Soil Phosphate Regime in Experimental Soil Profile Amelioration

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Abstract: The aim of the trials established on three representatives of the compacted hydromorphic soils was to investigate the efficiency and the lifetime (duration) of the soil profile amelioration consisting of the various combinations of following measures:

(1) mechanical loosening of the subsoil;
(2) application of ground limestone into the loosened subsoil;
(3) application of a mixture of mineral fertilizers (P and K) into the loosened subsoil.

The time development of the soil exchangeable reaction and of the plant available phosphorus level including its soil regime indices (phosphate sorption, intensity and capacity indices) were determined in the horizons of the soil profile in the all experimental variants. It has been found that the loosening of compacted subsoil horizon created conditions suitable to development of phosphate mobilization processes, to partial transformation of a phosphate fixed in the soil to less stable, plant available forms. Both the profile liming and the mineral fertilizers incorporation to loosened subsoil (and their combinations) influenced positively on the soil phosphate regime and on the other agrochemical properties in the subsoil. There was proved that the lifetime of the amelioration practices effects reached at least 4 years—5 years – not only regarding to soil chemistry terms but also in terms of crop yields.
Keywords: phosphate regime, compacted hydromorphic soils, soil profile amelioration

1 Introduction

Profile amelioration of soils with compacted subsoil is focused on gradual improvement of deeper layers of soil profile — mainly on improvement of structural conditions, of the biological activity of subsoil, on formation of more balanced proportions between the topsoil and subsoil — mainly from the agrochemical point of view (soil reaction and the plant available nutrients level) — hence on the overall improvement of productive and ecological functions of the soil.

There is commonly known (LHOTSKÝ *et al*.,1991) that it exists a considerable disproportion between the topsoils and the underlying subsoils — in numerous soil properties. Regarding to the agrochemical point of view — the differences occur particularly in the soil exchangeable reaction, in the cation exchange capacity and its saturation with bases, and, namely in the plant available nutrient level. The agrochemical properties in the underlying soil layers – mainly the soil phosphate regime — can hardly be influenced using the fertilizers incorporation into arable layer only, under common farming practices. Because of the strong phosphate fixation almost all the phosphate applied remains fixed in the topsoil and its movement in the profile is very limited. In this way the disproportion between the topsoil and subsoil by fertilization still increases. The present paper evaluates the efficiency of the soil profile amelioration regarding the phosphate regime and its time development in the soil profile.

2 Material and method

The experimental soil profile amelioration has been established in order to evaluate the efficiency and the life duration of the individual treatments in the subsoil, consisting of four experimental practices:

- mechanical subsoil loosening;
- ground limestone incorporated into loosened subsoil;

- mixture of mineral fertilizers (P,K) incorporated into loosened subsoil;
- both limestone and mixture of mineral fertilizers incorporated into loosened subsoil.

The experiments were established on the three different representatives of semihydromorphic soils with compacted subsoil horizon:

① Stagno-gleyic Luvisol (Lgs) formed on clay-loam (soil profile:Ap-Bt-Btg-B/Cg; mean annual temperature 8.1°C; mean annual precipitation 630 mm);

② Albo-gleyic Luvisol (Lga) formed on clay-loam,too (soil profile Ap-En/Bg-Btg-Bg; mean ann.temp. 7.3°C; precipations 640 mm);

③ Dystrict Planosol (Wd) formed on a solifluctional clay loam (soil profile:Ap-En-Btg-B/Cg ; mean temperature 6.2°C; mean precipitations 900 mm.

The geographical cordinates of the experiments are between 48°—50°N and 16°—17°E, respectively; height above see level from 360 m (Lgs) to 540 m (PGm). The basic agrochemical data of experimental soils offers Table 1:

Table 1 Agrochemical data of individual experimental soils

soil type	horizon	pH/KCl	electric.conductivity μs・cm^{-1}	Cox (%)	P - available (mg・kg^{-1})
Lgs	topsoil	5.55	88	1.64	104
	subsoil	4.79	28	0.25	17
Lga	topsoil	5.90	112	2.03	115
	subsoil	5.30	38	0.20	25
Wd	topsoil	5.10	88	2.60	78
	subsoil	4.32	27	0.13	12

The fertilizers and/or ground limestone destinated for the subsoil amelioration were applied on the soil surface after harvest, the soil was deep loosened and afterwards deep ploughed (the doses corresponded to 290 kg P, 515 kg K and/or 4,000 kg Ca per hectare); besides it, the regular fertilization to the arable layer took place every year (doses: 35 kg P, 55 kg K, 90 kg N, 3,600 kg Ca per hectare). The crop rotation on trials: maize – oats – grass – winter wheat – spring barley.

The soil samples have been taken away every year after harvest from the active soil profile. In the air dried soil samples the following determination have been done: pH/KCl, plant available phosphorus (and of the other nutrients) content according to Mehlich II method (MEHLICH,1978) and the soil phosphate regime indices: sorption index SI (BACHE and WILLIAMS,1971), intensity index FI (ASL□ING,1954), capacity index FQ (AMER *et al*.,1955). Besides it, an annual yield response evaluation has been executed.

3 Results and discussion

The individual reclamational treatments affected in different way on the level of pH/KCl (soil exchangeable reaction) in the subsoil horizons of all ameliorated soils. In the non-ameliorated but regularly limed and fertilized “0”-treatment no distinct changes in the subsoil could be observed – most likely stagnation, but the pH values development (Table 2) confirm that a quite distinct increase of originally very low pH-values can be observed in the treatment “A” - due to simple deep loosening of the subsoil - forming the favourable conditions for the development of aerobic processes (including those of phosphorus mobilization). The another reason of that pH-values increase can be the hightened leaching of the H_3O^+ ions from the loosened subsoil horizon. The considerably high initial pH-values (reached as a consequence of the deep incorporation of the ground limestone in the treatment “B”) decrease rapidly during a period of five years after the soil profile amelioration; the reacidification trends appeared. Similar circumstances could be found in the treatment “D”, in case of the combined profile amelioration (using both profile liming and profile fertilization). However, in the treatment “D” where not so high initial pH-level has been reached as in treatment “B” , the mean annual decrease was not so high as in treatment “B”.

Table 2 Average time development of pH/KCl values as influenced by soil profile amelioration

years after the reclamation	treatments				
	0	A	B	C	D
1	4.8	4.9	7.15	4.05	6.9
2	4.8	5.0	6.9	4.35	6.75
3	4.7	4.95	6.45	4.55	6.45
4	4.8	5.05	6.25	4.8	6.05
5	4.75	5.15	5.80	4.85	5.95

On the other hand, the initially very low pH/KCl values in a subsoil were reached as a consequence of a deep incorporation ("profile application") of industrial phosphoric and potassic fertilizers in the "C"- treatment (Fig.1); pH/KCl values - increased gradually (the mean annual increase was not less than +0.2 pH units).

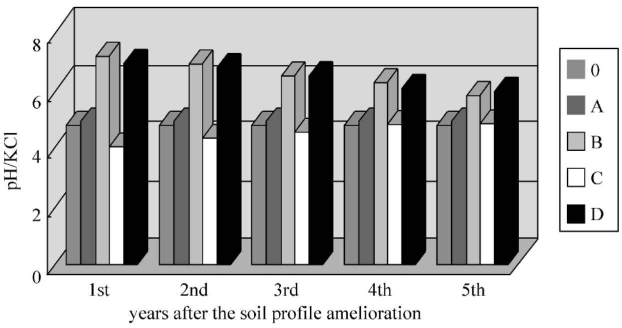

Fig. 1 The time development of pH/KCl values in the individual variants of the soil profile amelioration

On the base of above mentioned observation, the conclusion can be confirmed, that in the natural soils the spontaneous effort exists, to reach always the original balanced status: in case that the natural pH/KCl level has been artificially changed (both acidified and alkalized), then the soil tries to come back into its original conditions (on the principle of the action and reaction).

Table 3 illustrates the influence of the individual experimental treatments (A-D) on the content (concentration in the soil) of the plant available phosphorus (mg/kg) during the second year since the soil profile amelioration. It decribes also their mutual changes during the whole 5 year's period (using relative values: in % related to the phosphorus content in the "D" treatment equal 100%) in the individual years. Emphasis is given to the subsoil that reached its best conditions in first two years after the soil profile amelioration where the differences among individual treatments were at maximum.

Table 3 The influence of exp. treatments on the plant available phosphorus level: mg・kg^{-1} (in 2nd year) and its gradual changes - mean relative values (%) in the individual years after the reclamation (topsoil and subsoil)

horizon	treatment \ year	mg・kg^{-1}	% (mg・kg^{-1} in the treatment "D" = 100%)				
		2nd	1st	2nd	3rd	4th	5th
topsoil	A	104	99	99	98	98	96
	B	99	94	94	93	94	94
	C	106	99	101	101	102	104
	D	105	100	100	100	100	100
subsoil	A	23	23	28	29	29	30
	B	30	39	38	36	35	34
	C	61	71	76	81	85	88
	D	80	100	100	100	100	100

The simple deep loosening (treatment “A”) resulted itself in certain quite distinguishable increase of the plant available phosphate level in subsoil of all three soils under examination -compared to the non ameliorated soils (with non loosened subsoil - Table 1). More significant were the increases of the available phosphorus level as a consequence of the soil profile liming (treatment “B”), due to suitable changes of the fractional composition of the soil phosphate (the increase of more available Al- and Ca-phosphates on the account of the Fe-phosphates). As expected, the profile application of the mixture of both phosphoric and potassic fertilizers, resulted in sharp increase of available phosphorus level in the subsoil; Unfortunatelly, because of the significant acidification caused due to acid character of the industrial fertilizers incorporated, the fixation of prevailing part of phosphorus applied in fertilizers and its transformation into non available phosphorus formes (mainly Fe-phosphates) is non evitable in conditions originated in the subsoil of the “C”-treatment. The comparison of treatment “C” to that of “D”, in which the same doses of fertilizer (but together with ground limestone) have been applied, a following conclusion allows: the combined profile reclamation in its fullest shape (treatment “D”) was much more effective, as a considerably higher amount of plant-available phosphorus in the subsoil has been produced from the same dose of superphosphate. The acidification – causing higher phosphorus fixation - has been partly compensated by applied limestone, which resulted in a more favourable formation of Ca- and Al-phosphates, constituting the main source of phosphates available to plants (VOPLAKAL,1994).

The time development of the plant available phosphorus in the subsoil is also evident from Table 3 — relative values related to its content in “D” treatment in the individual years. It can be observed its decrease gradually (mainly in both the limed treatments “B” and “D”), and therefore, the phosphorus level in treatment “B” approaches step-by-step back to that in the treatment “A”, whereas , consequently, the concentration of P in the treatment “D” became gradually to be near to that in treatment “C”. The reason of it lies in successive decrease of the content of calcium - and consequently in a gradual decrease of pH/KCl values in the subsoil of both previously in the profile limed variants. Nevertheless, the differences among the individual treatments in the plant available P content (and partly even in pH/KCl values) persisted even four years after the reclamation (mainly in treatments “C” and “D” where the industrial fertilizers to the subsoil have been incorporated.

The soil profile reclamation affected distincly on the soil phosphate regime indices level in the subsoil (Table 4). An increase was observed, due to the deep loosening of subsoil (“A”) of both the intensity index FI expressing a degree of mobility of soil phosphate (ASL□ING,1954) and the capacity index FQ expressing the amount of phosphorus that can easy be released from the surface of the soil solid phase and becomes to be mobile(AMER *et al*.,1955) — compared to the untreated variant. Neverheless, a decreasing trend was displayed by the sorption index SI (which is in fact a degree of saturation of the soil with sorbed mobile P); when the soil becomes -due to deep loosening- more saturated with sorbed P, then the SI-index decreased (BACHE-WILLIAMS,1971).

Table 4 Values of phosphorus regime indices in the subsoil

soil type	P-regime index	treatments				untreated
		A	B	C	D	0
Lgs	FI	0.026	0.021	0.052	0.052	0.019
	FQ	33	42	44	52	26
	SI	4.33	3.72	2.61	2.73	4.62
Lga	FI	0.039	0.049	0.104	0.086	0.030
	FQ	76	72	97	101	61
	SI	3.62	3.43	2.42	2.05	3.77
Wd	FI	0.023	0.052	0.085	0.076	0.025
	FQ	35	36	38	43	32
	SI	4.40	4.33	3.05	3.21	5.53
average values	FI	0.029	0.041	0.080	0.071	0.025
	FQ	48	50	60	65	40
	SI	4.12	3.83	2.69	2.66	4.31

The deep incorporation of a ground limestone (treatm."B") influenced positively the amount of mobile phosphate in the subsoil: FQ-values increased and the sorption index (SI-values) decreased. In certain cases the profile liming can even reduce the concentration of phosphorus in the soil solution; we noticed in one case only (Lgs) the decrease of its FI-values (expressing the soil phosphate potential) due to profile liming -compared to the "A" treatment.

The profile incorporation of mixed fertilizers without limestone (treatment "C") influenced very positively all three soil phosphate regime indices in the subsoil of all the soils under examination. The combined application of both fertilizers and ground limestone (treatment "D") had a negative influence on the FI-values and partly even on SI-values compared to mere fertilizers application in the "C" treatment (probably due to liming), whereas the amount of mobile forms of phosphates (FQ-values) were influenced in a positive way.

Comparing the soil phosphate indices obtained in the particular years after the soil profile amelioration, suggests, that in the course of time the amount of mobile forms of phosphate (FQ-values) decreases, the sorpption saturation decreases,too (SI-values, due to their inverse character increase), but the mobility index FI does not vary significantly (Table 5).

Table 5 Mean annual changes of the soil phosphate regime values during five years since the soil profile amelioration

regime index	treatment				untreated
	A	B	C	D	0
FI	–0.003	+0.002	–0.006	+0.003	–0.001
FQ	–1.8	–1.2	–2.5	–1.3	–1.7
SI	+0.07	+0.04	+0.11	+0.06	+0.1

Table 6 gives the survey about the yields level (calculated in starch units in order to unificate them) as influenced by individual treatments (using simple linear time trend equations $y = a + b \cdot t$). The initialy high level yields, reached as a consequence of the soil profile amelioration in all the experimental treatments (A-D) were gradually decreasing in the course of the five years period since the soil profile amelioration. It can be calculated from the individual equations that the differences between the individual treatments would be almost minimized within 5—6 years.

Table 6 Time development (linear trend equations) of the yield level (calculated as starch units per hectare) as influenced by individual treatments on the experimental soils

treatment	Lgs	Lga	Wd	average
A	(3 732 – 163)t	(3 358 – 236)t	(3 916 – 598)t	(3 369 – 332)t
B	(4 419 – 291)t	(4 216 – 488)t	(4 961 – 955)t	(4 532 – 511)t
C	(7 688 – 915)t	(5 602 – 705)t	(6 195 – 1 146)t	(6 495 – 922)t
D	(8 014 – 1092)t	(5 721 – 767)t	(7 372 – 1 324)t	(7 036 – 1061)t

Nevertheless, even after four years since the soil amelioration, the influence of the individual reclamational treatments on the yields of spring barley (grain and straw) can distingly be recognized (Table 7).

Table 7 The yields of spring barley four years after amelioration: (tons of grain and straw per hectare and in % related to yield in A-treatment =100%) on the variants of individual soils

yield	treatment	Lgs		Lga		Wd	
		(t・ha^{-1})	%	(t・ha^{-1})	%	(t・ha^{-1})	%
grain	untreated	2.37	91	2.22	94	0.51	96
	A	2.60	100	2.35	100	0.53	100
	B	2.60	100	2.60	111	0.73	138
	C	2.76	106	2.66	113	0.80	151
	D	3.00	115	2.76	176	0.94	177
straw	untreated	3.40	98	2.90	98	0.94	101
	A	3.45	100	2.96	100	0.93	100
	B	3.30	96	3.15	106	1.20	129
	C	3.97	115	3.60	122	1.38	148
	D	4.15	149	3.90	132	1.59	171

4 Conclusions

The experiments demonstrated, that all the experimental treatments used in the soil profile amelioration of the acid soils with a compacted subsurface layers improved the soil phosphate regime in the subsoil and provided the conditions appropriate to development of mobilization properties, to gradual transformation of a part phosphorus fixed in the soil to less stable, more available forms. The profile liming and/or industrial fertilizers application to loosened subsoil affected positively on the plant available phosphorus whereas its soil phosphate regime indices were affected in different way during the several years' period after the amelioration. The long-lasting time effectiveness of the fertilizers profile application was longer than that of the profile liming and was clear distinguishable even four years since the soil profile amelioration.

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