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Fractionation of Inorganic Phosphorus in Nitisols of Welmera District, Ethiopia

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Abstract

The phosphorus fractionation process has been commonly used to investigate soil forms of inorganic P (Pi) and transformation of applied P chemical fertilizers, which is important for agronomic management of phosphorus and water quality related issues. In an attempt to understand phosphorus forms in soils, an experiment was carried out in 2018 to measure the amount of Pi contained in acidic Nitisols in various forms. Surface agricultural field soils (0 - 0.20 m depth) were sampled with at least 5 auger samples composited to one and bulked to form one composite per location from four representative acidic soils. The soils are sandy clay loam with a low to medium organic carbon content and a very strongly to extremely acidic soil reaction. According to the soil Pi fractionation results, the Al-p, Fe-P content exceeds the easily soluble P with high exchangeable acidity, whereas the Ca-P level is zero. The low avaible P supply creates the limitation of crop production. To bring these soil in good condition, integrated application of aglime with organic materials is required to release P from various pools, that results the beneficial changes for most of the soil chemical properties.

Key words: Phosphorus, soil pH, exchangeable acidity, fractionation, reductant P

Introduction

Phosphorus (P) is an essential component of various chemical substances involved in biological processes such as photosynthesis and respiration. It is a key component of adenosine diphosphate (ADP) and adenosine triphosphate (ATP), both of which provide energy for several metabolic activities in plants and animals. Phosphorus levels in soil can be used to determine whether phosphate fertilizer is required for plant growth, although plants cannot access all inorganic P in the soil (Patzold *et al*, 2013). Depending on the soil and plant species tested, different analyses are performed to evaluate extractable phosphorus. In the soil, phosphorus exists in several forms, only some of which are accessible to plants. To simulate, various phosphorous extraction methods applied P chemistry in soils is complex; inorganic P can react with Ca, Fe, and Al to form different phosphates, whereas organic P may exist in a wide range of forms with varied resistance to microbial degradation (Khan and Joergensen, 2009). Chang and Jackson's (1957) fractionation approach has been widely employed to explore the types of inorganic P (Pi) and changes of applied P fertilizers. Subsequent research revealed that the various extractants were not as specific as originally thought. When the Chang and Jackson method is employed with calcareous soils and sediments, for example, retention of P by CaF_2 created from $CaCO_3$ during ammonium fluoride (NH_4F) extraction impacts findings. Smillie and Syers (1972), Peterson and Corey (1966), and Fife (1962) all have made amendments to it since it first appeared. The original fractionation procedures and the most important modifications were summarized by Kuo (1996). The qualitative and quantitative information provided by the fractionation data is useful for agronomic and water quality issues. Thus, the experiment was undertaken to estimate the amount of inorganic P present in acidic Nitisols of the study area, Wolmera district, central highlands of Ethiopia.

Materials and Methods

The experiment was undertaken at Haramaya University soil laboratory in 2018. Four surface soils were sampled (0 - 0.20 m depth) with a wide range of physical and chemical properties .The soil samples were collected from Oromia Region Finfinee special zone of Welmera District from four villages (Dufa, Telecho, Robgebeya and Watabacha Minjaro), where the soils were Nitisols. Dufa is situated at 9.197° N, 38.462° E with altitude of 2737 meter above sea level (masl), Telecho is situated at 9.160° N , 38.456° E with an altitude of 2731 masl., Robgebeya at 9.136° N latitude and 38.443° E longitude, altitude of 2628 masl. and Watabacha Minjaro at 9.101° N latitude and 38.602° E longitude, altitude of 2702 masl and All samples were collected from the farmlands of the indicated locations.

Subsamples from at least five randomly collected sampling locations were combined to form one composite per location. Before being transported to Haramaya University's soil chemistry laboratory, the samples were air dried and pass through a 2-mm sieve. For analysis, two duplicate samples from each site were used, and the mean results were taken. The hydrometer method was used to investigate the particle size distribution of soil (Bouyoucos, 1962). The percentage of organic carbon was estimated using the Walkley and Black (1934) method, while soil pH was assessed using the Schofield and Taylor (1955) and Peech (1965) methods. Logan *et al.* (1985) identified exchangeable acidity and exchangeable aluminum. Following the John (2000) sequence technique, the fractionation procedures were based on the differential solubility of the various inorganic P forms in distinct extracts (Table 1). Upon removing solubility and insoluble P with ammonium chloride (NH_4Cl), Al-P was separated from Fe-P with (NH_4F), and Fe-P was removed with NaOH. Sodium citrate-sodium dithionite-sodium bicarbonate (CDB) extraction was implemented to remove the reductant-soluble P. When Ca-P was insoluble in CDB, it was extracted with sulfuric acid

(H_2SO_4). The extractants were evaluated at 710 nm using the ascorbic acid technique (Murphy and Riley, 1962). Interference with citrate and dithionite was avoided by enrichment with ammonium molybdate and ammonium persulfate, respectively (Ruiz *et al.*, 1997). The amount of P in each fraction was calculated using the following equation:

$$P\ conc.in\ given\ fraction\left(\frac{mg}{kg}\right) = \left(P\ Conc.\left(\frac{mg}{L}\right) * V\ of\ extractant\ (L)\right) \div mass\ of\ soil\ (kg)$$

Where: Conc=concentration, V- volume.

Table 1. Procedure for the fractionation of soil inorganic phosphate

No	Treatment	Extract
1	1M NH_4C1 for 30 min.	easily-soluble P
2	0.5M NH_4F, pH 8.2, for 1 hr, with correction for resorption of phosphate from solution during extraction.	Al-P
3	0.1N NaOH for 17 hr.	Fe-P
4	0.3 M $Na_3C_6H_5O_7$ and 5 mL of 1 M $NaHCO_3$ in a water bath at 85 °C followed by 1.0 g of $Na_2S_2O_4$ heated for 15 min.	reductant-soluble P
5	0.25N H_2SO_4 for 1 hr.	Ca-P

Result and Discussion

Physico-Chemical Properties of Soils

The results showed that the soil textural class was sandy clay loam at all four sites, with a higher percentage of sand separates observed as compared to clay and silt sized particles (Table 2). It also indicates that it has suitable internal drainage and may drain or leach cations and mobile nutrients somewhat rapidly.

A measure of soil acidity is one of the most valuable pieces of information we can obtain from soil testing. Soil pH is an indicator of the chemical properties of the soil and is a fundamental factor in determining nutrient availability, microbial activities, and plant growth. The pH H_2O in the research sites ranges from 4.53 to 5.11, indicating that the soil is very strongly to strongly acidic (Hazelton and Murphy, 2007). The pH of the soil in 0.1M KCl ranged from 3.93 to 4.43 (Table 2). Except for the Telecho soil, the exchangeable acidity of all soil was high. Soil organic carbon levels (OC) were less than 1.62% for all farms, which is the upper limit of the low range for agricultural soils (Berhanu, 1980). Soil organic carbon level implies poor to moderate structural condition and low to moderate structural stability (Hazelton and Murphy, 2007). Soil organic matter (OM) is an indicator of soil carbon as well as serves to assess overall soil health. It reveals that soil quality is improving or declining over many years of monitoring. Soil OM influences a wide range of soil chemical, physical, and biological properties. CEC, soil total N content, and other soil qualities such as water-holding capacity and microbiological activity increase as soil OM increases (Berhane and Sahlemedhin. 2003; Horneck *et al*., 2011).

Table 1 . Physical and Chemical Analysis Result for Soils of Welmera District

Village	pH H2O (1:2.5)	pH KCl (1:2.5)	Particle size distribution (%)			OC (%)	Ac
			Sand	Clay	silt		
Dufa	4.62	3.97	50	25	25	1.13	2.24
Telecho	5.11	4.43	49	35	16	0.97	0
Robgebeya	4.62	4.02	49	28	23	1.44	1.6
Watabacha Minjaro	4.53	3.93	52	22	26	1.62	3.12

OC- organic carbon, Ac- Exchangeable acidity.

The low organic carbon content of the soils might be attributed to a removal of crop residue from agriculture for various purposes, such as income generation and feeding livestock or the decomposition of existing leftovers. Furthermore, farmers apply little or no dung from animals to farms since they use it for energy and sell it for revenues.

Distribution of Soil Phosphorus Fractions

The soil is acidic with low to moderate organic carbon, the soil is almost null in Ca-P (Table 3) this may be due to strong acidity of the soil. The soil contains higher amounts of Al-P, Fe-P, reductant P and soluble P in decreasing order. The soil soluble P which is important to crop production is lower than Al-P, this might because of the activity of Al and Fe in the soil due to its acidity. The soil of Watabacha Minjaro has high amounts of Al-P, and soluble P than the other site soils, Telecho and Robgebeya site soil have the higher Fe-P and reductant than other soils (Table 3). As stated by (Ruiz *et al*.,1997) extractable P is part of soil-P which is released with the effect of a strong reductant and reductant soluble P provides an index of P that can be potentially released when soil material are subjected to reducing condition in natural environments and, generally is attributed to various forms of P occluded in crystalline Fe oxides. Although they are abundant in the soil and not readily accessible to plants, high levels of Al and Fe-P are not indicators of P availability due to the solubility of Al and Fe resulting from the significant acidification of the soil and elemental precipitations. Due to the high levels of Fe-oxides, low pH, and advanced stage of weathering, the active inorganic Pi fractions have higher amounts of Al-P and Fe-P than the other fractions (Table 3). In a field investigation with a comparable soil type, a similar outcome was also discovered (Shiferaw; 2004, Wakene and Heluf, 2003).

Table 2 . Pi Fractionation Result (mg Kg^{-1}) of Soils of Welmera District

Village	Soluble P (ppm)	Al- P (ppm)	Fe-P (ppm)	Ca-P (ppm)	Reductant P (ppm)
Dufa	93.8	395.0	150.0	0.0	124.0
Telecho	75.0	390.0	62.5	0.0	6.4
Robgebeya	77.5	587.5	212.5	0.0	0.0
Watabacha Minjaro	96.3	550.0	32.5	0.0	24.0

The behavior of phosphorus is quite simple; the inorganic form can exist in a variety of forms: as mineral (generally apatite) phosphorus; non-apatite inorganic-P. The inorganic phosphorus species are associated with the particulate phase. In studies of phosphorus movement from agricultural lands the largest amount is sorbed on to clay materials and transported as erosion products (Kolawole and Tian, 1972; Negassa and Leinweber .2009). This non-apatite inorganic-P fraction is considered to be available to plant roots and is rapidly solubilized under conditions of anoxia in the bottom of lakes and reservoirs (Alakeh *et al*., 2022)
The mean value of the studied soil contains higher amounts of Al-P, Fe-P, reductant P and soluble P in decreasing order (Figure 1). The Al-P and Fe-P are the dominant Pi in these soils, with relatively lower amount of soluble P, which is a peculiar characteristics of acidic soils. The same report was documented by Alemayehu *et al*., (2017).

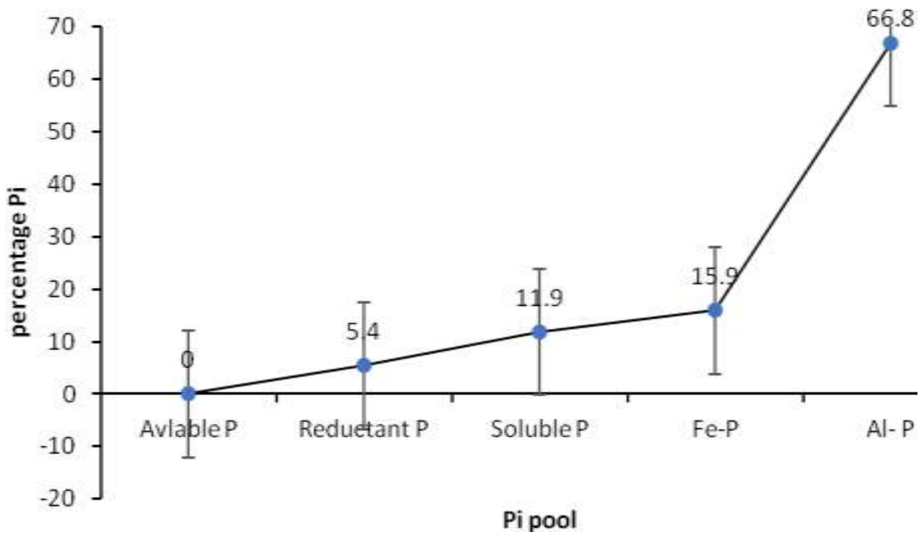

Figure 1. the proportional contents of inorganic phosphorus in the acid soils of Welmera.

In comparison to soils that have less or no exchangeable acidity, the concentration of Al and Fe coupled soil Pi is larger in acidic soils with higher exchangeable acidity content (Tables 2 and 3). Integrated application of aglime ($CaCO_3$) with organic fertilizer is helpful to lower soil pH, generate favorable soil chemical conditions, and improve the availability of Pi in the soils, as described by Geremew *et al*., 2020 a and b; Aye *et al*., 2016).

Conclusions

The soils at each of the four locations were sandy clay loam with low to medium OC level, a very strongly to extremely acidic soil reaction category, and a high exchangeable acidity for the majority of the soils. In accordance with the soil Pi fractionation findings, the Al-p, Fe-P content exceeds the easily soluble form of P with high exchangeable acidity, whereas the Ca-P level was zero. To enhance a soil's condition, the fixed phosphorus must be released, which could be performed by integrated application of agricultural lime and organic materials.

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