36%) among all tested fields. The ASM showed four delineations of different topsoil textures and one delineation of wasteland (N, Table 6 and Figure 6). The wasteland showed 0% of both purity and AA of the ASM in comparison with the recent ST evaluation, as it is currently included in the cropped area. However, the other two delineations of topsoil (płz and psp) also showed 0% purity and poor AA (12.5 and 29.2%, respectively). The most extensive delineation (10 ha with 17 samples taken) of silty clay (ip) also showed low purity (6%) and an AA of 38%. However, small delineation of pgl (about 4 ha) showed relatively good agreement between the map and a recent study, with 43% purity and 64% of the AA.

Consequently, it can be concluded that, in fields with generally good agreement of ST derived from the ASM and recent topsoil texture evaluation, areas of poor agreement are found, while in fields with overall poor agreement between the map and recent evaluation, areas of good agreement may be observed.

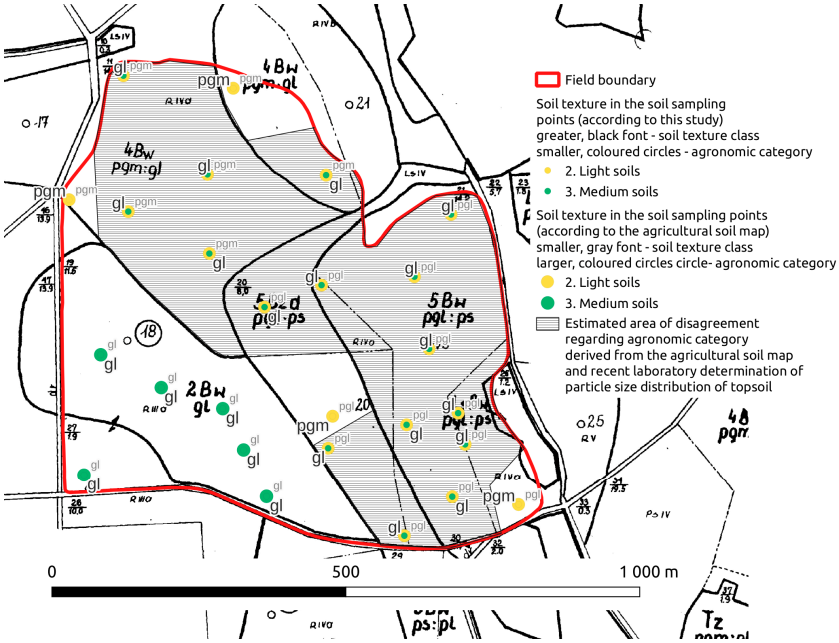


Figure 5. Field PPW: soil sampling points with soil texture classes and agronomic categories according to this study and the agricultural soil map, superimposed on the scan of the original ASM. For an explanation of acronyms coding ST classes see Table A1.

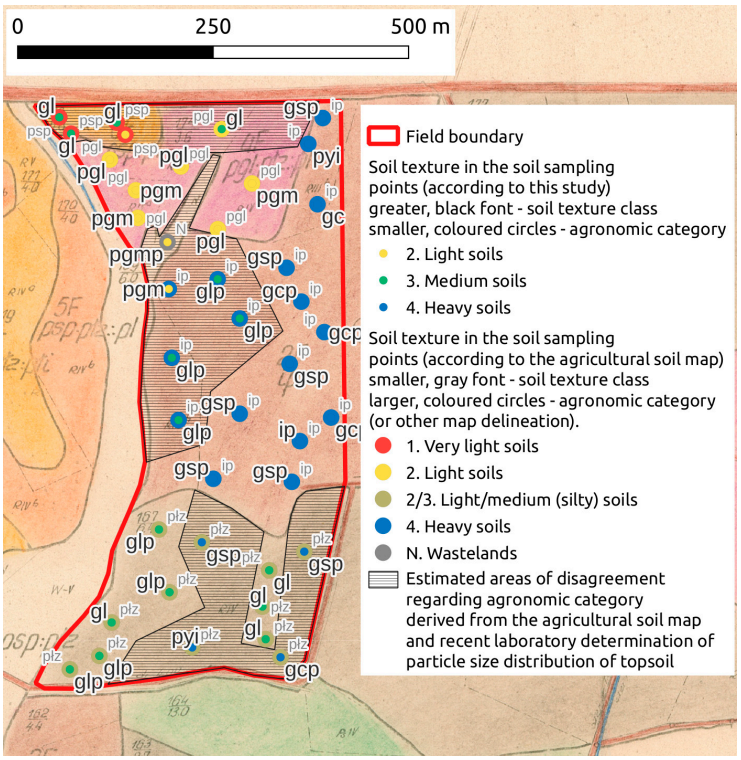


Figure 6. Field MI2: soil sampling points with soil texture classes and agronomic categories according to this study and agricultural soil map, superimposed on the scan of the original map. The area of disagreement regarding the agronomic category was delineated according to rules provided in Table 3, i.e., the soil texture classes gl and glp (medium soils) are considered to be in complete agreement with płz which actually may belong to both agronomic categories: light and medium soil, but cannot be exactly divided between them, so for the purpose of this study it was treated as a separate category of 2/3 Light/medium (silty) soils.

3.3. Reality: Agreement of the Topsoil Agronomic Categories According to the Agricultural Soil Map of the Fields with the Agronomic Categories Determined in This Study

Generally, agreements between ACs derived from the ASMs and from the recent soil ST evaluation of all studied fields were considerably higher than the respective agreements for ST classes. For entire fields (Table 6), map purities varied between 23 and 100% and exceeded 50% in the case of eight fields. The averaged agreement between ASMs and recent soil status exceeded 50% for all fields considered in this study.

As for STCs, the respective agreements for ACs were considerably lower for some particular delineations within fields than for whole fields (Table 6). The map purity of these delineations regarding ACs varied between 0 and 100%, but, in general, it was higher than for STCs. The null (0%) purity of the ACs was observed in 7 delineations for five fields, but it exceeded 50% in 11 delineations for eight fields. In the case of some fields (PG, PPW, MI2, MO, and LSG), delineations with the agreements of ACs derived from the ASMs and recent ST studies varying between 0 and 100% were found. However, some of these null agreements refer to small areas close to the field boundaries, which were delineated as organic soils (Emt or T) or wastelands (N, Figure 5) and are currently treated as arable land.

If we consider the same three examples of fields, as described in the previous section, considering the AC (Table 6) instead of STC (Table 5), the general agreement of ASM with recent evaluations did not change considerably for the PB field (Figure 4). Only for the most precisely mapped delineations of sandy loam (gl) did the AA slightly increase to 94%. In the PPW field (Figure 5 and Tables 5 and 6), the overall purity of the map and AA with recent evaluation increased to 39 and 69%, respectively. Surprisingly, the field MI2 (Figure 6) was characterized by poorer agreement of the ASM with the recent reality in terms of ST classes than field PPW, but it was better assessed in terms of ACs (63 and 76% of purity and AA, respectively).

3.4. Agreement of the Topsoil Agronomic Categories Derived from the Agricultural Soil Maps and Determined in the Recent Studies Across the Whole Dataset

The overall purity of the ASMs in all fields considered in this study in comparison with recent soil status on the field was about 24% regarding ST classes and 60% for the ACs (Tables 7 and A2). The average agreement was higher and amounted to almost 56% and 79% for ST classes and ACs, respectively.

If the delineations of the same ST class from the maps of all fields included in this study are considered, high variability in the values of agreement between ASM and recent ST status could be noted, as the purity varied between 0 and 88%, and the AA ranged from 0 to 92%. The lowest values of map agreement with recent ST status were observed most frequently for poorly represented delineations, such as pglp (four samples from one field, 0% of purity and the AA), ps (seven samples from two fields and two regions, 0% of purity and 7% of AA), psp (four samples from one field and region, purity 0% and AA 13%) and pgmp (six samples from one field and region, purity 0%, but AA 50%). Other delineations with poor purity (<10%) and AA (<50%) were relatively well represented, namely pgl (45 samples), płz (34) and ip (28). The assessment of agreement of glp (59 samples) and płi (26 samples) delineations of ASM with recent soil status in the field was quite ambiguous, as both delineations were characterized by very poor map purity (<1)%) and much better AA (56% and 54%, respectively). The best represented delineation of the STC in this study, pgm (111 samples from five fields and one region), still had relatively low map purity of 17% and not a very high AA of 58%. In contrast, poorly represented gcp delineation (13 samples from one field) had higher map purity of 23% and an AA of 62%. A relatively well represented delineation of a similar soil texture class, gcp (33 samples from two fields and one region), had a purity of 43% and AA of 68%. The unique delineation with very good agreement between the ASM and recent ST status was gl (64 samples from three fields, and two regions), with purity of 88% and AA of 92%.

Table 7. The agreements of STCs shown on agricultural soil maps and ACs derived from these classes for the eleven fields considered in this study.

Agreement Between ASM and Recent ST Evaluation		ACs, STCs *, and Other Mapping Units ** According to the Agricultural Soil Map																Across all Fields and Delineations
		1. Very Light		2. Light				2/3. Light/ Medium	3. Medium		4. Heavy				Emt	N	T	
Within	Measure of agreement	ps	psp	pgl	pglp	pgm	pgmp	płz	gl	glp	gsp	gcp	ip	pli				
ST class	Pur. (%)	0.0	0.0	20.0	0.0	17.1	0.0	8.8	87.5	3.4	42.9	23.1	3.6	7.7	0.0	0.0	0.0	24.4
	AA (%)	7.1	12.5	28.9	0.0	57.7	50.0	42.6	92.2	51.7	68.2	61.5	39.3	53.8	0.0	0.0	0.0	55.6
AC in ST classes delineated	Pur. (%)	0.0	0.0	53.3	0.0	25.5	0.0	55.9	87.5	90.0	75.8	100.0	75.0	100.0	0.0	0.0	0.0	60.3
	AA (%)	35.7	12.5	76.7	50.0	60.9	50.0	77.9	93.8	95.0	87.9	100.0	85.7	100.0	0.0	0.0	0.0	78.6
AC in general	Pur. (%)	0.0			30.7			55.9	89.4			85.0						60.3
	AA (%)	27.3			64.5			77.9	94.7			92.0						78.6
Number of soil samples/fields/regions (ST class)		7/2/2	4/1/1	45/5/2	4/1/1	111/5/1	6/1/1	34/2/1	64/3/2	59/3/1	33/2/1	13/1/1	28/2/1	26/2/1	1/1/1	1/1/1	3/1/1	
Number of soil samples/fields/regions (AC)		11/3/2		166/9/2				34/2/1	123/6/2		100/4/2				1/1/1	1/1/1	3/1/1	

*—for an explanation of acronyms coding STCs and codes and names of ACs, see Table A1. **—the other mapping units are the areas that were present during the preparation of the agricultural soil maps, which are currently cropped with annual crops. According to Bartoszewski et al. [3] the code Emt shown on the map of this field denominates a kind of Histosol (in Polish: gleby mułowo-torfowe, i.e., soils developed from limnic sediments on peat). The code N shown on the map of this field was used for waste lands. The code T shown on the map of this field denominates a kind of Histosol, particularly peat (in Polish: torf).

The evaluation of the agreement of ACs, which can be indirectly derived from ASMs, with recent soil status in the fields studied may lead to opposite conclusions. Poorly represented very light soils (two soil texture classes of 4, 11 samples from three fields and two regions) had null (0%) map purity and a low AA of 27%, in comparison with the recent ST status of the fields. Light soils were best represented in this study (166 samples, although mainly from two soil texture classes, nine fields and two regions) and had an overall map purity of 31% and AA of 65%. The modestly represented intermediate category of silty light/medium soils (płz) had an acceptable purity of 56% and AA of 78%. The measures of agreement for the medium (123 samples, six fields and two regions) and heavy soils (100 samples, two fields from one region) appeared to have very good purity (89% and 85% respectively), with an AA of 92%. It is clear that many medium and heavy soils were recently relatively common in the delineations of light and very light soils found on the ASMs. The opposite situation, the presence of light soils within the delineation of medium and heavy soils, could also occur but much less frequently. However, only nine soil samples (2% of all samples, Table A2) were attributed to a non-adjacent AC, five samples from delineations of very light soils, three samples of light soils, and one sample of heavy soil.

According to the Kruskal–Wallis test (Table A3), the differences in the agreement regarding the soil texture class (STCagr) and agronomic category (ACagr) were statistically significant. Soil types with notable representation in our study showed high agreement >72% regarding the agronomic category (B: 79%; D: 83%; A: 73%; and F: 79%), and two of them (B (61%) and D (58%)) showed lower but still higher than 50% agreement regarding STC. The soil types (E and T) or wastelands (N), which were marginally represented in this study, showed null agreement between ASMs and our measurements of ST. The major part of selected topographic features (Table A4), excluding the relationship between STCagr and DeltaHfld, was statistically significant but very weak and always higher for ACagr. DeltaHfldperarea showed consistent results with both STCagr and ACagr as it had a negative sign for the Spearman's rank correlation coefficient. This means that a higher variability in the altitude (the more intensive relief) within the fields decreased the map accuracy in comparison with recent ST status evaluations.

4. Discussion

In general, this study carried out on 11 fields located in three regions of Poland indicates variable but relatively poor to medium agreement between ASMs and recent topsoil status regarding STCs (purity of 20% and AA of 56%) and medium to good agreement of ACs (purity of 60% and AA of 79%). The results of this research are consistent with the previous work of Stępień et al. [14], which also indicated very variable agreement between ST derived from the ASM and the recent ST status of the field, not only between fields but also within fields. Moreover, this study included the same field PD1, named A in the study of Stępień et al. 2015 [14], which was sampled independently (58 topsoil samples). However, the agreement between ST on the map was very similar (purity regarding ST classes of 22.4%) in athe previous study [14] to that obtained in the current research of 21.6%.

It is difficult to compare our results with other studies on the accuracy of topsoil texture prediction based on soil maps with their status in the field because of the lack of a quantitative comparison of map accuracy or various measures of this accuracy applied in different studies.

Research by Koćmit and Podlasiński [12] on the accuracy of ASMs (1:5000) in Pomerania in north-west Poland proved the very high heterogeneity of soil cover and relatively small representativeness of these maps due to their generalization and posterior erosive transformation of soils, but the authors did not assess map accuracy quantitatively.

Van den Berg and Oliveira [15] studied the accuracy of soil maps at a scale of 1:100,000 from Sao Paolo State in Brazil and reported average purity regarding ST of 90%, both for topsoil (0–20 cm) and deep soil layers (60–80 cm). These authors used the FAO classification

of ST from 1977 [34] comprising six classes, i.e., corresponding roughly to the Polish ACs. Their study concerned 33 fields with relatively homogenous tropical soils in the homogenous soilscape. Other studies, which reported rather high quality of soil maps, were performed in Mexico by Lleverino González [22], with a purity of 76% regarding six land classes from the map legend. Brevik et al. [23] reported 50–60% purity in the identification of two main soils (of four delineated on the soil map at a 1:15,840 scale) within one field of 25 ha. Other authors observed relatively low accuracy of soil maps or DSM products [16–19,21].

Polish ASMs were prepared about 40–50 years ago [5] and, most frequently, have not been updated [35]. This indicates that causes of the disagreement between ST shown on ASMs and derived from recent soil analysis could have appeared both at the time of their preparation and later. These maps were prepared mainly on the basis of field (hand) ST determination, which is not as precise as a laboratory ST analysis. In Poland, the effectiveness of the evaluation of ST with a field method was verified by Zembaczyński [36] on the basis of 5787 soil samples in 1965. He reported that approximately 57% of the soil samples were classified to the same ST class, as the laboratory analysis indicated, and 27% to the adjacent ST classes, and these results correspond to a purity of 57% and AA of 71% according to the criteria used in this study. The results on ST agreement obtained by Zembaczyński [36] are better than the map accuracy assessment observed in this study. The main disagreements (38% of samples) in the study by Zembaczyński [36] referred to attributing coarser (lighter) ST classes compared to the laboratory analysis, and this is also better than the result in our study, in which 225 soil samples (51%) belonged to the coarser (lighter) ST class than indicated on the ASMs (Table A2). This is consistent with the result of this study, as the part of very light and light soils delineated on ASMs was actually medium or even heavy, according to the recent ST status. The accuracy of field-estimated ST classes according to FAO/USDA was studied and reviewed by Salley et al. [37]. In this study, the correct prediction (corresponding to purity) of ST classes of 66% was reported for professional soil scientists and only 27–41% for seasonal technicians. The accuracy of field ST determination depends not only on the knowledge and experience of the scientists or the technicians but also on the STC per se. According to the latest (2023) review on ST evaluation undertaken by Maynard et al. [21], the worst accuracy was observed for silt (19%), followed by sandy clay (28%), sandy clay loam (28%), and loamy sand (45%). All remaining STCs were characterized by a field estimation accuracy higher than 50%, being the highest for silt loam (79%), clay (74%), and sand (73%).

In addition to the inaccuracies related to the determination of ST with a field method, the generalization, which is actually performed during the creation of each map [38], was another reason for the disagreement between ASMs and the recent ST status of fields. In the case of ASMs, the main technique of generalization was the incorporation of too small delineations into adjacent and larger delineations. It was assumed that the smallest delineations shown on the map should have an area of 1.5 ha, but in the case of very heterogeneous soil cover, they could have an area of 0.4 ha. Consequently, the map generalization resulted in maps showing less variable soils than in reality, and, thus, the map accuracy was reduced. It is particularly important in moraine fields with intensive relief, where the notable differences in height occur at relatively small distances, as proved by Koćmit and Podlasiński [12]. For this reason, in each of the eleven fields studied, more ST classes were determined using a laboratory method than delineated on ASMs.

In our opinion, the human factor could also affect the level of agreement between the ST determined in or study and ST derived from the ASMs. SQMs, which were a basic source for the creation of ASMs, were prepared during very extensive field studies, which required a great number of people to classify soils during the period of about 10 years. The preparation of ASMs required an additional work consisting of an analysis of existing documentation and additional terrain studies performed by a smaller, but still significant, number of map editors. The methods of soil map preparation could not be standardized to a degree that is possible and common nowadays. For this reason, we are afraid that

the human factor (differences in the experience and interpretation of existing procedures) could have also had a certain effect on the ASM accuracy at the moment of their creation.

Moreover, soils change over time; thus, even the most accurate soil maps at the time of their creation may not reflect the current or recent soil status of the field. This was reported by Koćmit and Podlasiński [12], Podlasiński [13], and Pindral and Świtoniak [39]. Despite the fact that ST is one of the soil properties most stable in time [6], soil erosion and human activity may cause some changes in this property. Single soil tillage, particularly with mouldboard plough, causes translocation of soil particles, as reported by Hůla and Novák [40], who informed us on soil translocation both along and across the ploughing direction to a distance up to 1 m. Since the mouldboard plough has been used as the main tillage tool every year on our study fields, we assume that this method of soil tillage could cause translocation and gradual mixing of soil from adjacent delineations, thus changing and homogenizing ST within certain limits within some areas of the field. The STC in a study by Hůla and Novák [40] was sandy loam, so it was very similar to that found on all Pomeranian and one Mazovian field in our study. Another cause of the possible change in ST over the years is soil erosion, including truncation, i.e., removal of topsoil layer from summits and upper slopes [39]. The soils of Pomeranian fields included in this study are located in an undulated landscape, and a significant part of field areas was covered by sandy soils (pgl or pgm) underlaid by sandy loam (gl, see delineation of 4Bw pgm:gl in Figure 5), so erosion and deep tillage on these fields could have contributed to a gradual change in ST from sandy to more loamy during about 40 years after the preparation of ASMs [14]. On the undulated field LSG in Lower Silesia, the silty topsoil was underlaid by glacial tills, sands, and gravels [41,42], and it is likely that soil erosion occurred in this field. Moreover, water erosion, sometimes observed by authors during studies on some Pomeranian and LSG fields, could have also contributed to ST changes. In other words, erosion by remotion of the upper layer of soil in sloped and elevated areas and the deposition of soil in other, lower areas may cause a change in the original ST. As a result, a high level of map accuracy achieved at the time of its creation might be reduced later by erosion.

The poorest agreement reported in this study regarding very light soils results partly from the poor representation of these soil ACs, because the delineations of very light soils represented only about 2.5% of all soil samples taken and only about 1% of the study area. However, according to data derived from the digitalized ASMs at a scale of 1:25,000 [8], very light soils comprise about 28% of the area of agricultural land in Poland. This small representation of very light soils in this study results from the fact that the data were collected from fields often cropped with winter wheat, a crop that should not be grown on very light, sandy soils due to relatively high water requirements [6]. In contrast to the very light soils, delineations of the light soils were well represented in this study, 25% of soil samples and 45% of the study area. The level of agreement of ASMs in the studied fields regarding this AC with recent ST evaluations is not very satisfactory, with purity of 31% and AA of 65%. This may partly result from the changes in ST status, which occurred during the time between map preparation and this study. The need for revision of the ASMs is well known [12,35]. On the other hand, the agreement between the ASMs and recent topsoil status regarding ACs of medium and heavy soils found in this study was very high, as it amounted to purity higher than 80% and AA exceeding 90%.

The inconsistencies regarding the results of the present study led us to perform statistical analysis of the relationship between these results and soil types delineated on ASMs and simple topographic features. The soil types represented in this study, with 22 soil samples, showed agreement of more than 72.7% regarding ACs and more than 41% regarding STC, while the marginally represented organic soils (E, one sample and T, three samples) and wastelands (N, one sample) had a null agreement with ASM. However, the character of our data, including different and frequently small representations of soil samples, in particular STCs, ACs and soil types, makes it difficult or even impossible to objectively assess the effect of different factors on the current agreement of ST status between ASMs

and our laboratory analyses. The relationships between topographic features derived from EU-DEM and agreement between ASMs and results of our studies regarding STC and AC are statistically significant but very weak. These relationships indicate that an increase in relief intensity—relative altitudes within the field—negatively affects the ASM accuracy regarding ST. However, these relationships are so weak that they may explain up to 5% of the variability regarding the agreement between ST shown on ASMs and determined in this study. This means that there are other and more important factors that may explain the differences in the agreement of ST status between ASMs and our studies. More extensive and detailed analysis of these factors requires additional studies.

Although our findings indicate that ASMs provide some useful information about topsoil texture, their accuracy is frequently insufficient for site-specific soil management and conservation because these activities require accurate information on soil in every area of a particular field. As a result, the revision of and improvement in existing maps, or preparation of new maps, are needed, as stated many years ago by Koćmit and Podlasiński [12]. The current development of direct (e.g., measurements of soil electrical resistivity (ER)), proximal (e.g., use of electromagnetic induction (EMI), use of active optical sensors or gamma spectrometry), and remote sensing (aerial photographs and satellite images) of soil and crops offers many possibilities for the detection of homogeneous ST areas within the fields. These areas might be precisely delineated and then characterized with traditional terrain studies. The areas of different topsoil texture may be delineated more precisely using gamma spectrometry [43,44]. Although other methods, such as measurements of soil apparent electrical conductivity with ER and EMI methods [41,45] and derivation of vegetation indices (e.g., NDVI) from aerial or satellite images covering crop fields, may also be very useful [45,46].

5. Conclusions

This study provides preliminary information on the predictive quality of the ASMs of Poland at a 1:5000 scale regarding topsoil texture. Consequently, our results should not be used as a basis for drawing far-reaching conclusions about the quality of these maps. Therefore, our conclusions are applied, above all, to the 11 fields examined in this work. These conclusions may also be, to a certain degree, useful for similar areas of Central European Lowlands, which occupy 59% of the area of Poland and extensive areas of Germany, the Netherlands, and Belgium. The agreement between topsoil texture shown on ASMs and the recently determined ST varies greatly between fields and within particular fields, even those with very high agreement values.

Despite the rather unsatisfactory AA of ASMs with recent STCs found for the studied fields, the AA regarding topsoil ACs was much better, and only 2% of soil samples belonged to distant AC compared to those derived from ASMs. Since ASMs are applied to derive the ACs and these are used together with the laboratory results on nutrient availability to recommend doses of agricultural inputs, readily available ASMs for the whole area of arable land in Poland might still be a good starting point for the more common implementation of precision agriculture techniques. However, these maps provide rather general information on topsoil texture, as even maps with good agreement with recent soil status of any field may contain some areas with bad agreement. For this reason, all maps, even the most accurate ones, may require an update of some delineations, and this is possible with the extensive use of direct, proximal, and remote sensing methods, which might be very helpful in indicating the most representative areas for traditional soil studies in the field.

A small percentage of very large disagreements were found between the topsoil ACs derived from ASMs and the categories determined using laboratory techniques in our study. This indicates that these maps are still, relatively, the best source for the preparation of maps at smaller scales and for modeling various phenomena requiring ST data, e.g., soil erosion, hydrologic properties, etc.

Further studies, regarding, above all, fields with very light and light soils in the topsoil layer and more fields in all regions of Poland, are needed. There is still a lack of studies

assessing the agreement between the ST of subsurface soil layers shown on agricultural soil maps and the current soil status. On the other hand, the general need for an improvement in the accuracy of soil maps, most recommended with the extensive help of direct, proximal, and remote soil sensing methods and the use of DEM, is indisputable.

Author Contributions: Conceptualization, M.S.; methodology, M.S., S.S. and D.G.; investigation, M.S., D.G. and S.S.; resources, S.S.; data curation, M.S.; writing—original draft preparation, M.S.; writing—review and editing, S.S. and D.G.; visualization, D.G. and M.S.; supervision, S.S.; project administration, S.S.; funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Polish Ministry of Science and Higher Education project NN 310 089036 in years 2009–2012. The research on soil spatial soil variability was co-supported by a scientific project POIG.01.03.01-14-041/12—"BIOPRODUCTS, innovative technologies of pro-health bakery products and pasta with reduced caloric value", co-financed by the European Regional Development Fund under the Innovative Economy Operational Programme 2007–2013 and by Farm Frites Poland SA company.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: Elżbieta Bodecka, Jarosław Choromański, Eike Stefan Dobers, Joanna Groszyk, Magdalena Wijata, Grzegorz Sobczyński, Marcin Studnicki, Jan Szatyłowicz, Daniel Szejba, and the Master students employed in these projects for the participation in collection and analyses of field data. The soil data were collected from the fields managed by the AGRO-POLEN sp. z o. o., the Farm Frites Poland Dwa sp. z o. o., and the Research Farm of Warsaw University of Life Sciences in Wilanów-Obory. The authors thank the management of these farms for their technical support and for agreeing to undertake the study in their fields. We acknowledge the reviewer's comments, which helped us to improve the quality of this study.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Soil texture (granulometric) groups: codes, names and size separate contents used on agricultural soil maps (PTG 1956) and their attribution to ACs.

AC *	ST Classification	The Content of Soil Separates (%) Range: Min.–Max.			Main Equivalents According to USDA ST Classification ** (Probability)
	ST (Granulometric) Class PTG 1956	Sand (1.0–0.1 mm)	Silt (0.02–0.1 mm)	Fine Particles (<0.02 mm)	
1. Very light soils	pl—loose sand	70–100	0–25	0–5	S (98%)
	plp—silty loose sand	55–75	25–40	0–5	S (54%), LS (43%)
	ps—weakly loamy sand	65–95	0–25	5–10	S (67%), LS (33%)
	psp—silty weakly loamy sand	50–70	25–40	5–10	LS (83%), S (12%)
2. Light soils	pgl—light loamy sand	60–90	0–25	10–15	LS (87%), S (7%)
	pglp—silty light loamy sand	45–65	25–40	10–15	LS (53%), SL (47%)
	pgm—strong loamy sand	55–85	0–25	15–20	SL (58%), LS (42%)
	pgmp—silty strong loamy sand	40–60	25–40	15–20	SL (93%), LS (7%)
2/3. Light/medium (silty) soils ***	płz—ordinary silt	0–60	40–100	0–35	SiL (45%), SL (35%)
3. Medium soils	gl—light loam	40–80	0–25	20–35	SL (91%), SCL (6%)
	glp—silty light loam	25–55	25–40	20–35	SL (77%), L (16%)
4. Heavy soils	gs—medium loam	25–65	0–25	35–50	SCL (48%), SL (24%)
	gsp—silty medium loam	10–40	25–40	35–50	SiL (42%), L (33%)
	gc—heavy loam	10–50	0–25	50–90	CL (48%), C (27%)
	gcp—silty heavy loam	10–25	25–40	50–65	SiL (72%), CL (17%)
	i—clay	0–10	0–25	65–100	C (32%), SiCL (30%) SiC (26%)
	ip—silty clay	0–10	25–50	50–75	SiL (65%), SiCL (16%)
	płi—clayey silt	data	data	35–50	SiL (89%)

* AC is a grouping of ST classes which was introduced in 1986 [10]. ** according to Stępień et al. [24,35]. *** This category was not distinguished by the professional standard BN-78/9180-11 [9], it was created for the purposes of this study. The standard mentioned divided former płz (ordinary silt) into three STgroups płp (sandy silt), płz (ordinary silt—the same name as according to PTG 1956), which are classified to light soils (category 2) and płg (loamy silt) which is classified as medium soil (category 3). As it is not possible to distinguish these three newer groups of silts on agricultural soil maps, in this study they are treated as light/medium soil.

Table A2. The number of soil samples in particular ACs and STCs and their agreement with respective units shown on theagricultural soil map (soil texture) or indirectly derived from these maps (agronomic category).

According to This Study			ACs, STCs * and Other Mapping Units ** According to Agricultural Soil Map																	
AC	Number of Samples	ST Class	Number of Samples	1. Very Light		2. Light				2/3. Light/ Medium	3. Medium		4. Heavy				Emt	N	T
				ps	psp	pgl	pglp	pgm	pgmp	płz	gl	glp	pli	gsp	gcp	ip			
2. Light	69	**pgl**	18	*1*	*1*	**9**		*5*			2								
		pgm	42	3		*12*		**19**			*4*	*2*				1		1	
		pgmp	9	1		3		*3*		*1*							1		
2/3. Light/ medium	7	**płz**	7							**3**				*1*		2			1
3. Medium	251	**gl**	227		3	20	4	*77*	*6*	5	**56**	*52*		4		4			
		glp	24			1		*4*		*10*		**2**		*3*					
4. Heavy	112	**pli**	13							*4*			**2**		4	3			
		gs	11	1				3		2	*2*	*3*							
		gsp	59	1						*8*			*19*	**12**	*6*	*13*			
		gc	1													1			
		gcp	27							1			*5*	*13*	**3**	3			2
		ip	1													**1**			
Sum	**439**		**439**	**7**	**4**	**45**	**4**	**111**	**6**	**34**	**64**	**59**	**26**	**33**	**13**	**28**	**1**	**1**	**3**
Sum in category (map)				**11**		**166**				**34**	**123**				**100**		**1**	**1**	**3**

bolded—number of topsoil samples belonging to the same STC according to agricultural soil map and laboratory analysis. underlaid—number of topsoil samples belonging to map delineations of similar (adjacent in soil texture triangle) STC, as determined in laboratory. *italic*—number of topsoil samples belonging to similar (adjacent in soil texture triangle) STCs within delineation of particular STC. * For explanation of ACs and STCs see Table A1. ** The other mapping units are the areas which were present during preparation of agricultural soil map, which currently are cropped with annual crops. The code Emt shown on the map of field PG denominates a kind of Histosol (in Polish: gleby mułowo-torfowe, i.e., soils developed limnic sediments on peat), the code N shown on the map of field MI2 is used for waste lands and the code T shown on the map of this field LSG denominates peat (in Polish: torf) [Bartoszewski i in. 1965].

Table A3. The effect of soil type according to ASM on agreement between ASM and ST status on the fields according to this study assessed using Kruskal–Wallis test.

Soil Type ASM	Number of Soil Samples	Mean STCagr	Mean ACagr
A	22	0.432	0.727
B	271	0.607	0.793
D	68	0.581	0.831
E	1	0.000	0.000
F	73	0.418	0.788
N	1	0.000	0.000
T	3	0.000	0.000
p-Values		<0.001 *	0.002 *

* statistically significant at 0.05 significance level.

Table A4. The Spearman's rank correlation coefficients (s) between selected topographic measures and agreement between ASM and ST status on the fields according to this study.

Characteristics	Static Measure	DeltaHfld (m)	DeltaHfldperarea (m/ha)	Hrel_Point (m)
STCpagr	s	0.037	−0.136	0.097
	p-Values	0.442	0.004 *	0.043 *
ACagr	s	−0.232	−0.139	−0.105
	p-Values	0.000 *	0.003 *	0.028 *

* statistically significant at 0.05 significance level.

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