

Effects of soil properties on phosphorus fractions in subtropical soils of Iran

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Abstract

The distribution of inorganic P fractions and their relationships with soil properties was studied in 17 slightly acidic to slightly alkaline soils (pH range 5.37 to 7.61). The soils were selected from agricultural fields of the north of Iran. Inorganic P fractionation included successive extraction with NaOH (NaOH-P), citrate-bicarbonate (CB-P), citrate two times (C1- and C2-P), Citrate-ascorbate (CAs-P), citrate-dithionite-bicarbonate (CBD-P), sodium-acetate buffer (NaOAc-P) and HCl (HCl-P). Results showed that the abundance of P fractions was in the order NaOH-P (35.67 mg kg⁻¹), NaOAc-P (39 mg kg⁻¹), C2-P (49 mg kg⁻¹), CBD-P (102 mg kg⁻¹), CB-P (136 mg kg⁻¹), CAs-P (156 mg kg⁻¹), C1-P (197 mg kg⁻¹), HCl-P (417 mg kg⁻¹). Among soil properties, pH had almost a linear negative relationship with NaOH-P and a linear positive relationship with HCl-P; in addition, it significantly affected C1-P, CAs-P and NaOAc-P. Oxalate extractable Fe showed a significant positive correlation with NaOH-P and CAs-P, while calcium carbonate equivalent (CCE) had a significant positive correlation with NaOAc-P and HCl-P.

Keywords: Inorganic phosphorus fractions, agricultural fields, pH.

1. Introduction

Phosphorus (P) fractionation is an applicable technique to determine the P status of soils and to study the chemistry and genesis of soils (Chang and Jackson, 1957; Cross and Schlesinger, 1995). Accurately characterizing P forms is a prerequisite to developing effective remediation strategies to minimize the adverse environmental impact of agricultural expansion. Knowledge of P fractions is important for evaluation its status in soil and understanding soil chemical properties that influence soil fertility and environmental quality. Soil P fractionation has been investigated since 1957 and was later applied to soils and sediments to overcome the limited information that total P analysis can provide (Zhou *et al.*, 2001).

Principles of the fractionation methods are to displace PO_4^{3-} from its sorption sites (through anion competition), to alter the adsorption surface, or to dissolve compounds containing P. The most easily desorbed and labile compounds are removed first with dilute reagents and the strength of the extractants increases stepwise, in order to separate more strongly bound P forms. Sequential chemical extraction methods have often been used to study the nature of P forms in soils and sediments. These methods are based on the selective extraction of operationally defined P fractions by using single extractants in a sequential manner (Hieltjes and Lijklema, 1980; Olsen and Sommers, 1982; Jiang and Gu, 1989; Ruiz *et al.*, 1997). In calcareous soils, P is mainly bound to adsorption surfaces at low (<10⁻⁴–4.5 M) concentrations of orthophosphate in solution (Borrero *et al.*, 1988; Tunesi *et al.*, 1999), whereas it is mainly precipitated as Ca phosphates at higher concentrations (Castro and Torrent, 1998; Tunesi *et al.*, 1999). Soils that dominate humid temperate and tropical regions are highly weathered, acidic and dominated by large quantities of sesquioxides. These soils easily adsorb and geochemically fix phosphorus in many cases leading to phosphorus limitations (Cross and Schlesinger, 1995). In acid to neutral soils, Fe and Al phosphates are the typical precipitation products (Lindsay, 1979;

Pierzynski *et al.*, 1990; Cross and Schlesinger, 1995). However, some heavily fertilized acidic soils contain significant amounts of Ca phosphates (Lookman *et al.*, 1996), and hydroxyapatite has been found as a product of the dissolution of superphosphates in acidic and slightly acidic soils (Kumar *et al.*, 1994). Pierzynski *et al.* (1990) showed that P-rich particles resulting from fertilizer dissolution in acid soils included not only Al and Fe but also Si and Ca.

Soils of Guilan province, in the north of Iran, are characterized by acidic to neutral pH, and more Fe and Al oxides than soils from other parts of the country (Ghasemi Fasaie *et al.*, 2007). The climate is subtropical with an average rainfall of 1000 mm (Bahrami *et al.*, 2010). Soil characteristics and suitability of the area for intensive crop production favor high application of inorganic P fertilizers annually, which has an important effect on the quality of surface water reservoirs (Sharpley and Tunney, 2000). Many studies has been conducted about P chemistry and fractions in other parts of Iran (Khanmirzaie *et al.*, 2009; Adhami *et al.*; 2007 and 2006) while, such studies are rare in the north of Iran. The objectives of this study were to evaluate the status of P fractions in soils from agricultural fields of Guilan, in the north of Iran, and also investigate the relationships between soil properties and inorganic P fractions.

2. Materials and methods

Seventeen surface soil samples (0 - 0.30 m depth) with a wide range of physical and chemical characteristics from Guilan province in Iran were selected for this experiment. The soils were all from agricultural fields. One composite sample, consisted of at least 8 samples, of each soil was collected. The soil samples were air-dried and passed through a 2-mm sieve before analysis. Sand, silt and clay content were determined by hydrometer (Gee and Bauder, 1986). Cation exchange capacity (CEC; Sumner and Miller, 1996) by substitution of exchangeable cations with

sodium acetate, calcium carbonate equivalent (CCE) by neutralizing with HCl (Loeppert and Suarez, 1996), organic matter content (Nelson and Sommers, 1996) by wet oxidation process, pH from a saturated paste (Thomas, 1996), and oxalate-extractable Fe (Fe_o ; Loeppert and Inskeep, 1996) were determined (Table 1).

The inorganic P sequential fractionation scheme (Table 2) followed the Ruiz *et al.* (1997) sequence. Briefly, the procedure includes successive extraction with NaOH to remove soluble/exchangeable P and Al- and Fe-bound P; Na citrate bicarbonate (CB-P) to extract P reabsorbed in the previous step and labile pedogenic Ca-phosphates; Na citrate 2 times (C1 and C2-P) reagents for extracting pedogenic Ca-P; sodium-citrate ascorbate (CAs-P) for P occluded in poorly crystalline Fe oxides; citrate-dithionite bicarbonate (CBD-P) for P occluded in crystalline Fe oxides; Na acetate buffer for Ca-P excluding lithogenic apatite; and HCl to remove mostly lithogenic apatite. All extractions were carried out on 1^g samples, in duplicate, with a ratio of 1: 40 soil: extractant. Following each step the samples were centrifuged at 6000g for 15 min and the supernatant filtered through Whatman No. 42. Reactive P in the supernatant was determined using the ascorbic acid method at 882 nm (Murphy and Riley, 1962). Interference with citrate and dithionite was overcome by enrichment with ammonium molybdate (Ruiz *et al.*, 1997) and ammonium persulfate, respectively.

3. Results and discussion

3.1. NaOH-P

The mean of NaOH-P was 35.67 mg kg⁻¹ and it ranged from 13.2 to 72.61 mg kg⁻¹ which accounted for 3.16 % of the sum of the fractions. The amount and percentage of this fraction was obviously higher than those reported by Adhami *et al.* (2007) for 16 calcareous soils of the south of Iran. Most of the fractionation sequences for both calcareous and non-

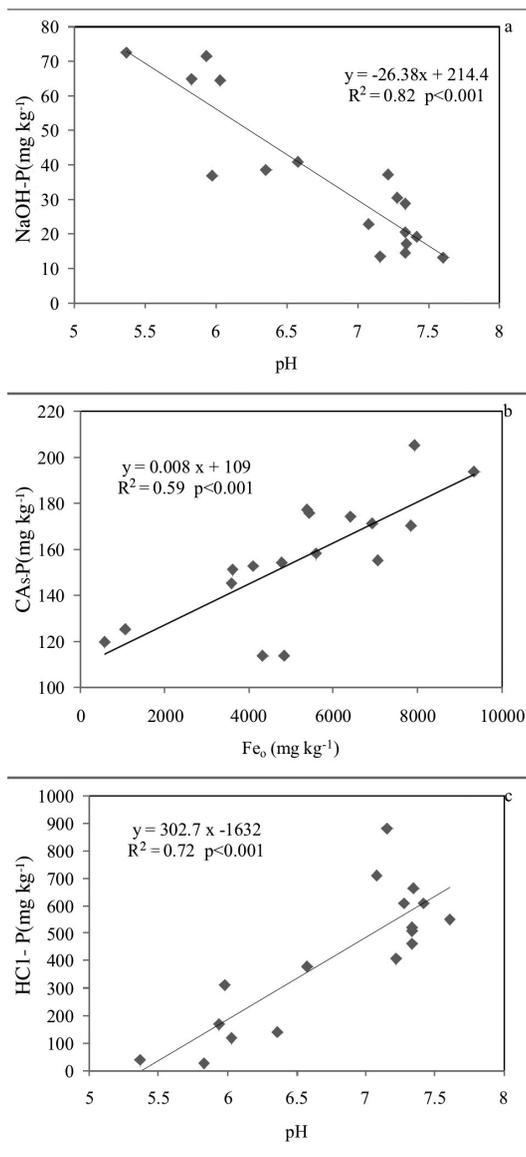


Figure 1. Relationships between a) NaOH-P and pH; b) citrate-ascobate extractable P (CAsP) and Oxalate extractable Fe (Fe_o); c) Relationship between HCl-P and pH

calcareous soils starts with NaOH and attribute it to Fe- and Al-P (Chang and Jackson, 1975; Williams *et al.*, 1971; Solis and Torrent, 1989; and Ruiz *et al.*, 1997). This fraction constitutes a small fraction of P in calcareous soils (Solis and Torrent, 1989; Adhami *et al.*, 2007). Although Chang and Jackson (1957) observed that NaOH could dissolve $\text{FePO}_4 \cdot 2\text{H}_2\text{O}$, its ability to extract Fe- and Al-P in the presence of CaCO_3 has been questioned (Williams *et al.*, 1971). In the present study, NaOH-P constituted a higher portion of inorganic P in more acidic soils (6-11 % of the sum of P fractions) than neutral to slightly basic soil (2-6 % of the sum of P fractions). The content of NaOH-P was lower than those reported by Ruiz *et al.* (1997) in 10 neutral to acidic soil (28 to 657 mg kg^{-1}). Ruiz *et al.* (1997) reported that in more acidic soils NaOH-P accounted for a substantial amount of the sum of inorganic P fractions.

Relationships between NaOH-P and soil properties showed that it was negatively correlated with CCE and pH; while it was positively correlated with Fe_o (Table 4). Among these properties, pH was the best variable to describe NaOH-P variation (Figure 1a). Tyler (2002) studying 110 soils of northeast Sweden reported a close, almost linear, relationship between soil acidity and P-Fe. It was observed that P-Fe fraction constituted about 50% of inorganic P in most acid soils but less than 1% in moderately alkaline (calcareous) soils. Relationship between NaOH-P and soil properties is in agreement with the general assumption that NaOH extracts Fe- and Al-P. Since the decrease of soil pH is generally associated with the increase of Al- and Fe-oxides, the common expectation is the increase of NaOH-P with decrease in soil pH.

3.2. Pedogenic Ca-P

Citrate bicarbonate, and 2 consecutive citrate extractions used in the sequential fractionation scheme are proposed to remove pedogenic Ca-P (Ruiz *et al.*, 1997; Delgado *et al.*, 2000). Ranges for CB-P, C1-P and C2-P, were 41.5-261; 144-359 and 31-77 mg kg^{-1} , respectively. Adhami *et al.* (2007) found that the

average content of the sum of CB-, C1- and C2-P in 16 highly calcareous soils of the south of Iran was 238, while in the present study it was 378 mg kg^{-1} . The content of pedogenic Ca-P is also higher than those reported by Ruiz *et al.* (1997) in 10 slightly acidic soils. Climate of Guilan province is sub-tropical with an average rainfall of 1000 mm (Bahrami *et al.*, 2010) which has resulted in soils with lower pH, and more Fe and Al oxides than soils from other parts of the country. Thereupon, the general expectation was a lower content of pedogenic Ca-P such as CB-, C1- and C2-P (Cross and Schlesinger, 1995); the opposite trend is probably caused by intensive application of inorganic P fertilizers in the region.

It is likely that metastable phases (i.e. dicalcium, octacalcium, and tricalcium phosphate) and possibly a small fraction of stable phase (hydroxyapatite) were dissolved in CB reagent (Delgado *et al.*, 2000). Pedogenic Ca-P could be partly available to plants (Samadi, 2006; Khanmirzaie *et al.*, 2009). Delgado *et al.* (2000) reported that part of Olsen P is originated from CB-P. On the other hand citrate is common reagent to evaluate P availability of fertilizers. The high content of pedogenic Ca-P in the studied soils indicates the high risks of adverse effects of P on both agricultural production and environmental quality.

In the present study CB-P and C-P (sum of C1- and C2-P) accounted for 12 and 21% of the sum P fractions; respectively. Saavedra and Delgado (2005) reported that the dominant P fractions in 17 soils from Spain were CB-P and C-P which were accounted for 31% and 30% of the sum of P fractions; respectively. Adhami *et al.* (2007) studying 16 calcareous soils of Iran observed that CB-P and C-P constituted 9.4 % and 31% of the sum of P fractions.

Correlation of pedogenic Ca-P (CB, C1- and C2-P) with soil properties showed no significant correlation except for C1-P with silt and pH (Table 4). Multiple regression analysis showed that pH and silt jointly could predict 51 % of C1-P variation (Eq. 1):

Table 1. Some physico-chemical characteristics of the select soils.

Soil No.	Altitudes	Sand	Silt	Clay	OC ^a	CCE ^b	Fe _o ^c (mg kg ⁻¹)	pH	CEC ^d (cmol _c kg ⁻¹)
1	49° 38' 59" E, 37° 11' 56" N	6.0	59.0	35.0	2.63	1.9	5387	5.37	28
2	50° 10' 02" E, 37° 10' 01" N	54.0	25.5	20.5	1.76	2.9	5440	5.83	20
3	49° 13' 50" E, 37° 31' 26" N	21.0	41.0	38.0	5.67	8.0	9348	5.94	52
4	49° 53' 41" E, 37° 02' 51" N	18.0	47.0	35.0	4.62	4.0	4785	5.98	43
5	49° 14' 01" E, 37° 19' 38" N	16.0	56.0	28.0	2.46	2.4	6932	6.03	28
6	49° 28' 48" E, 37° 20' 46" N	2.0	46.0	52.0	2.93	2.6	7921	6.36	36
7	48° 51' 44" E, 38° 20' 11" N	8.0	52.0	40.0	1.98	5.1	7840	6.58	41
8	49° 42' 02" E, 37° 15' 40" N	31.3	40.7	28.0	3.03	3.4	4107	7.08	37
9	48° 54' 26" E, 37° 58' 02" N	26.0	38.0	36.0	2.29	7.8	5594	7.16	44
10	50° 15' 43" E, 37° 06' 21" N	24.0	48.0	28.0	2.80	6.3	6404	7.22	42
11	49° 25' 45" E, 36° 49' 06" N	42.0	41.0	17.0	3.20	12.2	1091	7.28	27
12	49° 49' 16" E, 37° 21' 42" N	12.0	44.0	44.0	3.51	14.0	4335	7.34	45
13	49° 38' 36" E, 37° 15' 34" N	4.0	48.0	48.0	2.58	12.4	3610	7.34	43
14	49° 34' 54" E, 36° 59' 55" N	31.0	48.0	21.0	1.65	11.8	4834	7.34	29
15	49° 57' 15" E, 37° 17' 36" N	63.7	28.5	7.8	0.89	9.9	582	7.35	14
16	50° 22' 46" E, 37° 05' 12" N	32.0	48.0	20.0	4.07	16.5	7072	7.42	37
17	49° 30' 09" E, 36° 53' 49" N	3.0	47.0	50.0	1.61	16.0	3593	7.61	38

^a organic carbon; ^b calcium carbonate equivalent; ^c oxalate extractable Fe; and ^d cation exchange capacity. Current land uses of the soils are flooded rice; except for soil 11 which is under olive trees.

$$C1-P = 542 - 50.1 \text{ pH} \quad R^2 = 0.33 \quad p < 0.015 \quad (1)$$

$$C1-P = 358 - 44.3 \text{ pH} + 3.10 \text{ silt} \quad R^2 = 0.51 \quad p < 0.007 \quad (2)$$

Adhami *et al.* (2007) observed a positive correlation between CB-P and silt fraction of the studied soils. Delgado and Torrent (2000) believe that C-P essentially correspond to sparingly pedogenic Ca-P. Presumably, two consecutive citrate extractions, should extract mainly pedogenic Ca-P compounds. Delgado *et al.* (2000) explained that citrate in Ruiz's sequence essentially releases P related to Ca-phosphate as a consequence of Ca complexation by citrate.

3.3. Forms of Reductant P

CAs-P ranged from 114 to 205 mg kg⁻¹ (average 156 mg kg⁻¹) and accounted for 14% of the sum of P fractions. Citrate ascorbate extractable P can be considered as mild reductant soluble P, and is assumed to be P associated with poorly crystalline Fe oxides (e.g. ferrihydrite) (Ruiz *et al.*, 1997, Delgado *et al.*, 2000). The range of CBD-P was 36 to 262 mg kg⁻¹ with the average of 102 mg kg⁻¹, and in average constituted 9 percent of the sum of P fractions. Citrate-bicarbonate-dithionite extractable P is part of soil-P which is released with the effect of a strong reductant (dithionite), generally is attributed to various forms of P occluded in crystalline Fe oxides (Ruiz *et al.*, 1997). In most soils CAs-P was higher than CBD-P and in average CAs-P was 1.5 fold of CBD-P. This indicates that most of reductant soluble P in the studied soils is "mild reductant P". Ruiz *et al.* (1997) found that CAs-P ranged from 13 to 133 mg kg⁻¹ in 12 soils of Europe and in most soils it accounted for more than 50% of reductant soluble P. Saavedra and Delgado (2005) reported that the average amount of CAs-P in 17 mediterranean soils was 11 mg kg⁻¹. Although, the results of chemical P fractionation could not be

directly used to P dynamics in natural environments, reductant soluble P (CAs-P and CBD-P) provides an index of P that can be potentially released when soil material are subjected to reducing condition in natural environments. Thereupon, the high content of CAs-P in the studied soils indicates that most of the reductant soluble P could be easily reduced and solubilized when subjected to reducing conditions, i.e. in waterlogged rice fields or sediments of water reservoirs.

In the present study, multiple regression analysis showed that Fe_o could predict 59 percent of CAs-P variation (Figure 1b); while introducing CCE as the second variable increased R² to 0.74 (Eq.3):

$$CAs-P = 136 + 0.007Fe_o - 2.205CCE \quad R^2 = 0.74 \quad p < 0.0001 \quad (3)$$

Although, citrate ascorbate is not a selective extractant for P associated with Fe oxides in highly calcareous soils (Ruiz *et al.*, 1997; Adhami *et al.*, 2007); the results of the present study shows that in acidic to slightly alkaline soils, citrate ascorbate mainly extracts P associated with Fe_o. Relationship between CAs-P and Fe_o is in accordance with the assumption that CB followed by 2 citrate extractions will remove all of the pedogenic Ca-P; therefore, the use of citrate ascorbate should increase the P release as a result of its reductant effect, and will not affect Ca-P (Ruiz *et al.*, 1997; and Delgado *et al.*, 2000).

3.4. Lithogenic Ca-P

NaOAc-P ranged from 7.26 mg kg⁻¹ to 99.6 mg kg⁻¹; and in average consisted 4 % of the sum of inorganic P fractions. In slightly acidic to neutral soils, NaOAc-P constituted 1 to 4 % of the sum of P fractions while, in slightly alkaline soils it constituted 1 to 9 % of the sum of P fractions. Sodium acetate buffer pH 4 was introduced in fractionation schemes to extract Ca phosphate

Table 2. Sequence of the used fractionation scheme

Step	Extractants	pH	Shaking time (h)	P forms extracted	Abbreviation
1	0.1 M NaOH ;1M NaCl	-	16	Al- and Fe-bound P	NaOH-P
2	0.27 M Na Cit.; 0.11 M NaHCO ₃	6-7	16	P readsorbed in the previous step; labile pedogenic Ca- rich phosphates	CB-P
3	0.25 M Na Cit.	6	16	Pedogenic Ca-P, much of the NaOH extractable P forms, if not dissolved	C1-P
4	0.20 M Na Cit.	6-7	8	Same as the previous step	C2-P
5	0.2 M Na Cit.; 0.05 M ascorbate	6	16	P occluded in poorly crystalline Fe oxides	CAs-P
6	0.27 M Na Cit.; 0.11 M NaHCO ₃ ; 0.12 M Na dithionite	-	16	Various forms of P occluded in crystalline Fe oxides	CBD-P
7	1 M NaOAc buffer	4	6	Ca-P excluding lithogenic apatite	NaOAc-P
8	1 M HCl	-	16	Mostly lithogenic apatite	HCl-P

excluding lithogenic Ca-P (Jiang and Gu, 1989; Ruttenberg, 1992; Barbanti *et al.*, 2004; Ruiz *et al.*, 1997). Adhami *et al.* (2007) observed that NaOAc-P in 16 calcareous soils from south of Iran ranged from 8 to 76 mg kg⁻¹ with an average of 36 mg kg⁻¹. Ruiz *et al.* (1997) reported that NaOAc-P ranged from 3 to 72 mg kg⁻¹ in 12 noncalcareous and calcareous soils of Europe. Relationship between NaOAc-P and soil properties showed a significant positive correlation with CCE, Clay and pH (Table 4). Multiple regression analysis showed that 70% of NaOAc-P variation could be predicted by CCE and Clay (Eq.5):

$$\text{NaOAc-P} = 9.182 + 3.714 \text{ CCE} \quad R^2=0.45 \quad p<0.004 \quad (4)$$

$$\text{NaOAc-P} = -2732 + 3.778 \text{ CCE} + 1.116 \text{ Clay} \quad R^2=0.70 \quad p<0.001 \quad (5)$$

The relationships of NaOAc-P with CCE and clay are in accordance with the assumption that NaOAc in the Ruiz *et al.* (1997) sequence is capable of

Table 3. Inorganic P fractions.

Soil No.	NaOH-P	CB-P	C1-P	C2-P	CAs-P	CBD-P	NaOAc-P	HCl-P
	(mg kg ⁻¹)							
1	72.6±4	63.5±4	280.7±6	31.4±0	177.2±7	57.4±2	10.0±1	37.4±1
2	64.6±8	118.4±5	144.2±11	37.9±3	175.9±13	66.5±4	7.3±2	27.2±1
3	71.3±7	143.0±10	229.7±15	43.1±2	193.7±2	58.4±5	32.7±2	166.0±7
4	36.9±1	261.4±7	252.4±10	43.5±5	154.2±5	112.4±4	40.3±2	311.3±24
5	64.0±3	105.3±5	358.5±12	45.6±7	171.2±10	185.4±9	18.7±1	116.2±2
6	38.6±3	141.0±9	161.7±8	39.1±1	205.0±5	262.4±2	21.6±3	139.6±7
7	40.9±4	180.3±5	230.4±6	55.1±4	169.7±13	100.8±0	31.8±3	377.3±10
8	22.7±0	41.6±3	163.9±10	45.1±2	152.6±12	49.6±2	19.4±8	709.9±23
9	13.3±3	89.9±8	144.0±8	38.7±2	158.1±7	63.3±5	61.3±0	880.3±31
10	37.1±2	182.9±8	182.2±12	54.1±3	174.2±12	135.9±0	26.6±1	404.±85
11	30.3±3	253.3±15	267.4±15	53.3±4	125.2±4	131.9±8	19.4±1	609.±329
12	20.6±2	137.9±8	153.6±6	54.1±5	113.7±3	99.1±5	99.6±3	462.8±28
13	14.5±1	134.0±3	150.7±8	31.2±5	151.1±5	69.7±2	91.4±5	508.8±12
14	28.7±0	149.9±7	144.0±6	53.1±3	113.7±5	140.7±7	20.4±0	520.8±15
15	17.1±3	122.3±6	167.5±8	34.2±2	119.5±3	36.3±3	41.6±2	662.1±20
16	19.2±0	100.1±9	157.9±5	77.0±5	155.5±5	70.9±4	47.0±5	608.5±24
17	13.2±0	93.4±5	154.2±4	32.9±2	145.2±8	88±1	76.6±2	550.4±15
Average	35.7	136	197	45.2	156	101.7	39.1	417.2
% of Sum	3.2	12	17	4	13	9	3.6	37

extracting Ca phosphate excluding lithogenic apatite. Content of HCl-P ranged from 27 to 880 mg kg⁻¹ with an average of 419 mg kg⁻¹ and in average constituted 37% of the sum of P fractions. Adhami *et al.* (2007) reported that the average content of HCl-P in 16 calcareous soils of Iran was 125 mg kg⁻¹. The content of HCl-P is also more than those observed by Ruiz *et al.* (1997) in 12 non-calcareous and calcareous soils of Europe (4 to 129 mg kg⁻¹). Saavedra and Delgado (2005) found that the average content of HCl-P in 17 agricultural soils of SW Spain was 14 mg kg⁻¹. It is believed that phosphorus extracted with a dilute acidic solution (e.g. HCl 0.25 M; or H₂SO₄ 0.25 M) is primary phosphorus minerals such

as hydroxylor flourapatite (Chang and Jackson, 1957; Jiang and Gu, 1989; Adhami *et al.*, 2007). Due to higher weathering, general expectation was the lower content of lithogenic Ca-P as the primary phosphorus minerals (Cross and Schesinger, 1995) in the region than the soils of south of Iran, the opposite trend is probably an effect of intensive application of inorganic P fertilizer. It has been reported heavily fertilized acid soils may contain significant amounts of Ca phosphates (Lookman *et al.*, 1996), and hydroxyapatite has been found as a product of the dissolution of superphosphates in acid and slightly acid soils (Kumar *et al.*, 1994). The least content of HCl-P was belong to soil 2 (pH=5.83)

Table 4. Correlation coefficient between inorganic P fractions and soil properties (n = 17)

Soil properties	NaOH-P	CB-P	C1-P	C2-P	CAs-P	CBD-P	NaOAc-P	HCl-P
OM	0.26 ^{ns}	0.28 ^{ns}	0.25 ^{ns}	0.33 ^{ns}	0.31 ^{ns}	-0.01 ^{ns}	0.04 ^{ns}	-0.19 ^{ns}
Clay	-0.043 ^{ns}	-0.08 ^{ns}	-0.10 ^{ns}	-0.32 ^{ns}	0.39 ^{ns}	0.27 ^{ns}	0.49*	-0.20 ^{ns}
Silt	-0.19 ^{ns}	0.00 ^{ns}	0.51*	0.18 ^{ns}	0.20 ^{ns}	0.36 ^{ns}	0.01 ^{ns}	-0.26 ^{ns}
Sand	-0.06 ^{ns}	0.06 ^{ns}	-0.18 ^{ns}	0.14 ^{ns}	-0.37 ^{ns}	-0.36 ^{ns}	-0.34 ^{ns}	0.26 ^{ns}
CCE	-0.66**	0.06 ^{ns}	-0.44 ^{ns}	0.35 ^{ns}	-0.63**	-0.24 ^{ns}	0.67**	0.58*
pH	-0.90**	0.00 ^{ns}	-0.58*	0.31 ^{ns}	-0.66**	-0.11 ^{ns}	0.56*	0.84**
CEC	-0.12 ^{ns}	0.12 ^{ns}	-0.10 ^{ns}	0.18 ^{ns}	0.27 ^{ns}	0.02 ^{ns}	0.48 ^{ns}	0.11 ^{ns}
Fe _o	0.53*	-0.11 ^{ns}	0.15 ^{ns}	0.26 ^{ns}	0.77**	0.30 ^{ns}	-0.23 ^{ns}	-0.50*

^{ns}, not significant; * and ** significant at $p < 0.05$ and $p < 0.01$; respectively.

4. Conclusion

The results reported herein showed that the abundance of inorganic P fractions in 16 slightly acidic to slightly alkaline soils of the north of Iran was in the order NaOH-P (33 mg kg⁻¹) < NaOAc-P (39 mg kg⁻¹) < C2-P (49 mg kg⁻¹) < CBD-P (102 mg kg⁻¹) < CB-P (136 mg kg⁻¹) < CAs-P (156 mg kg⁻¹) < C1-P (197 mg kg⁻¹) < HCl-P (417 mg kg⁻¹). The studied soils showed a high inorganic P content, appeared almost in all of the P fractions, which is probably an effect of the intensive inorganic P fertilizer application. Meanwhile the accumulation of pedogenic Ca-P (CB-P and C-P) shows the risk of adverse effect of P on environmental quality. The average content of reductant soluble P (Sum of CAs- and CBD-P) was 257 mg kg⁻¹ of which 70% was belong to mild reductant P that might be easily solubilized under reducing conditions.

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