

Article

Impact Assessment of the Long-Term Fallowed Land on Agricultural Soils and the Possibility of Their Return to Agriculture

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Abstract: Agricultural land abandonment is a process observed in most European countries. In Poland and other countries of Central and Eastern Europe, it was initiated with the political transformation of the 1990s. Currently, in Poland, it concerns over 2 million ha of arable land. Such a large acreage constitutes a resource of land that can be directly restored to agricultural production or perform environmental functions. A new concept for management of fallow/abandoned areas is to start producing biomass for the bioeconomy purposes. Production of perennial crops, especially on poorer soils, requires an appropriate assessment of soil conditions. Therefore, it has become crucial to answer the question: What is the real impact of the fallowing process on soil, and is it possible to return it to production at all? For this purpose, on the selected fallowed land that met the marginality criteria defined under the project, physicochemical tests of soil properties were carried out, and subsequently, the results were compared with those of the neighboring agricultural land and with the soil valuation of the fallow land, which was conducted during its past agricultural use. The work was mainly aimed at analyzing the impact of long-term fallowing on soil pH, carbon sequestration and nutrient content, e.g., phosphorus and potassium. The result of the work is a positive assessment of the possibility of restoring fallowed land for agricultural production, including the production of biomass for non-agricultural purposes. Among the studied types of fallow plots, the fields where goldenrod (*Solidago L.*—invasive species) appeared were indicated as the areas most affected by soil degradation.

Keywords: unutilized agricultural areas (uUAA); abandoned areas; land use and land-use change; carbon sequestration; soil properties (physical and chemical)



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1. Introduction

1.1. The Process of Setting Aside/Fallowing Land in the Political and Environmental Context

The time of political transformations that took place in Poland in the 1980s and 1990s significantly contributed to changes in land use [1]. The process of agricultural land abandonment on large scale became visible then. Besides the economic effects resulting from abandoning agricultural activity, also structural and functional transformations of landscape units took place [2,3]. The first visible effect of land abandonment is regrowth of vegetation through natural secondary succession [4]. In many regions of the country, as a result of land use discontinuation and succession of natural vegetation, a significant part of the agricultural plots became permanently covered with trees and bushes. At the same time, regional nature of this process became apparent [5]. It is difficult to assess unequivocally whether it is a negative or a positive phenomenon, it depends mainly on the local environmental, political, or social conditions. In some cases, such a change may result in restoration of the old ecosystem or emergence of completely new landscape or utility functions [6], and in the case of mountain areas, it may also affect the functioning of valley ecosystems [7]. Currently, in order to identify abandoned areas, a number of

remote sensing methods are being developed, using satellite photos or Airborne Laser Scanning (ALS), which allows for precise identification of the size of areas covered with high vegetation and the dynamics of changes over time [8]. According to some researchers, tree stands resulting from spontaneous succession are much more abundant in elements of environmental value than conifer monoculture stands [3]. Natural succession also creates ecological corridors, prevents soil erosion thanks to vegetation cover, increases carbon sequestration in the soil, and can be a stronghold of biodiversity in intensively utilized agriculturally areas [9,10]. On the other hand, uncontrolled succession may pose a threat to the biodiversity in open areas and the species occurring there, e.g., by the invasive plants entering those areas, causing the loss of cultural landscapes [6,11]. Invasive plants have a negative effect on native species, not only by displacing them from their growing area, but also by modifying soil conditions [12]. For example, in Poland, we can observe how the goldenrod species (*Solidago L.*) enters after the segetal phase of natural succession as an invasive plant, creating dense fields [13]. Just as it is difficult to unequivocally assess the process of farmland abandonment, so are the decisions on how to manage it. Bell [14] identified three main categories of strategies that are undertaken in the process of abandoned land management in relation to its new functions:

1. Naturality (with or without controlled natural succession),
2. Multi-functionality (e.g., extensive agricultural production, hobby farming (traditional, small-scale food production, agri-tourism),
3. Productivity—sustainable agricultural production or bioenergy and renewable energy sources.

The researchers also admit that implementing the most appropriate post-abandonment strategy will be based on a number of variables. The aforementioned production function related to the acquisition of biomass has recently gained particular importance in formulating bioeconomy development strategies. The research shows that the cultivation of perennial industrial plants on marginal lands can represent a significant potential in obtaining biomass [15–19].

In addition to the many challenges associated with this issue, some opportunities were also recognized for the sustainable management of fallow land to compensate for the consequences of climate change. This is because soils, in addition to the basic functions of food production and ensuring food security, also provide ecosystem services that are necessary for the functioning and resilience of the environment on Earth. The main non-agricultural functions are: (i) Storage of massive amounts of carbon, which helps to regulate CO₂ emissions and shape climate processes; (ii) functioning as the largest water filter and storage tank on Earth, which ensures control of its circulation, retention, and quality of freshwater resources; and (iii) storage of nitrogen, phosphorus, and other essential nutrients [20].

1.2. Testing Conditions of the Fallow Soil

The possibility of carbon sequestration in soil was and still is widely discussed in many publications, also in the context of abandoned agricultural land. Among other things, the effect of converting agricultural land into other forms of land use (arable land to grassland, arable land to abandoned agricultural land, and arable land to afforested land), and the possibility of SOC sequestration in the topsoil were investigated. Kazlauskaitė-Jadzevice et al. [21] showed, among others, that carbon sequestration in the Arenosol soil layer was positively influenced by long-term fallowing and transformation into grassland. Abandoned land or fertilized grassland accumulated significantly more CO₂ (48% and 38%—respectively), compared to arable land. Whereas the potential of “mature” forest succession in terms of CO₂ sequestration was confirmed by the studies conducted by Foote and Grogan [22], showing that the total contents of organic carbon and nitrogen in soil at a depth of 10 cm were lower in arable fields compared to forests with secondary succession, by about 32% and 18%, respectively.

Studies on the impact of the natural succession diversity on the storage capacity and rate of C accumulation in soil over a period of two decades were conducted by Yang et al. [23]. The authors concluded that the annual rate of carbon storage was higher in the second period of the study (years 13–22), in the same time suggesting that restoring high plant diversity could significantly increase carbon capture and storage on degraded and abandoned agricultural land. The impact of afforestation and deforestation on soil carbon content was also investigated [24]. The impact of land use change in Mediterranean areas on the processes of co-carbonization, decarbonization, and recarbonization was taken up by researchers Lozano-García et al. [25], anticipating at the same time the possibility of soil regeneration and climate change. The topic of reclamation of degraded agricultural land by changing the variety of vegetation and restoring organic matter was also discussed by researchers Zhang et al. [26].

In publications concerning fallow land, the influence of land use change on physical and chemical properties of soils is often discussed. The negative influence of relatively young (5–10 years) fallow land on the properties of the soil environment was found by Strączyńska et al. [27]. It was manifested in the unfavorable change in pH and reduction of humus resources in silty and clay soils, while in light soils, the humus content slightly increased. Moreover, Tomaszewicz and Chudecka [28] did not find any enrichment of fallow rusty soils with humus either. At the same time, fallow soil was characterized by a lower content of plant-available forms of magnesium, potassium, and phosphorus. On the other hand, the positive effect of setting aside on the properties of the soil environment was observed by Włodek et al. [29]. In their research, the authors observed that after several years of excluding the field from agricultural production, there was a significant increase in the content of carbon, phosphorus, potassium, and magnesium in the soil. In the study of the physicochemical properties of soils, a detailed analysis of changes in the quantitative and qualitative composition of humus compounds is of key importance. Based on their research results, Licznar et al. [30] concluded that the fractional composition of humus compounds in fallow soils shows strong relationships with their physicochemical properties. They also noticed that in set-aside light soils, the process of organic matter accumulation occurs, thus showing a lower degree of humification than in a cultivated soil.

The results presented in this paper were obtained as part of the BioMagic [31] project, whose main objective is to develop bioproducts from lignocellulosic biomass obtained from marginal soils to fill the gap in the national bioeconomy. On the selected fallow land, meeting the marginality criteria defined in the project, physicochemical tests of soil properties were carried out, the results of which were then compared with the neighboring utilized agricultural lands. The main aim of the study is to answer the question, whether it is possible to restore weak and marginal soils to biomass production after a long-term abandonment. The obtained results, within the BioMagic project, were also used to estimate the technical and economic potential of fallow soils to be used for the production of perennial industrial plants.

2. Material and Methods

2.1. Main Assumptions

The following research hypothesis was assumed: Fallowing process does not cause a significant deterioration of soil conditions, which would be a problem when they are returned to agricultural production. An alternative to the research hypothesis is to show that long-term set aside affects the soil in such a negative way that its restoration to agricultural production requires expensive agrotechnical treatments. The following properties were considered essential for soil fertility: Carbon content in the topsoil, soil pH, phosphorus, and potassium content. The nitrogen content in the soil was not analyzed, because this element is not stable (its content changes rapidly during vegetation period, especially in case of intensive agricultural production).

In this study, it was assumed that the necessity to use “expensive treatments” to restore the soil to agricultural production will occur if the tested soil parameters for fallowed land

deteriorate so that the ranges adopted in the determination of soil fertility in Poland will be exceeded twice. In the case of soil carbon, it is a 1.7% decrease in its content (compared to the content determined for the sample from arable land). For pH, it is an increase in soil acidity by two units. In the case of phosphorus and potassium, it is a reduction of 10 mg per 100 g of soil (forms: P_2O_5 and K_2O).

In order to assess the impact of fallowing on soil conditions, the following work was carried out:

- A region representative of the country was selected, where fallowing agricultural land is a serious problem for agriculture.
- Materials were collected to track the course and dynamics of the fallowing process.
- Basic types of fallow land were defined with their location on the map of the research area.
- For selected sites, the impact of fallowing on the soil condition was analyzed—by determining its chemical properties and comparing it with soil samples collected in adjacent agricultural fields.

2.2. Area of Research

The research was carried out in the area of Puławy municipality (gmina), Local Administrative Unit (LAU code:1006061121409) according to the Eurostat nomenclature, located in the north-western part of the Lubelskie Voivodeship (NUTS-2: PL81). This municipality is directly adjacent to the city of Puławy and constitutes its suburban area, which is visible, among others, in employment the structure: In 97% of farms, at least 1 person has an additional non-agricultural source of income [32]. The economic situation and the large fragmentation of farms in this region determine the high percentage of fallow land in the agricultural landscape.

For soil sampling 17 sites were chosen. Research area and locations of sampling plots were shown on the Figure 1. The article's supplement includes a download link of the KLM file, which contains the location of the sampling sites, enabling their identification in the Google Maps/Earth application, which visualizes this region on high-resolution orthophotomaps (like in the right picture on Figure 1).

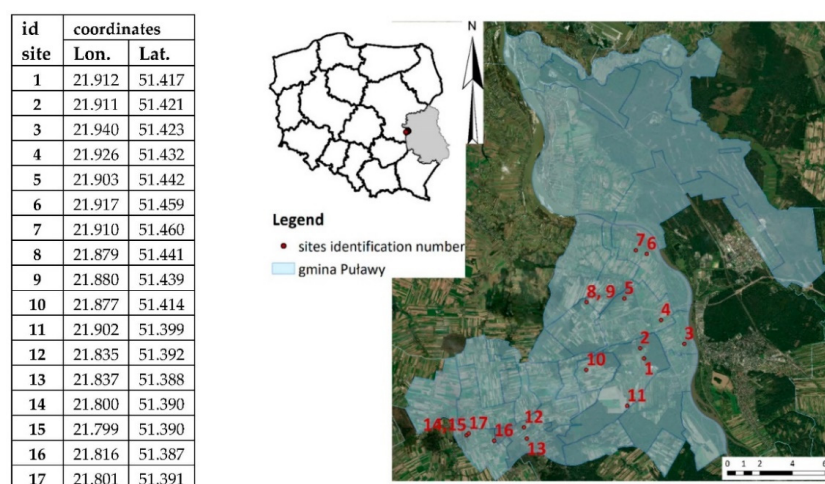


Figure 1. Research area—locations of sampling sites.

2.3. Spatial Data Collection

In the study, the following types of spatial data were used:

- Cadastral maps showing the range of cadastral parcels and classifications of agricultural usefulness of soils (source: GUGiK [33], SIP Puławy [34]).
- Historical orthophotomaps from the years: 1997, 2006, 2010, 2017–2018—Figure 2 (source: GUGiK [33]).

- Geo-referenced photos taken in-situ during visits at the selected sites (for examples, see Section 2.4).



Figure 2. Time sequence of aerial photographs, showing the approximate moment of the entry of natural succession (1997, 2006, 2010, after 2017). Source: GUGIK [33].

The above data fed the geographic information system, which was built in the QGIS (open source environment).

2.4. Definition of Fallow Types

Due to the diversity of natural succession within the selected plots, the investigated areas of fallow plots have been divided into:

- Grassland (FGL)—mostly newly abandoned agricultural land, possibly fallow land, with a predominance of grassland vegetation, with only a few plantings of later succession, e.g., goldenrod (*Solidago* L.) (Figure 3).



Figure 3. Example of photos on-site No. 2 (left side) and No. 5 (right side).

- Goldenrod (FG)—areas with a predominance of plants of later succession stages, mainly goldenrod (*Solidago* L.), tansy (*Tanacetum vulgare* L.). Criterion: Over 80% share of goldenrod or tansy in land cover (Figure 4).



Figure 4. Example of photos on-site No. 1 (left side) and No. 16 (right side).

- Bushy (FB)—areas where apart from ruderal plants, such as goldenrod (*Solidago* L.), there are bushes, e.g., in the form of blackberries (*Rubus* L.), blackthorn (*Prunus spinosa* L.) and single self-seeded trees. Criterion: Over 30% share of bushes in land cover (Figure 5).



Figure 5. Example of photo on-site No. 8.

- Wooded/afforested (FW)—areas with trees, dense shrubs, advanced succession. Criterion: Samples were taken in places where young forest covered at least 0.10 ha (Figure 6).



Figure 6. Example of photos on-site No. 10 (left side) and No. 14 (right side).

2.5. Field Work, Soil Sampling and Laboratory Tests

Selection of 17 sites for the comparison of soil samples collected from fallow land with samples from neighboring utilized agricultural fields was carried out according to the following assumptions:

- Each tested fallowed parcel has to have a fallowing period documented on the aerial photographs, and meet the marginality criteria for agricultural plots, defined by Pudełko et al. [5].
- In the immediate vicinity of the fallow plot, there are agricultural plots with similar site conditions (soil class, topography, water conditions), with no episodes of fallowing.
- One site must consist of at least one fallow plot and one utilized agricultural plot (arable land). However, most often chosen sites offered several types of succession in the unutilized field and both types of land use the utilized field (arable and grassland)—see Figure 7.



Figure 7. Example of soil sampling strategy—site 17, where in the close vicinity were sampled: Two arable plots and three fallowed plots covered by goldenrod, wood, and bushes.

In total, 72 soil sampling points were identified for the 17 selected sites. Soil samples were taken from the top soil layer, 0–20 cm, where the reaction to the change in land use should be clearly visible. For each sample, the following characteristics were determined: Physical and chemical properties of soil, type of land use (arable land, grassland, and fallow type), and site affiliation.

The valuation class of the soil sampling site was preliminary determined based on the utilization class map available in the Spatial Information System of the Puławy powiat (SIS Puławy) [34] and then verified by laboratory methods. National soil classification used in this work focuses on soil suitability for agricultural purposes, taking into account the morphological features and physicochemical properties of the soil, such as location and structure of the soil profile, water relations/conditions, and pH [35]. For better soil characteristics, each sample was described by its granulometric properties: pl (loose sand), pg (clay sands), ps (weak loamy sand), gp (sandy loam), and pyg (clay dust) [36,37]. Relation between the (Polish) classification used in this study and the international USDA classification was shown on Figure S1 (in the Supplementary part).

The scope of the performed analyses of soil samples included the basic physicochemical properties, including: pH in a 1-molar KCl solution, granulometric composition according to the norm: BN-78/9180-11 and PTG (2008) [38], which were determined by the laser method. The Egner–Riehm method was used to determine the content of assimilable forms of nutrients (phosphorus, potassium). The Egner–Riehm method is a chemical laboratory method. It involves extraction of the available forms of nutrients from the soil by means of special solutions, usually a buffer one. The same extraction solution is used for phosphorus and potassium. It is lactic acid buffered with calcium lactate, pH = 3.6. This solution is obtained by dissolving calcium lactate with hydrochloric acid. It is well buffered against both hydrogen ions and calcium ions—two factors significantly affecting the solubility of phosphorus compounds in the soil. Organic carbon (C_{org}) and Humus were determined using the modified Tiurin method [39].

2.6. Statistical Analyses

In order to verify the working hypothesis, the results of determination of the chemical properties of soils between the adjacent fallowed and used plots were compared. In the first step, corresponding pairs were selected (classes of pairs):

- 8 pairs of arable (AL) and grassland, former arable (GL),
- 6 pairs of arable and fallow grassland (FGL),
- 17 pairs of arable and fallow goldenrod (FG),
- 15 pairs of arable and fallow bush (FB),
- 13 pairs of arable and fallow wood (FW).

For all classes of pairs, differences in carbon content in soil, pH, and potassium and phosphorus content were assessed in comparison to arable plot. If there were more than one arable plot sampled on the site, then higher values were taken into account. Choosing the highest value in the significance test introduces a more restrictive approach because the working hypothesis is always rejected when the upper-tailed critical region is exceeded. In the first step of statistical analyses, the significance level (α) at which the criteria of the research hypothesis are met was estimated.

Principal component analysis (PCA based on correlations) was also used to capture the correlation between particular parameters in different types of land use [40]. This approach was to test whether the change in land use may affect the relationship between the parameters. Principal components analysis creates new artificial variables (principal components) based on the variables (features) that we analyze. Its main assumption was the possibility of visualizing the relationships of individual variables on a two-dimensional graph, which shows the coordinate system representing the first two principal components. Based on the position of the vectors in space, it can be determined which features are correlated with each other. The smaller the angle between the vectors, the stronger the positive correlation. When vectors are aligned on the same line but in opposite directions, there is a strong negative correlation between the variables. However, when the vectors are at an angle close to 90 degrees, no correlation occurs. Statistical analyses were performed using Statistica software package Statistica v13.1 (TIBCO Software Inc., Palo Alto, CA, USA).

3. Result

The summarized results of field work, remote sensing and laboratory tests are listed on Figure S2 (see Supplementary). For each site, it is specified: Chemical and physical properties for each tested land cover, soil granulometric type and fallow period. The conducted research confirmed the influence of the change in the use of agricultural land on its physicochemical properties. It should be noted that the specific granulometric composition and the valuation class within each of the sites were similar, which made it possible to attempt a comparison of the results of chemical analyses at the sites level. The vast majority of the tested samples belonged to the granulometric group of sandy loam—gp (31 samples) and clay sands—pg (25 samples). Only in sites no. 1, 12, 14, and 15 were the sampled soils classified as lighter groups such as: Loose sand—pl, weak loamy sand—ps and heavy group such as clay dust—pyg in site no. 4 (Figure S2). Detailed characteristics of the granulometric fractions are presented on the Ferret's triangle (see Supplementary, Figure S1).

3.1. Changes in Carbon Content

The conducted research showed differences in the content of organic carbon within the sites in relation to different types of land use. The content of organic carbon in arable land ranged from 0.63% to 1.42%. It can be seen that a relatively high percentage of C_{org} was determined for site No. 12 despite its poor valuation soil class, which is associated with straw management in this field and manure fertilization. Newly abandoned land (FGL) with a predominance of grassy vegetation and several goldenrod instances showed an increased % C_{org} content, compared to arable land, on average by 32%, even up to 46.5%. Similar results were obtained by comparing arable land and permanent grassland (GL), where % of carbon content increased by max. 71.2%. In these soils, similar to meadow soils, the increase in carbon content is associated with the year-round cover of vegetation forming a compacted turf, which promotes binding of carbon from the atmosphere in the process of CO_2 assimilation by these plants [41]. Different tendencies are observed in the

case of abandoned land dominated by species of later succession, in this case by goldenrod (*Solidago* L.). FGL species, for in this type of abandoned land one can see a clear decrease in carbon content even by 23.7% compared to arable land. On abandoned lands of the later succession, overgrown with FB bushes or trees, in sites similar to the FW forest, the carbon content in the studied samples is quite diversified. The highest increase, by 103.6%, was recorded for sites no. 14 and no. 7 and 10, by 95.2% and 90.4%, respectively. However, in addition to the increase in carbon content in this type of fallow land, we can also notice a decrease in carbon content in comparison with arable soils, which applies to sites no. 1, 3, and 17. In the case of site no. 1, carbon loss amounted at 52.3%, and the sample from this area was taken six months after the removal of bushy vegetation with single trees.

In general, it can be stated that in all researched sites, no case was observed in which the carbon content determined in the fallow fields, in relation to arable land, fell below the adopted critical value (1.7%). However, in most cases (except for fallow goldenrod—FG) an increase in the content of organic matter was noted. It should also be noted that in each considered case of the fallow type, values of standard deviations in the sample set (SD C%—presented in Table 1) are significantly smaller than the adopted critical value (1.7). A low variance in this case confirms that the observed relationships are not accidental.

Table 1. Standard deviations (SD) of chemical soil properties in various types of land use and various types of fallow land.

Land Use	SD (C%)	SD (pH)	SD (P ₂ O ₅)	SD (K ₂ O)
arable land (AL)	0.25	0.80	7.45	5.70
grassland (GL)	0.71	0.86	4.54	3.06
grassland fallow (FGL)	0.07	0.75	3.19	5.79
goldenrod fallow (FG)	0.27	0.83	6.28	5.29
bushy fallow (FB)	0.41	1.11	5.92	7.23
wooded (afforested)—FW	0.26	0.86	4.89	16.41

3.2. Changes in pH

The pH indicator in the top layer of the investigated arable lands was mostly very acidic < 4.6 and acidic 4.6–5.5, only in sites 3, 7, 12, and 17 the soil pH was more favorable—slightly acid 5.6–6.5 (Figure S2). Comparing the average values of this parameter in individual types of use (Figure 8), we notice that the most favorable values were found in grasslands and grasslands fallow (pH = 5.3 and 5.1), besides with increasing pH, the percentage of organic carbon also increased.

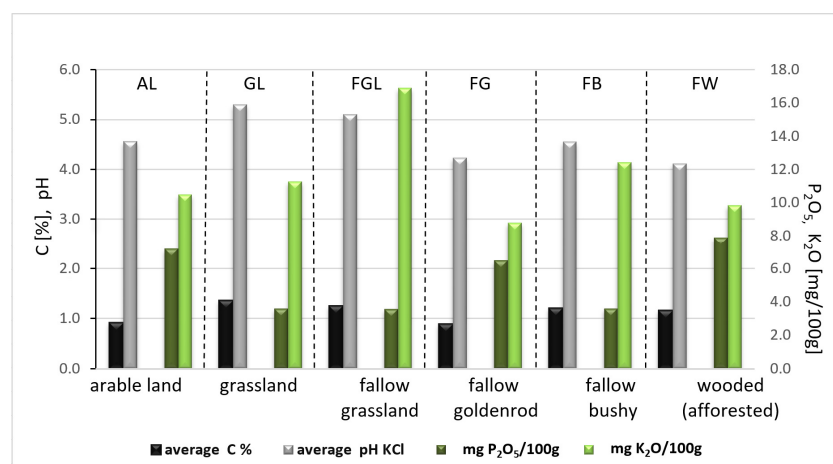


Figure 8. Average chemical soil properties in various types of land use and various types of fallow land.

In the case of the remaining types of fallow land, the mean pH is lower in relation to arable land, and the lowest for perennial fallow land covered with older trees, where the beginning of natural succession is determined for the years 1996, 2006. Despite the lower pH in these lands, the average organic carbon content is about 30% higher than in arable land. The amount of organic carbon was restored through the annual deposition of organic matter from tree leaves.

In general, it can be stated that in all researched sites, four cases were observed in which the pH value determined in the fallow fields, in relation to arable land, fell below the adopted critical value (2). In three cases it was the site no. 17, which may indicate the specificity of this site and its lack of representativeness in relation to other sampling sites. If we reject these outliers, we can conclude that the research hypothesis has been rejected for 1.8% of cases ($\alpha < 0.05$). Similar to the carbon content, in each considered case of the fallow type, values of standard deviations in the sample set (SD pH—presented in Table 1) are smaller than the adopted critical value (2.0). A low variance confirms that the observed relationships are not accidental.

3.3. Changes in K_2O and P_2O_5 Content

Potassium and phosphorus are, besides nitrogen, macronutrients of essential importance in plant nutrition. Phosphorus is one of the compounds building plant cells. Its presence in the soil and absorption by plants determines the absorption of other nutrients, mainly nitrogen. Phosphorus plays an important role in various plant life processes (regulates cell division, root development, flowering processes, seed setting, and maturation processes). The factor that strongly limits phosphorus absorption is the low pH of the soil, and the content of organic matter also plays an important role in this process [35,42,43]. On the other hand, potassium, unlike nitrogen and phosphorus, does not form basic organic substances of the plant. The natural content of potassium in soils depends on their mineralogical structure and granulometry, especially the content of clay minerals, the presence of which is reflected in the share of floated parts in the soil composition. In light soils, the natural potassium content is usually lower than in more compact soils, but with the increase in the share of colloidal parts, the absorption of potassium decreases, because it is strongly bound in the inter-packet spaces of clay minerals. The available forms of potassium are subject to losses due to plant uptake and leaching, especially in light soils. [35,42,43]. Average content of available forms of potassium and phosphorus in relation to the land use type are presented in Figure 8.

In general, it can be stated that in all researched sites, nine cases were observed for phosphorus and six cases for potassium, in which the content of these elements determined in the fallow fields, in relation to arable land, fell below the adopted critical value (10 mg per 100 g of soil). We can conclude that the research hypothesis has been rejected for 15% of cases ($\alpha \sim 0.15$) and 10% ($\alpha \sim 0.1$) respectively for each of these elements.

Contrary to carbon content and pH, potassium and phosphorus are the more labile elements in the soil. In this case, the greater variance in the sample set is expected and natural. Despite this feature, only in one case (Table 1: SD of K_2O for wooded) the values of the standard deviation exceeded the critical value (10), and in others they are close to half of its value. It should be noted, however, that in the case of potassium, the mean values of its content in fallow soils are most often higher than in arable soils (Figure 8).

3.4. Principal Component Analysis (PCA)

The analysis showed different relations between individual parameters depending on the land use type. In the case of arable agricultural land (AL), the positively correlated parameters are: C_{org} content and pH, which are not related to the other group of parameters: content of floatable parts < 0.002 mm and available form of potassium. In case of this group, a negative correlation with the content of available phosphorus can be observed (Figure 9A).

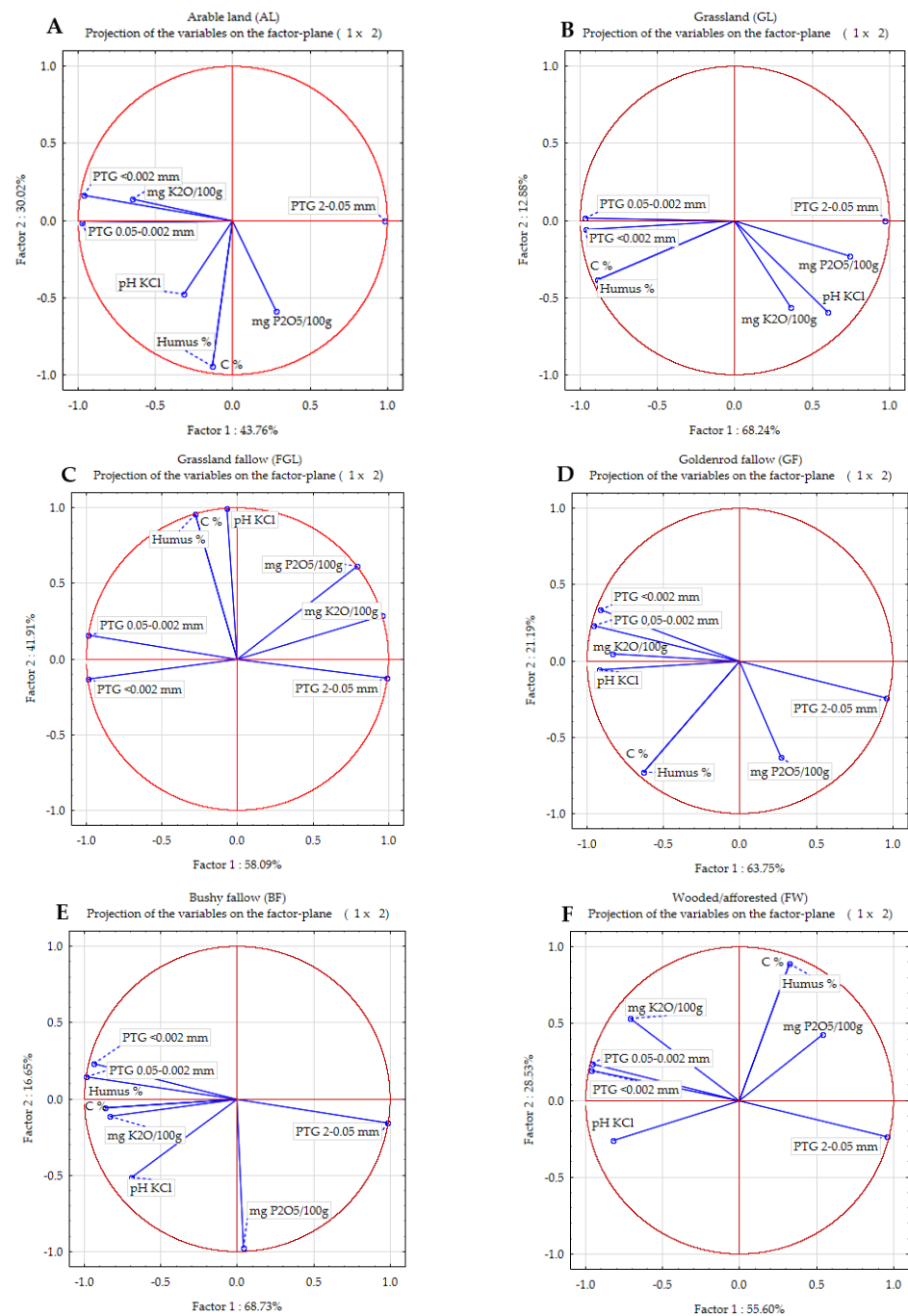


Figure 9. Variables charts showing relationships between different parameters depending on land use types. Subfigures: (A)—arable land, (B)—grassland, (C)—grassland fallow, (D)—goldenrod fallow, (E)—bushy fallow, (F)—wooded/afforested.

In the case of grassland (GL), the variables form two groups. The first group of correlated parameters is pH, the content of potassium and, to a lesser extent, of phosphorus. The second group, on the other hand, is the C_{org} content and the share of fraction 0.05–0.002 and < 0.002 (Figure 9B). A similar correlation between the C_{org} content and the granulometric composition can be observed in bushy fallow land—FB (Figure 9E), where we can also see a relationship between those parameters and the content of potassium.

Grassland fallow (FGL) shows correlation between the content of C_{org} and pH, which demonstrates in high values of those parameters compared to the other groups (Figure 9C),

as it is in the case of grassland, where the content of potassium and phosphorus is negatively correlated with the content of floatable parts < 0.002 and fraction $0.05\text{--}0.002$.

Moreover, in this group it can be observed that the first two principal components (PC1 and PC2) explain the largest percentage of the total variation, respectively (58.1% and 41.9%). Goldenrod fallow (FG) shows some similarities in relation of some factors with regard to arable land (AL), and afforested fallow areas (FW), applying mainly to potassium, which depends on the content of fraction < 0.002 and fraction $0.05\text{--}0.002$. The content of C_{org} , on the other hand, is not correlated with any other parameter (Figure 9D).

The last group, which represents advanced succession with trees (FW), shows correlation between the content of C_{org} and phosphorus, which at the same time are negatively correlated with pH (Figure 9F). In this case, the higher content of C_{org} the lower pH value (Figure S1).

4. Discussion

4.1. Impact of Fallowing on Soil

The obtained results generally show that fallowing on weak soils does not lead to such deterioration of chemical properties, which would make it difficult to restore plant production. In the case of fallowing agricultural land as grassland—without allowing secondary succession, even an improvement in the condition of the soil can be observed, i.e., no tendency to soil acidification, high humus and potassium content, which confirms the results published by Kazlauskaite-Jadzevici et al. [21]. Similar consistency with the results described by Foote and Grogan [22] was obtained for the assessment of the impact of mature succession (afforestation), but in this case, the effect of carbon sequestration was not so noticeable, which could have been influenced by the selection of sites for testing (poor and very poor soils).

Another important research result is the negative impact of goldenrod (*Solidago* L.) succession. This invasive species is now common in the agricultural landscape of the country and, as shown in the research of Orczewska [12], Sekutowski and his team [13], as well as this work—it has a negative effect on soil and environmental conditions. For this reason, one of the recommendations for maintaining the soil in good condition should be the requirement to mow fallow land with this type of succession.

The works carried out by the teams of Stolarski [15] and Matyka [10,18] prove that plantations of perennial energy crops can be established even on the weakest soils, classified as marginal soils. This work proves that setting aside agricultural land with poor soils is not an obstacle in restoring it to the production of this type of biomass. This applies in particular to the goldenrod succession sites—in such case, conversion may also contribute to a more sustainable use of agricultural production space.

4.2. Possibility of Returning Fallow Land to Agriculture

Michna et al. [1] wrote about the purposefulness of restoring fallow land to agricultural production. To the conclusion that: “Land of individual farmers may be transformed or used for other purposes only with the consent of the owners. Thus, there is the ownership barrier to transformation and changes in the forms of land use of all, including fallow, soils”, we can now add the fact that over the three decades of intensified changes in agricultural production in Poland, which unfortunately show the constantly growing trend of abandoning agricultural land, not much intervention by the administration has taken place. Also, the expected changes after Poland’s accession to the EU structures in 2004 did not result in any visible process of returning fallow land to production, but only slowed down the trend of land abandonment [5].

Moreover, the subsequent solutions in the field of bioeconomy, promoting an increase in the share of biomass in the energy mix, did not change the observed situation. Although the RED Directive [44] obligated EU countries to increase the sustainable use of biomass, it was not reflected in the relevant national regulations, which would provide tangible support to farmers and target recipients of the biomass produced [45]. This resulted in

a lack of response from industry and energy, which could lead to the creation of a stable biomass market and allow the recovery of fallow land for the production of this raw material, or, alternatively, the resumption of food production.

The new concept of the Green Deal is another attempt to draw attention to the sustainable use of biomass in agriculture and bioeconomy [46]. These activities once again stimulate the interest of the energy and industry sectors in biomass of agricultural origin. This was manifested by the need to estimate the raw material potentials reported to the Ministry of Agriculture and Rural Development and the need to regulate the possibility of non-agricultural use of biomass along with the possibility of reusing waste from biomass processing as fertilizer for soil conservation. The solutions can directly contribute to the greater use of straw, hay, and manure in the bioeconomy, but they can also have a significant impact on the consolidation of fallow land and their recovery to biomass production.

In the BioMagic project, which financed this work, the presented results were used to estimate the theoretical, technical, and economic potentials of producing perennial industrial plants on fallow soils. In subsequent works carried out on this subject, a remote sensing tool will be developed for the remote sensing recognition of the degree of natural succession, and the density and type of biomass on the analyzed land plot.

5. Conclusions

Fallow land in Poland constitutes a significant percentage of agricultural land. Most of it has great potential to be restored for food or biomass production for bioeconomy purposes—such as providing raw materials for the chemical and pharmaceutical industries and energy. The observed effects of fallowing are not an agro-technical problem in this case. Based on the obtained results, it can be concluded that:

- Basic soil parameters, such as the content of organic matter and its acidity—do not deteriorate noticeably during the process of setting aside. In this case, the research hypothesis is accepted at a significance level $\alpha < 0.05$.
- Fallowing shows significant effect on the content of potassium and phosphorus in the soil. In this case, the research hypothesis is satisfied at a significance level $\alpha \sim 0.15$ (P_2O_5) and $\alpha \sim 0.1$ (K_2O). However, fertilization with these components is, in the case of agricultural use, a typical agrotechnical treatment that effectively increases soil fertility.
- Among the examined types of fallow, maintaining it with succession of goldenrod (*Solidago* L.) is the least favorable.
- Changes in the dependence and correlation of the analyzed soil properties are observed in the tested types of use and fallowing. Long-term fallow, which develops mature forms of succession (trees, shrubs), diversifies the carbon content and the acidity of the soil. In this case, a positive aspect is the increase in the content of organic matter in the soil, but at the same time increases also its acidity.
- For agricultural plots where the deterioration of soil conditions has been observed, these conditions can be quickly restored for the selected type of biomass production by applying agro-technical practices in accordance with the recommendations of the Code of Good Agricultural Practices [47].

Supplementary Materials: The following are available online at <https://www.mdpi.com/2077-0472/11/2/148/s1>, Figure S1: A ternary diagram of the soil texture triangle showing the USDA-based soil texture classifications [S1]., Figure S2: Primary results characterizing each tested site.

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