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Original Research

Influence on Selected Physical Properties of a Haplic Podzol during a Ten-Year Fallow Period

J. Pranagal[1]*, E. Podstawka-Chmielewska[2], A. Słowińska-Jurkiewicz[1]

[1]Institute of Soil Science and Environmental Management, University of Agriculture, Leszczyńskiego 7, 20-069 Lublin, Poland
[2]Department of Agricultural Ecology, University of Agriculture, Akademicka 13, 20-033 Lublin, Poland

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Abstract

The physical properties of Haplic Podzol developed from loamy sand and left fallow for ten years have been studied. As a method of fallowing, natural succession of the plot was applied. A number of physical properties of this soil were studied, including bulk density, total porosity, moisture at the sampling moment, field water capacity, field air capacity and field air permeability. After ten years in a fallow state, the physical condition of the soil studied had improved. A decrease in soil compaction and an increase in field water capacity can be regarded as especially valuable. It was found that long-term fallow could be a good method for the physical regeneration of the soil structure destroyed year by year by intensive mechanical agricultural cultivation. Leaving arable soils fallow should be treated as a special protective farming method. However, it requires further interdisciplinary studies to formulate systemic solutions.

Keywords: Haplic Podzol, fallow, long-term, soil physical properties

Introduction

In the 1990s, the exclusion of some fields from agricultural usage was a common practice in Poland. The rationale was both the re-structuring of agriculture following changes in the Polish political system, as well as a decrease in production profitability [1, 2]. Numerous studies have shown that fallowing of arable fields influences the whole natural environment, mostly by changes in the biological diversity of agro-ecosystems [3, 4]. According to some authors, no production activities for a number of years leads to the development of unwelcome plant cover on the fallowed areas [5-8] and changes in the soil environment both in terms of chemical and physical soil properties [9-11]. As far as physical soil properties are concerned, initially an increase in the actual moisture, compactness, total and capillary porosity were observed [10]. Researchers dealing with the consequences of long-term fallowing show that changes in the soil environment can be of varied nature. Usually they are positive as far as the environment and soil science are concerned [2, 12-15], and from a purely agricultural point of view, i.e. for farming, they can be sometimes viewed as unfavourable [5-8].

Hence, the quality determination of fallowed soil becomes a very important issue. According to numerous authors [15-20], soil quality can be determined on the basis of a number of properties. Some of the most frequently mentioned physical properties determining soil quality are: density, total porosity, field water capacity, soil ability to retain water types most valuable for plants, as well as infiltration – water and air movement.

The positive influence of fallowing on some soil properties has already been reported [12-15, 21-23]. However, it should be mentioned here that the length of the fallowing period is decisive in this case, as a worsening of some

*Corresponding author; e-mail: jacek.pranagal@ar.lublin.pl

basic soil quality parameters can take place in the first years following the soil's exclusion from farming. Only long-term fallowing, of at least five years, is visibly favourable for soil quality. Altieri [24] and Stoate et al. [25] stressed that the long-term fallowing of arable lands can be the primary method of reintroducing natural regeneration to agro-ecosystems and self-purification abilities to the natural environment.

Hence, the question may be formulated as to whether fallowing should disappear from the Polish landscape. Is there a possibility to restore their original agricultural function or should they be used for other purposes [26]? Understanding the consequences of long-term fallowing of arable lands is very helpful when correct decisions have to be taken in this respect.

The present authors undertook an attempt to evaluate changes in some selected quality parameters in the physical properties of podzol soil left fallow.

Material and Methods

A ten-year study (1995–2004) on physical properties of fallowed haplic podzol non-uniform soil were carried out, lying on limestone and originating from loamy sand soil from fluvioglatial accumulation. The granulometric composition of the arable layer of this soil was as follows: 1.0-0.1 mm fraction – 60%; 0.1-0.02 mm fraction – 24% and <0.02 mm fraction – 16%. Solid phase density was ρ_s = 2.64 Mg · m^{-3}, total organic carbon content TOC = 11.4 g·kg^{-1}; $CaCO_3$ was not found.

Within the area of the above soil unit, a plot with a surface of about 0.1 ha was excluded from agricultural usage at the Experimental Agricultural Station in Bezek (the macro-region of the Polesie Wołyńskie, and mezzo-region of Pagóry Chełmskie). The study area is situated in the temperate and transitional zone under strong influence by the continental climate. In 1994-2003, the average annual precipitation was 542.4 mm. The average temperature of the warmest month (July) over the set-aside period was +17.9°C whereas the temperature of the coldest month (January) was -3.7°C.

An oat and barley mix was grown on this plot immediately before fallowing started. As a method of fallowing, natural succession of the plot was applied. In the analyzed decade, no field work was carried out on the plot. There also was no traffic (including tractors and agricultural machinery) in the area. In the course of time, the biodiversity of the plant community increased. At the same time, relationships between different plant groups changed. Herbaceous plants were replaced by perennial species. *Elymus repens* was a dominant species, even though its part in the vegetation showed a downward trend at the end of the studied period. Since the 4th year of fallowing, there was a clear dominance of perennial species over herbaceous ones. Over ten years, vegetation dynamics resulted in the development of the phytocenosis with brushwood and forest plants (*Betula pendula*, *Sorbus aucuparia*, *Frangula alnus*, *Pyrus communis*, *Prunus spinosa*) accounting for 26% of all species. For a detailed review of the phytosociological composition (76 taxons) of the analyzed fallow see Podstawka-Chmielewska et al. [27], Kurus and Podstawka-Chmielewska [28].

Soil samples preserving their natural structure were collected twice during the vegetation season (in spring – May/June and in summer – August) from the 2–7 cm layer in eight replications to 100 cm^3 metal cylinders. At the same time, samples from two agriculturally used fields (Field I and Field II) directly adjacent to the fallowed area, also were taken on the same dates and from the same layers. A sequence of plants was applied on these latter arable fields, i.e. Field I: field pea with barley, spring rye, field pea with barely, spring barley, rye, oat, barley and oat mix, oat, potatoes; Field II: oat, spring barley, spring barley, oat, spring barley, oat, oat, oat and barley mix, oat and potatoes. As a method of soil cultivation, conventional tillage was applied: stubble cultivator (10 cm) + harrow, mouldboard ploughing (18-20 cm) + harrowing, sowing + harrowing.

A series of physical soil properties such as: bulk density, total porosity, soil moisture at the sampling moment, field water capacity, field air capacity and field air permeability were studied [29, 30]. Determination of pF-curve with ceramic plates was carried out with the use of apparatus of Eijkelkamp Agrisearch Equipment (The Nederlands). The level of field soil saturation with water was compatible with soil moisture level at a potential value of -15.54 kPa.

The results were then subjected to statistical analysis. Variance analysis for the single orthogonal classification was carried out (variance factor – utilization method – "U"), for double orthogonal classification for the following variance factors: study date – "T" and utilization method – "U". The statistical analysis was carried out at a significance level of α = 0.05.

Results and Discussion

The results of the first four years of the present experiment were published earlier [10]. Already in the first study period, it was found that with time all the physical properties studied were taking on more favourable values in the fallowed soil than in the farmed soil; however, the differences were not statistically significant in most cases. The most favourable changes resulting from fallowing and statistically confirmed were found in the case of actual humidity and field air permeability. Mean four-year values for both of the above properties for the fallowed soil were significantly higher than for the farmed soil. Undoubtedly, already the lack of worsening of the physical soil condition in the soil on which farming cultivation stopped is a positive phenomenon. In this situation, a re-building of a natural soil structure, re-creation of a net of durable and permeable (patent) biogenic pores [12-15] which are destroyed every year during intense mechanical cultivation, is a long-term process and some initial effects of such transformations may even be unfavourable [22].

The effects of four years of our experiment caused us to continue the present studies for a subsequent six-year period. The ten-year research material obtained in the present research clearly showed a stable favourable trend in the changes of the most important physical soil properties. In the case of soil density, years five and six (1999 and 2000) of the present experiment were very important. In this period, density (Table 1) of the fallowed soil began to decrease very clearly when compared to the arable soil (with one exception, i.e. spring term Field I, year 2001). Moreover, in the fallowed soil a decisive reduction of seasonal differentiation of density was observed. Such differentiation was very high in the soil subjected to agrotechnical cultivation. An average value from ten years and two study dates of density determination for the fallow soil was 1.53 $Mg \cdot m^{-3}$, and for the arable soil it was 1.63 $Mg \cdot m^{-3}$ in the case of Field I and 1.61 $Mg \cdot m^{-3}$ in the case of Field II. With a decrease in soil density, an obvious increase of total porosity took (Table 2). A mean total porosity value for the fallowed soil after 10 years was 0.425 $cm^3 \cdot cm^{-3}$ for Field I – 0.382 $cm^3 \cdot cm^{-3}$, and for Field II – 0.390 cm^3 cm^{-3}.

The soil moisture at the sampling moment (Table 3) was very strongly related to both the soil utilization

Table 1. Bulk density, ($Mg \cdot m^{-3}$).

Year	Term (T)	Fallowing (U)	Tillage (U)	
			Field I	Field II
1995	I II	1.64 1.63	1.56 1.61	1.54 1.55
1996	I II	1.61 1.55	1.53 1.62	1.52 1.53
1997	I II	1.50 1.58	1.54 1.65	1.65 1.62
1998	I II	1.54 1.55	1.61 1.63	1.48 1.70
1999	I II	1.52 1.55	1.78 1.71	1.63 1.54
2000	I II	1.53 1.56	1.60 1.67	1.60 1.74
2001	I II	1.52 1.52	1.51 1.76	1.57 1.74
2002	I II	1.52 1.52	1.60 1.80	1.58 1.64
2003	I II	1.49 1.48	1.57 1.65	1.60 1.68
2004	I II	1.40 1.44	1.58 1.63	1.66 1.63
[1)]$LSD_{\alpha=0.05}$		0.377		
Mean from 1995-2004		1.53	1.63	1.61
[2)]$LSD_{\alpha=0.05}$		0.054		

Explanations for Tables 1-6: [1)]$LSD_{\alpha=0.05}$ – Term (T) × Use (U); [2)]$LSD_{\alpha=0.05}$ – Use (U)

Table 2. Total porosity, ($cm^3 \cdot cm^{-3}$).

Year	Term (T)	Fallowing (U)	Tillage (U)	
			Field I	Field II
1995	I II	0.379 0.383	0.409 0.390	0.417 0.413
1996	I II	0.390 0.413	0.420 0.386	0.424 0.420
1997	I II	0.432 0.402	0.417 0.375	0.375 0.386
1998	I II	0.417 0.413	0.390 0.383	0.439 0.356
1999	I II	0.424 0.413	0.326 0.352	0.383 0.417
2000	I II	0.421 0.409	0.394 0.367	0.394 0.341
2001	I II	0.424 0.424	0.428 0.333	0.405 0.341
2002	I II	0.424 0.424	0.394 0.318	0.402 0.378
2003	I II	0.436 0.439	0.405 0.375	0.394 0.364
2004	I II	0.470 0.455	0.402 0.383	0.371 0.383
[1)]$LSD_{\alpha=0.05}$		0.151		
Mean from 1995-2004		0.420	0.382	0.390
[2)]$LSD_{\alpha=0.05}$		0.022		

Explanations as in the Table 1.

Table 3. Soil moisture at the sampling moment, ($kg \cdot kg^{-1}$).

Year	Term (T)	Fallowing (U)	Tillage (U)	
			Field I	Field II
1995	I II	0.138 0.122	0.122 0.117	0.102 0.108
1996	I II	0.076 0.118	0.034 0.103	0.042 0.091
1997	I II	0.160 0.142	0.124 0.120	0.109 0.092
1998	I II	0.120 0.138	0.060 0.098	0.063 0.090
1999	I II	0.175 0.119	0.125 0.103	0.121 0.105
2000	I II	0.097 0.131	0.071 0.159	0.076 0.097
2001	I II	0.110 0.177	0.096 0.131	0.079 0.166
2002	I II	0.133 0.099	0.127 0.086	0.100 0.066
2003	I II	0.141 0.036	0.113 0.015	0.102 0.029
2004	I II	0.111 0.078	0.099 0.062	0.078 0.063
[1)]$LSD_{\alpha=0.05}$		0.069		
Mean from 1995-2004		0.121	0.098	0.089
[2)]$LSD_{\alpha=0.05}$		0.011		

Explanations as in the Table 1.

method and the sampling date. In the last two years, the actual humidity in the spring term exceeded actual humidity from the summer term, and on each of these terms, the highest actual humidity was noted on the fallowed field.

Field water capacity of the soil (Table 4), fallowed since 1997, started to take on the highest values, and since 2001 the above trend was strengthened irrespective of the sampling date. In 2004, field water capacity of the fallow soil was, on average, 0.234 kg · kg^{-1} for the soil from Field I – 0.172 kg · kg^{-1}, and 0.166 kg · kg^{-1} for the soil of Field II.

Air field capacity took on a different course (Table 5) closely related to the presence of the biggest pores most often produced during the soil cultivation process, mainly mouldboard ploughing, and also as the result of activity of soil fauna and growth of plant roots. Even though their durability is short-lived, at this specific moment they decide on the values of the property discussed. Mean values of the ten-year period are as follows: fallow – 0.127 cm^3 · cm^{-3}, Field I – 0.109 cm^3 · cm^{-3}, Field II – 0.127 cm^3 · cm^{-3}. It should be stressed, however, that even though air field capacity of the fallowed soil was the lowest among the results obtained, in the last year it was the highest.

Field air permeability (Table 6) is a feature related both to soil structure with its density and field water and air capacity. When the whole of the ten-year period studied is taken into consideration, the advantages of fallow-

Table 5. Field air capacity, (cm^3·cm^{-3}).

Year	Term (T)	Fallowing (U)	Tillage (U)	
			Field I	Field II
1995	I II	0.113 0.117	0.138 0.126	0.149 0.171
1996	I II	0.126 0.165	0.142 0.132	0.161 0.183
1997	I II	0.152 0.148	0.148 0.139	0.137 0.146
1998	I II	0.152 0.120	0.132 0.125	0.187 0.093
1999	I II	0.131 0.122	0.066 0.078	0.142 0.123
2000	I II	0.132 0.120	0.119 0.066	0.138 0.078
2001	I II	0.109 0.088	0.140 0.052	0.119 0.061
2002	I II	0.128 0.128	0.141 0.052	0.148 0.125
2003	I II	0.122 0.090	0.102 0.048	0.132 0.042
2004	I II	0.134 0.124	0.133 0.099	0.102 0.104
1)LSD $_{\alpha=0.05}$		0.113		
Mean from 1995-2004		0.127	0.109	0.127
2)LSD $_{\alpha=0.05}$		0.016		

Explanations as in the Table 1.

Table 4. Field water capacity, (kg·kg^{-1}).

Year	Term (T)	Fallowing (U)	Tillage (U)	
			Field I	Field II
1995	I II	0.162 0.163	0.174 0.164	0.174 0.156
1996	I II	0.164 0.160	0.182 0.157	0.173 0.155
1997	I II	0.187 0.161	0.175 0.143	0.144 0.148
1998	I II	0.172 0.189	0.160 0.158	0.170 0.155
1999	I II	0.193 0.188	0.146 0.160	0.148 0.191
2000	I II	0.189 0.185	0.172 0.180	0.160 0.151
2001	I II	0.207 0.221	0.191 0.161	0.182 0.161
2002	I II	0.195 0.195	0.158 0.148	0.161 0.154
2003	I II	0.211 0.236	0.193 0.198	0.164 0.192
2004	I II	0.239 0.230	0.170 0.174	0.162 0.171
1)LSD $_{\alpha=0.05}$		0.081		
Mean from 1995-2004		0.192	0.168	0.164
2)LSD $_{\alpha=0.05}$		0.012		

Explanations as in the Table 1.

Table 6. Field air permeability, (·10^{-8}m^2·pa^{-1}·s^{-1}).

Year	Term (T)	Fallowing (U)	Tillage (U)	
			Field I	Field II
1995	I II	52.0 44.6	13.9 15.7	11.1 79.8
1996	I II	16.3 114.0	14.4 10.4	8.0 38.6
1997	I II	47.0 44.3	30.6 20.6	7.8 32.8
1998	I II	47.3 38.4	6.4 8.4	23.5 4.1
1999	I II	45.8 24.6	9.4 22.3	24.0 37.9
2000	I II	36.8 64.4	37.9 20.6	38.4 10.6
2001	I II	34.6 61.9	60.1 11.3	5.6 54.5
2002	I II	27.4 20.5	61.3 4.2	27.5 20.1
2003	I II	48.5 6.1	6.7 2.8	11.7 2.4
2004	I II	37.5 69.8	29.7 3.0	6.4 6.3
1)LSD $_{\alpha=0.05}$		105.3		
Mean from 1995-2004		44.1	20.0	22.6
2)LSD $_{\alpha=0.05}$		15.1		

Explanations as in the Table 1.

ing are very clearly visible – field air permeability of the fallowed soil was $44.1 \cdot 10^{-8} \cdot m^2 \cdot Pa^{-1} \cdot s^{-1}$, soil from Field I – $20.0 \cdot 10^{-8} \cdot m^2 \cdot Pa^{-1} \cdot s^{-1}$, and soil from Field II – $22.6 \cdot 10^{-8} \cdot m^2 \cdot Pa^{-1} \cdot s^{-1}$. Exceptionally low values of air permeability found in 2003 – term II could result from the disappearance of macropores due to the expansion of overdried soil during its saturation to total water capacity. In the last study year, the advantages of the fallow were clear, especially during summer.

Changes observed in the physical conditions of podzol soil probably resulted from an increase in the activity of the soil fauna and plant root mass. Other authors who carried out similar observations stressed that abandonment of cultivation stimulates the formation of durable macropores [22]. It is usually a result of the penetration activity of plant roots, natural fissures and an increase in the number of earthworms [12, 23]. According to House and Parmelee [12], 50 earthworms were registered per 1.0 m^2 in the non-treated soil, whereas they were completely absent in the soil treated with the traditional plough. Similar results also were obtained by Shipitalo and Protz [13] and Dress et al. [14] who pointed to the fact that an abandonment of intensive mechanical soil cultivation favourably influences the activity of earthworm populations, changes in the macro-pores content (> 50 μm) and soil aggregation.

The results obtained correspond to observations by the authors quoted above in the present study and moreover show that fallows can function in the environment as one of the stable elements of the agro-ecosystems [24, 25]. After a ten-year fallow period, the physical status of podzol soil developed from loamy sand improved. A decrease in the soil compaction and an increase in the field water capacity should be treated as especially valuable. Favourable trends observed in the first years of the present experiment [10] were intensified, and there were no signs of any worsening of the basic physical properties. It should also be strongly emphasized that favourable changes in the physical condition of the fallowed soil took place in all properties analysed in the present study, and their differences for the average ten-year values and study dates were statistically significant (Tables 1, 2, 3, 4, 5 and 6).

Conclusions

1. A positive influence of fallowing on the physical properties of Haplic Podzol developed from loamy sand can be unequivocally stated in light of the present results.
2. Long-term fallowing can be a good method to regenerate physical soil structure destroyed every year by intensely mechanized agricultural cultivation.
3. Fallowing of arable lands can be treated as a special protective method in agriculture. However, it requires further interdisciplinary research to establish suitable systemic solutions.

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