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Changes in Olsen P in Relation to P Balance in Contrasting Agricultural Soils

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ABSTRACT

Maintaining soil phosphorus (P) at adequate levels for plant growth requires assessing how the long-term P balance (*viz.*, the difference between P inputs and outputs) results in changes in soil test P. The hypothesis that routinely measured soil properties can help predict the conversion factor of P balance into Olsen P was tested at 39 sites in agricultural areas of the Mediterranean region in Spain. A set of soil samples from each site was analyzed for Olsen P, inorganic P (P extracted using 0.5 mol L^{-1} H_2SO_4), pseudototal P (P extracted using 0.5 mol L^{-1} H_2SO_4 following ignition at 550 °C), and organic P (the difference between pseudototal P and inorganic P). Organic and Olsen P were uncorrelated in most of the 39 soil sets, which suggests that organic P content changed little with P inputs and outputs. The slopes of the regression lines of Olsen P against pseudototal and inorganic P, which were used as two different measures of the conversion factor, ranged widely (from 0.03 to 0.25 approximately), with their average values (about 0.10) being similar to those found in long-term experiments conducted in temperate areas. Neither conversion factor was significantly correlated with any routinely measured soil property; however, the conversion factor for inorganic P was significantly lower for calcareous soils than for noncalcareous soils. Our negative results suggest the need to isolate the influence of soil properties from that of management systems and environmental factors relating to P dynamics in future studies.

Key Words: calcareous soils, conversion factor, inorganic P, noncalcareous soils, organic P, pseudototal P, soil property, soil test P

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INTRODUCTION

Ideally, the amount of bioavailable phosphorus (P) in soil should be large enough to ensure good crop performance without posing significant risks of environmental pollution. In practice, when the level of plant-available P as evaluated *via* a soil P test reaches the so-called "critical level" (*i.e.*, the level above which the crop does not respond to application of fertilizer P), one plausible course of action is to maintain that level. This is achieved by properly managing P inputs (mainly P in mineral and organic fertilizers, seeds, and biosolids) with provision for outputs (mainly P exported by harvests).

Long-term changes in soil test P relate to P balance, which is defined as the difference between P inputs and outputs. So, long-term field experiments have revealed basically linear relationships between soil test P and P balance (Blake *et al.*, 2000, 2003; Messiga *et al.*, 2010; Cao *et al.*, 2012; Shen *et al.*, 2014). The slope of this linear relationship can then be taken as the "conversion factor" of the P balance into soil test P with a view to facilitating decisions on the rates of fertilizer P to be used in order to reach or maintain the target soil test P values.

The conversion factor for Olsen P (Olsen *et al.*, 1954), which is a widely used test parameter for soils in temperate areas, ranges broadly. Thus, reported conversion factors calculated on the assumption that the P balance was basically restricted to a typical arable layer include values of about 0.15 for a temperate acid soil after 3 years of experimentation (Shepherd and Withers, 1999), 0.14 for a slightly acidic sandy soil in a 6-year experiment and 0.12 for a neutral, loamy Luvisol soil in a 32-year experiment (Boniface and Trocmé, 1988), 0.11 for a calcareous Vertisol over an experimental period of 18 years (Bravo *et al.*, 2006), 0.13 for a slightly alkaline Arenosol studied for up to 17 years, 0.06–0.23 for seven Chinese soils including three Inceptisols, two Mollisols, one Ultisol, and one Aridisol to which ferti-

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lizer P was applied for periods ranging from 4 to 12 years (Cao *et al.*, 2012), and an average of about 0.22 for three alkaline, clay-poor Chinese soils supplied with mineral P fertilizers for 5 years (Shen *et al.*, 2014).

Such a wide range of reported Olsen P/P balance conversion factors has likely arisen from differences in the nature and content of P-reactive soil constituents (mainly silicate clays, Fe and Al oxides, and carbonate) affecting P sorption and desorption, and hence P extractability by bicarbonate, as well as from the nature and kinetics of these processes being influenced by the moisture and temperature regimes of the soil (Staunton *et al.*, 2015). The experimental period over which calculations are made is also important in the presence of slow reactions leading to a decline in P test values (Barrow, 1980). Finally, conversion factors are usually calculated on the assumption that P inputs and outputs affect the arable layer when deeper soil layers can in fact supply P to plants or incorporate P-rich particles or dissolved P *via* different pathways (Bravo *et al.*, 2006). As suggested by some researchers (Cao *et al.*, 2012), these sources of variability hinder assessing to what extent conversion factors are correlated with soil properties. In this study, we tested the hypothesis whether routinely measured soil properties can actually help predict conversion factors. To this end, we examined a large group of soils from the Mediterranean region of Spain.

MATERIALS AND METHODS

Soils used and soil analysis

A total of 49 sets of soil samples from different agricultural areas of the Spanish Mediterranean region were studied. The location, climatic data, and parent material of the sites and the classification, use, and characteristics of the corresponding soils are described elsewhere (Sánchez-Alcalá *et al.*, 2014). The soil sets consisted of 8–33 samples of 0.3–0.5 kg taken from the arable layer of 2–5 adjacent or nearby plots differing in land use, crop type, appearance, soil management system, history of P application, and hence in Olsen P, but not in major soil properties.

The composite soil sample obtained from each soil set was found to range widely in carbonate-free clay content, organic carbon, pH, cation exchange capacity, citrate-bicarbonate-dithionite-extractable Fe (Fe_d), and ammonium oxalate-extractable Fe (Fe_{ox}). Calcium carbonate equivalent and active calcium carbonate equivalent (ACCE) or active lime ranged widely in calcareous soils, acid oxalate-extractable Al (Al_{ox}) in noncalcareous soils, and Olsen P in both types of soils. A detailed description of the corresponding methods of soil analysis can be found in Sánchez-Alcalá *et al.* (2014). The significance of the Olsen P-P balance linear relationship was used to discard 10 of the initial 49 soil sets. Twenty of the soils were noncalcareous, including two containing small amounts of sand-sized fragments of calcite nodules, and 19 calcareous. Table I shows the minimum, maximum, median, mean, and standard deviation of the relevant properties of the composite soil samples of the 39 soil sets, and Table II the corresponding individual data of each soil set.

The individual samples in each set were analyzed for Olsen P (Olsen *et al.*, 1954) and for inorganic, pseudototal, and organic P. Inorganic P was operationally

TABLE I

Selected properties of the composite soil samples of the 39 soil sets from different agricultural areas of the Spanish Mediterranean region

Property[a)]	Minimum	Maximum	Mean	Standard deviation	Median
Carbonate-free clay (g kg^{-1})	31	640	247	149	242
Organic carbon (g kg^{-1})	4	20	10.0	4.0	10
CCE (g kg^{-1})[b)]	61	613	264	151	234
ACCE (g kg^{-1})[b)]	18	178	97	53	86
pH (water)	5.1	8.4	7.5	0.9	7.9
CEC ($cmol_c$ kg^{-1})	3	52	19.8	12.6	16
$EC_{1:1}$ (µS cm^{-1})	65	749	308	147	273
Fe_d (g kg^{-1})	1.8	27.1	10.4	6.9	8.2
Fe_{ox} (g kg^{-1})	0.16	3.36	0.87	0.59	0.83
Al_{ox} (g kg^{-1})[c)]	0.24	1.56	0.70	0.38	0.57
Olsen P (mg kg^{-1})	7.9	19.5	13.6	2.8	13.6

[a)] CCE = calcium carbonate equivalent; ACCE = active calcium carbonate equivalent; CEC = cation exchange capacity; $EC_{1:1}$ = electrical conductivity of the 1:1 soil:water extract; Fe_d = citrate-bicarbonate-dithionite extractable Fe; Fe_{ox} = ammonium oxalate-extractable Fe; Al_{ox} = ammonium oxalate-extractable Al.

[b)] For soils containing > 35 g kg^{-1} CCE ($n = 19$).

[c)] For soils containing < 35 g kg^{-1} CCE ($n = 20$).