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Physico-chemical Changes of Paddy Soils under Long-term Intensive Fertilization

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Abstract: The main objective of the experiment was to evaluate the impact of intensive fertilization and cropping on some physical and chemical properties of soil. Low bulk density and high pore volume remain in surface layer than the subsurface layer due to long-term fertilization. Laboratory experiment was carried out with soil samples (Sonaltola silt loam) from different depths of a permanent manurial experimental field of the Department of Soil Science, Bangladesh Agricultural University (BAU) farm, Mymensingh. Relatively low bulk and particle densities were found in FYM treated soil. Results showed that P and FYM are more effective in maintaining large aggregate in soils. Lowest amount of >2mm size aggregate and highest amount of 0.1-0.01 mm size aggregates were obtained in NS plot due to solubility of gypsum in water. Soils of surface layer were slightly acidic to neutral and the sub-surface layer was alkaline having pH values ranging from 6.81 to 7.11 and 7.48 to 7.85 in 0-10 and 10-20 cm layers respectively. The status of total organic matter, total nitrogen, available P and S also decreased with increasing depth although the status varied widely among the treatments and decreased due to treatments in which P was not included.

Key words: Long-term fertilization, soil physical properties, soil chemical properties

INTRODUCTION

Fertilizers are essential parts of modern farming, with about 50% of the world's production being attributed to fertilizer use[1]. Fertilizer nutrients use in different countries of the region has increased considerably with maximum (509 kg ha^{-1}) in the Republic of Korea as against only 102 kg ha^{-1} yr^{-1} in Bangladesh[2]. The importance of fertilization and manuring of our land is increasing day by day and farmers are supposed to use these inputs intensively for sustained crop production. Practices of intensive fertilization and manuring undoubtedly bring some changes in the physical and chemical properties of soil as well as biological properties.

Chemical properties that prevail under aerated conditions undergo a drastic change upon submergence. Flooding of water logging reduces the soil and consequently, the oxidized material viz., SO_4^{-2}, NO_3^{-}, Fe^{+3} and Mn^{4+} are replaced by their counterparts S^{2-}, NH_4^{+}, Fe^{2+} respectively. The concentration of P, Fe^{2+} and Mn^{2+} increases and decreases at the initial and final stages of submergence respectively[3].

Long-term application of FYM and GM increases the organic matter and total nitrogen content in soil[4,5]. The status of P, K and S, in soil is enhanced due to intensive application of these fertilizers and manures. This increase in nutrient reserve of soils due to intensive fertilization and manuring may ultimately lead to decline in crop yields as well as limit the use of this natural resource by creating nutritional imbalance.

The deficiency of primary nutrient elements like N, P, K and the beneficial effects of single and combined application of these nutrients in rice production have already been established. But the deficiency of sulfur and zinc has been established recently and its area and severity are increasing day by day at alarming rate particularly in HYV rice cultivation. The cause for this increased deficiency of nutrients in paddy soils are many, among which the intensive cropping, use of HYV's and chemical fertilizers are thought to be the main factors. In addition to higher uptake by intensive cropping with HYV's, high temperature accompanied by high rainfall also enhance the loss of nutrients through weathering of soil materials[6]. Ali[7] stated that an amount of 1054 thousand tons of nutrients (N, P and K) is being lost every year from arable land of Bangladesh. The phenomenon of nutrient depletion or mining from soils risking the prospect of increased food production has been highlighted and well documented by the FAO in recent years[1]. Khan *et al.*[8] stated that application of TSP

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fertilizer increased the availability, total and soil solution content of Zn, Cu, Fe and Mn. If the problem of nutrient depletion is not rectified, it will result in remarkable damage to the soil and the welfare of the farmers who depend entirely upon the land. Since fertile soil is the fundamental resource for higher crop production, its maintenance is a pre-requisite for long-term sustainable crop productivity. In view of above facts, the present research was undertaken to see the impact of long-term fertilization on physical characteristics and to see the status of nutrients in paddy soils.

MATERIALS AND METHODS

A laboratory experiment was carried out with soils collected from a permanent manurial experimental field of Department of Soil Science, Bangladesh Agricultural University Farm, Mymensingh, Bangladesh during the period of 1998-99 (after two decade of starting the permanent experiment). This farm belongs to the Sonatola Series under the general soil type of non-calcareous dark grey floodplain alluvium. This may be correlated with Aeric Heplaquapt of USDA soil taxonomy and Eutic Gleysol of FAO-UNESCO soil unit.

This manurial experimental plot was started in the year 1978. The initial soil was silt loam in texture having pH 6.8, organic matter 2.16%, total nitrogen 0.06%, available phosphorus 9.0 mg kg^{-1}, available potassium 0.20 cmol kg^{-1} as mentioned in Table 1. The treatments include control, N, NP, NPK, NS, NPKSZn, NFYM and NPKFYM. The fertilizer doses used in the experiments were 60 kg N ha^{-1} from urea, 20 kg P ha^{-1} from TSP, 15 kg K ha^{-1} from MP, 30 kg S from gypsum.

Collected soil samples from various depths (0-10 and 10-20 cm) were collected, grind, sieved and preserved in polithyne bag for analysis. Particle size analysis of soil was done by hydrometer method[9] and the textural class was determined by plotting the values for sand, silt and clay% in the Marshall's triangular co-ordinate following USDA system. Particle density and bulk density was determined by volumetric flask method and core sampler method respectively[9]. Total porosity of soil calculated from bulk and particle density after Vomocil[10]. Water stable aggregate were determined following the method described by Savvinov[11]. Total soluble salts was estimated from electrical conductivity of aqueous soil extracts from 1:5 soil:water suspension after Biswas and Mukherjee[12]. Soil pH was measured by glass electrode pH meter as outlined by Page[13]. Total nitrogen was determined by semi micro kjeldahl distillation method[13]. Available P and available S was determined after Olsen *et al.*[14]. Amount of organic matter, CEC, exchangeable K and exchangeable Ca was determined after Page[13].

Table 1: Physical and chemical properties of initial (1978) soils *(Results expressed on oven dry basis)

Characteristics	0-15 cm depth
Textural class	Silt loam
pH	6.8
Organic matter (%)	1.25
Total nitrogen (%)	0.06
Available phosphorus (mg kg^{-1})	9.0
Available potassium (cmol kg^{-1})	0.2

Initial soil was collected and analyzed just before starting the permanent experiment in 1978 (HSTL Report 1. 1983)

RESULTS AND DISCUSSION

Texture: Results on particle size distribution of soil of the plots under study were medium in texture and contained highest amount of silt ranging from 70-80% in surface layer and 74-78% in sub-surface layer (Table 2). Considering the vertical distribution of different sized particles, it appears from Table 2 that in general the sand content of top soil was higher than sub soil (10-20cm depth) whereas in case of clay the sub surface soil content was higher than surface soil. However, the silt content did not show any definite trend between the layers. It may be speculated from vertical distribution of different sized particles that the finer particles were transported from surface layer to sub surface layer with leaching water and deposited there. Result of mechanical analysis showed decrease of clay content in surface layer and increase in the sub-surface layer when compared with initial soil. From the lower sand content in the sub-surface layer of fertilizer treated plots it may be further speculated that in addition to physical weathering, strong chemical weathering of sand particle also occurred in sub-surface layer. This might be possible for the organic and inorganic acids produced in the surface layer from the residues of applied fertilizers as well as decomposition of organic matter. These acids are leached down from surface and accumulated in the sub-surface layer for relatively long period and helped in chemical weathering.

Bulk density: Bulk density of 0-10 cm layer varied from 1.0 to 1.2 g cm^{-3} whereas in 10-20 cm layer it varied from 1.35 to 1.43 g cm^{-3} irrespective of seasons (Table 3). The lower values in the surface layer are attributed to the higher content of organic matter in comparison to sub-surface (10-20 cm depth) layer. Moreover, frequent cultivation of land made the soil loose and ultimately contributed to the lowest density in this layer. Results did not show remarkable variation in wet or in dry season although some variations existed between the treatments. In the sub-surface layer, on the other hand, bulk density showed a wide variation among the treatments. The treatment NS tended to show its superiority over other treatments. The value of the treatments N, NP, NPK and

Table 2: Results of mechanical analysis of different depth

	Sand (%)		Silt (%)		Clay (%)	
Treatments	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth
Control	3.2	5.2	80	76	16.8	18.8
N	13.2	11.2	76	74	10.8	14.8
NP	13.2	5.2	74	76	12.8	18.8
NPK	11.2	7.2	76	76	12.8	16.8
NS	9.2	3.2	76	74	14.8	22.8
NPKSZn	9.2	3.2	74	76	16.8	20.8
NFYM	17.2	3.2	72	76	10.8	14.8
NPKFYM	17.2	7.2	70	78	12.8	14.8

Table 3: Bulk density, particle density and porosity of soils in different depths

	Bulk density (g cc^{-1})							
	Wet season		Dry season		Particle density (g cc^{-1})		Total porosity (%)	
Treatments	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth
Control	1.11	1.40	1.20	1.46	2.41	2.49	55.19	45.78
N	1.12	1.35	1.18	1.49	2.46	2.50	56.00	46.00
NP	1.12	1.37	1.20	1.48	2.45	2.58	56.37	48.06
NPK	1.13	1.38	1.10	1.50	2.45	2.45	55.70	46.12
NS	1.16	1.40	1.26	1.64	1.46	2.61	54.15	46.32
NPKSZn	1.12	1.36	1.24	1.62	2.44	2.53	57.68	47.04
NFYM	1.00	1.43	1.12	1.58	2.34	2.48	59.41	50.40
NPKFYM	1.00	1.24	1.12	1.59	2.36	2.46	60.17	51.22

Table 4: Distribution of different sized aggregates of soils of different depths

	Aggregates (%)											
	>2 mm		1 mm		0.5 mm		0.25 mm		0.1 mm		<0.1 mm	
Treatments	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Control	38.08	26.00	2.92	2.16	6.36	7.16	12.9	12.16	23.62	23.28	13.12	29.24
N	38.70	54.68	5.26	3.90	15.14	8.54	13.52	8.72	10.60	9.96	16.78	14.20
NP	46.30	50.12	5.68	3.82	12.92	7.60	11.22	9.90	9.74	12.42	14.14	16.14
NPK	61.46	45.00	3.42	4.18	7.50	10.36	7.18	8.40	5.78	14.00	14.66	18.06
NS	31.40	20.34	2.76	1.58	7.78	6.48	14.54	12.40	24.74	27.20	18.78	32.00
NPKSZn	54.22	70.46	5.80	3.02	10.36	6.22	9.38	5.82	7.22	4.60	13.02	9.88
NFYM	65.70	50.60	2.44	3.00	7.52	7.06	7.34	9.98	5.54	10.70	11.46	18.66
NPKFYM	58.22	44.24	3.36	2.68	6.16	6.70	9.84	10.76	8.82	16.30	13.60	19.92

NPKSZn were almost identical and followed the NS treatment. The values of the treatment NFYM, NPKFYM were identical and lower than any other treatment under study, both in wet as well as in dry period, specially in the surface layer. The high bulk density in the sub-surface layer indicated the presence of compacted sub-surface layer. Brammer[15] also reported the presence of compacted (plough pan) sub-surface layer due to accumulation of outwash from the upper horizon and the pressure produced from the animals and machineries used for the cultivation of lands. It also appears that there was a wide seasonal variation in bulk density of soils. The reason(s) for such seasonal variation in bulk density is not clearly understood. However, the relatively too low bulk density in wet season indicated that the soil contained expanding type of clay minerals which upon submergence of the field expanded and resulted in the low bulk density.

Particle density: The values of particle density varied from 2.34 to 2.46 g cm^{-3} and 2.45 to 2.61 g cm^{-3} at 0-10 and 10-20 cm depths respectively (Table 3). The different fertilizer treatments did not show remarkable variation in their effect on particle density of soil. However, the relatively low particle density as obtained due to FYM containing treatments might be possible for the increase in organic matter. The variation in particle density between the layers is mainly related to the variation in organic matter, although the presence of heavy metals could not be ignored.

Porosity: Data on soil porosity varied from 54.15 to 60.17% (vol.) and 45.78 to 51.22% (vol.) at 0-10 and 10-20 cm depths respectively (Table 3). The higher amount of pore space in the surface is attributed to the higher amount of organic matter as well as loosening of soil material during cultivation/puddling of soil. This is also evidenced from the higher pore space in FYM treated plots the lower amount of pore space in the sub-surface layer on the other hand is associated with higher bulk density due to compactness as well as presence of lower

Table 5: Soil pH, electrical conductivity, CEC and organic matter content of different depth

	Soil pH		EC ($\mu S\ cm^{-1}$)		CEC (me/100 g soil)		Organic matter (%)	
Treatments	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth	0-10 cm depth	10-20 cm depth
Control	6.95	7.85	306	271	11.2	11.1	1.75	0.69
N	6.87	7.62	475	322	11.5	10.9	1.83	0.70
NP	6.82	7.60	497	265	12.1	12.0	1.88	0.70
NPK	6.88	7.53	492	421	12.3	12.5	1.87	0.73
NS	7.11	7.85	549	372	13.0	12.7	1.87	0.69
NPKSZn	7.08	7.89	601	531	11.7	11.6	1.82	0.69
NFYM	6.86	7.51	411	363	15.6	15.3	2.25	0.81
NPKFYM	6.82	7.48	329	289	16.1	16.0	2.20	0.79

organic matter. The porosity decreased with increase of soil depth probably due to lower organic matter content and higher bulk densities and compactness of soil[16].

Aggregate stability: The amount of aggregates of <0.1 mm size in general followed the >2 mm size except the control and NS treatments whose amount of 0.1 mm size particles was next to >2 mm size particles (Table 4). Considering the effects of different treatments it was noted that P and FYM containing treatments were effective in maintaining larger aggregate in soils. However, among these treatments the effect of NFYM was the best which was followed by NPK in surface soil whereas the treatment NPKSZn was more effective than any other treatment. It may be mentioned here that the calcium sulfate (gypsum) is a cementing material and it was expected to obtain higher amount of larger aggregate in NS treated plot. But unexpectedly the lowest amount of <2 mm sized aggregate was obtained in this plot. The highest bulk density and lowest amount of pore space also indicated the cementing effect of gypsum. It is rather difficult to explain the reason(s) for such a low content of larger aggregates and higher content of fine aggregate (0.1 to <1 mm). However, it seems that the residual sulfur of applied gypsum remained in soil as water soluble sulfate salts which after shaking with water was dissolved as a consequence the aggregates were destroyed resulting in lowest amount of larger aggregate and lowest amount of fine aggregate. The higher amount of larger aggregate found in P and FYM treated soil was probably due to calcium as well as organic matter respectively which also has strong cementing effect in soil. The relatively low amount of larger aggregate and higher amount of finer aggregate compared to other treatments (except NS) are attributed to the absence of cementing materials in these treatment. The amount of aggregates of 1, 0.5, 0.25 and 0.1 mm did not follow any definite trend due to different treatments and depths.

Soil pH: The data on soil pH at different depths appears that the pH value of soils varied considerably due to different treatment combinations but it did not follow any definite trend (Table 5). The pH values of all fertilizer treated soils varied from 6.82 to 7.11 and 7.48 to 7.85 at 0-10 and 10-20 cm depths respectively. In general, the pH of soil increased with increasing soil depth irrespective of treatments under study. An increase in soil pH was found due to long-term application of NS and NPKSZn treatments over all other treatments as well as original pH of 6.8 (Table 1). The values for the rest of the treatments were almost identical and equal to original values although some variations existed among the treatments. The higher values are found in NS and NPKSZn treatments might be possible for the relatively high content of Ca^{2+}, supplied with gypsum. The pH of sub-surface (10-20 cm) varied from 7.51 to 7.85 i.e., slightly alkaline in reaction. This is probably due to decrease of clay and organic matter with the increase of soil depth. Chowdhury[17] observed that the pH of Sonatola series ranged from 6.8 to 7.2, which is very close to the results obtained under the present study.

The low pH in surface layer may be attributed to the oxidation of ammonium to nitrate during air drying of soils which produce H^+ as stated by McLaren[18] as follows:

$$2NH_4^+ + 3O_2 = 2NO_2^- + 2H_2O + 4H^+ \quad (1)$$

$$2NO_2^- + O_2 = 2NO_3^- \quad (2)$$

In addition Fe^{2+} also produces H^+ ion during its oxidation to FeOOH[19].

$$Fe^{2+} + {}^1/_4O_2 + H^+ \rightarrow Fe^{3+} + {}_{1/2}\,H_2O$$
$$Fe^{3+} + 2H_2O \rightarrow FeOOH + 3H^+$$
$$Fe^{2+} + {}^1/_4\,O_2 + {}^3/_2H_2O \rightarrow FeOOH + 2H^+$$

The sulfur is reduced to sulfide under wetland condition when the sols are strongly reduced and forms Metal Sulfide (MS)[20]. When the soils dry out during the dry season these sulfides are oxidized to sulfate and become soluble. After dissociation of sulfate salts in

Table 6: Total N, available P, exchangeable K, available S and Ca of soils of different depth

	Total N (%)		Available P (ppm)		Exchangeable K (me/100 g soil)		Available S Ppm		Ca (me/100 g soil)	
Treatments	0-10 cm	10-20 cm	0-10 cm	0-10 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Control	0.08	0.05	0.16	0.16	0.18	0.18	10	9	5.2	4.1
N	0.13	0.09	0.18	0.18	0.19	0.19	12	10	6.0	4.7
NP	0.11	0.07	0.17	0.17	0.18	0.18	12	9	5.6	4.7
NPK	0.12	0.08	0.22	0.22	0.24	0.24	13	10	5.8	5.7
NS	0.11	0.08	0.16	0.16	0.20	0.20	22	15	6.6	6.0
NPKSZn	0.11	0.08	0.22	0.22	0.22	0.22	22	16	6.6	6.0
NFYM	0.14	0.07	0.16	0.16	0.17	0.17	20	15	5.7	5.8
NPKFYM	0.13	0.09	0.20	0.20	0.21	0.21	19	16	6.2	5.2

solution the sulfate ions may produce acids as H_2SO_4. The lowering of surface soil pH due to S and Zn may be explained according to Schachtschabel *et al.*[19] as follows:

$$MS + {}^{1}/_{2}O_2 + {}^{1}/_{2}H_2O \rightarrow MOOH + H_2SO_4$$

Organic matter content: Soil organic matter content was higher in the 0-10 cm layer which is similar to Sood and Kanwar[21] and Rajamannar *et al.*[22]. In the surface layer lower value was found in control plot which did not receive any fertilizer for the last 19 years (Table 5). The addition of N, NP, NPK, NS, NPKSZn, NFYM and NPKFYM gradually increased the organic matter status over control although it was not remarkable except the NFYM and NPKFYM treatments. Application of FYM with N and NPK for period of 19 years increased the organic matter content of soils over all of the treatments under study. This increase in organic matter was mainly due to higher biomass production through manuring (FYM). In general, the status of organic matter even in control plot was higher than the initial status. This might be possible for the undecomposed roots and crop residues as soil sampling was done immediately after harvest of crop. USDA Soil Survey Staff[23] also observed decreasing trend of organic matter with increasing depth. On the other hand, low organic matter content in sub soils might be possible for the presence of compact plough-pan in the sub-surface layer of the field. This compact layer restricted the penetration of plant roots to the deeper depths contributing to high status of organic matter in the surface layer[15,24,25]. In addition to this the high microbial population and crop residues also contributed to the high organic matter status in the surface layer[13].

Electrical conductivity: In all treated soils the electrical conductivity was found higher than control plot where the conductivity was the highest in the S-containing treatments (Table 5). In other treatments the EC although showed higher values over control and it did not follow any definite trend in surface as well as sub-surface soil. The higher EC found in S-treated plots is attributed to the presence of higher amount of water soluble sulfate salt produced from the residues of applied fertilizers. Such increase in EC due to sulphur fertilization was also noted by Abedin Mian (1991).

Cation Exchange Capacity (CEC): The CEC of soils did not show any remarkable variation among different treatments as well as depths (Table 5). The continuous cropping for a period of 19 years with fertilizers slightly decreased cation exchange capacity of soil in control plot when compared with other fertilizer treated plots. It appears from the data that long-term use of chemical fertilizers in different combinations had no influence on the CEC both in surface and sub-surface soils. Similar results were also found by Shinde and Ghosh[5]. A considerable increase in CEC was obtained in NFYM and NPKFYM treated plots due to continuous application of FYM[26,27]. It appears from the results that CEC of soils slightly decreased with increasing the depth of soils. Similar decreasing results were also reported by Chowdhury[28].

Total nitrogen: The total N content of soils showed a wide variation between the depths (Table 6). The soils from surface 0-10 cm layer always showed dominance over the soils from 10-20 cm depth. This variation in total N content between the depths is mainly associated with the variation in organic matter content between the layers. Considering the effect of different fertilizer treatment it appears from the result that all the fertilizer treatments tended to show their superiority over the control plot in both the depths. The variation of total N content of soil due to different fertilizer treatments were very negligible. However, the slightly lower values found in P and S treated plots might be possible for the replacement of a part NO^{3-} by PO_4^{-3} and SO_4^{-2} by NH_4^+ and additional calcium supplied with TSP and gypsum fertilizer.

Available phosphorus: The data on phosphorus at different depths appears that the continuous cropping for long period without P fertilizer remarkably decreased the P-content of soil in the P control plots when compared to other fertilizer treated plots (Table 6). The treatments NP, NPK, NPKSZn and NFYM were found almost equally effective in maintaining t he high availability P in soil due to the residues of applied P mainly. The treatment NPK showed its superiority over all other treatments in maintaining the highest P level in surface layer. This higher concentration of P in NPKFYM treated plot indicates that in addition to P fertilizer the application of organic matter (FYM) over a period of 19 years also contributed to some extent on available P contents. This result is in accordance with the previous results of Khan *et al.*[29]. It is further apparent from the data that the level of P also increased in both surface and subsurface layers over the initial value of 9.0 ppm due to the treatments without P. This may be possible for relatively high organic matter produced from higher biomass production mainly.

Exchangeable potassium: Results on exchangeable K content of soils did not show any remarkable variation between the treatments as well as soil depths (Table 6). The treatments containing K fertilizer tended to show a high status but practically it did not vary from the other treatments. This almost uniform K status of different treatments indicated that the urea-N applied with fertilizer has some adverse effect on soil K due to the increase of NH_4^+ concentration produced from hydrolysis of urea in soil. Khan[30] reported a higher adsorption of K soils from NK treated plot than control plot due to displacement of K^+ by NH_4^+ mainly. However, this finding of the present study is in confirmation with the above finding.

Available sulphur: Result pertaining to the available sulphur content of soils showed wide variation among different treatments and depths (Table 6). The continuous cropping for a period of 19 years without S-fertilizer slightly decreased the S-content of soil in control plot when compared to other fertilizer treated plots. However, a significant influence of S-fertilization over a period of 19 years brought about remarkable increase in available S content of surface soil. A considerable increase of available S was also obtained in NFYM and NPKFYM treated plots. This increase was probably due to continuous application of FYM, which is one of the main sources of sulphur in soils[13]. In a sulphur fractionation study Abedin Mian[31] also found an increase in sulphur status due to S-fertilization. The result obtained in the present study might be possible for intensive fertilization. The status of sulphur in control treatment was just at or below the critical level of 14 ppm as reported by BARC. The variation as noted between the surface and sub-surface concentration was associated mainly with organic matter.

Exchangeable calcium: Results on exchangeable Ca content of s oils from different fertilizer treated plots showed almost a similarity irrespective of depths (Table 6). The concentration of Ca varied from 5.2 to 6.6 me 100^{-1}g and 4.1 to 6.0 me 100^{-1}g soil at 0-10 and 10-20 cm depths, where the lowest value was obtained in control plot. In general, it is apparent that the P and S treated plots tended to show higher concentration of Ca than of other plots. The Ca supplied by P and S containing fertilizers might be one of the reasons for this high status.

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