



Research article

Phosphorus availability from rock phosphate: Combined effect of green waste composting and sulfur addition

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ARTICLE INFO

Article history:

Received 24 January 2016

Received in revised form

2 August 2016

Accepted 7 August 2016

Available online 17 August 2016

Keywords:

Compost

Phosphorus solubility

Organic phosphorus

Elemental sulfur

Organic agriculture

ABSTRACT

Rock phosphate constitutes a natural phosphorus (P) source for organic farming systems, but with a limiting direct agricultural use due to its poor inherent reactivity. Thus, this work studies the effect of the co-composting of rock phosphate with green wastes and elemental sulfur on phosphorus availability. Six composts were prepared combining different green wastes and rock phosphate in three different proportions (0%, 0.27% and 0.54% P fresh mass basis) and elemental sulfur in two proportions (0% and 0.5% S fresh mass basis). During composting, the temperature of the mixtures was monitored, as were physico-chemical and chemical parameters, especially those related to phosphorus. The co-composting of green wastes with rock phosphate improved phosphorus mobilization and also constituted a viable method to manage green wastes, obtaining P-enriched compost for organic farming systems. Sulfur addition favored the composting process and also phosphorus solubilization, especially in the mixture with the lowest proportion of rock phosphate.

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1. Introduction

In recent years, organic farming systems have been steadily growing, with an annual rate of approximately 20% in the last decade, even becoming a mainstream practice for some crops (Ceglie and Abdelrahman, 2014; Kaur and Reddy, 2014). Organic farming enhances soil quality and fertility, avoids soil erosion and minimizes environmental pollution. In addition, these agricultural systems provide healthier food and contribute to the economy, specifically the rural economy (Ceglie and Abdelrahman, 2014). In organic agricultural systems, crop production mainly depends on nutrient release as a result of mineralization processes in soils. Therefore, to sustain and increase soil fertility overtime, as well as to prevent reductions in crop yield compared to conventional practice, it is necessary both to reintegrate organic matter in the soil and to maintain a pool of available nutrients. Phosphorus (P) is an essential element for plant growth and development, which is often a limiting nutrient in its plant-available form in the soil of organically managed systems (Kaur and Reddy, 2014). Thus, the maintenance of an adequate soil phosphorus status constitutes an

agricultural priority, particularly in organic farming systems (Evans et al., 2006), especially in those with low animal densities and thus, limited access to livestock residues, e.g., farmyard manure (Rick et al., 2011; Walker et al., 2012). In this sense, organic farming regulations prohibit the use of chemical fertilizers to provide available P for crops, only including natural sources of P fertilizer, such as composts and ground rock phosphate. However, rock phosphate, apart from the specific properties that vary depending on the source, often shows several agronomic limitations. These limitations are basically based on its low inherent reactivity that limits the release of adequate quantities of P into the soil solution in short-term. This conditions its direct application for annual crops with high P requirement. In this sense, the solubility of rock phosphate and thus, its P plant availability, depends on several factors: its characteristics (particle size, mineral composition) and especially on site-specific factors, such as soil properties (pH, moisture and cation exchange capacity), the leaching impact by removal of dissolution products (e.g. Ca), and the specific crop ability to improve plant P utilization efficiency (Rick et al., 2011; Walker et al., 2012; Knox et al., 2014).

Several studies have been carried out to increase the availability of phosphorus from rock phosphates, especially in organic farming systems. Several of these works were based on the application of

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sulfur fertilizers (Evans et al., 2006; Stanisławska-Głubiak et al., 2014), the incorporation of microorganisms (Chung et al., 2005; Chi et al., 2007), the combined use of both strategies (Ghani et al., 1994; Kaur and Reddy, 2014; Aria et al., 2010) and the use of green manures (Rick et al., 2011). The co-composting of rock phosphate with organic wastes also can constitute a feasible alternative to increase rock phosphate solubility. Indeed, the by-products of microbial metabolism, during organic matter degradation, can improve the release of plant available phosphate compounds (Korzeniowska et al., 2013). The enhanced solubility of phosphorus achieved by co-composting is a result of the effect on rock phosphate produced by organic acids, humic substances and other chelating substances secreted by microorganisms while decomposing organic matter (Singh and Amberger, 1998; Vassilev and Vassileva, 2003). In addition, this process continues in the soils where these composts are applied (Biswas and Narayanasamy, 2006; Korzeniowska et al., 2013). Moreover, some studies have reported the inoculation of microorganisms to improve the co-composting process (Zayed and Motaal, 2005a; Biswas and Narayanasamy, 2006; Nishanth and Biswas, 2008).

Different organic materials have been used for the co-composting of rock phosphate, such as manure (Odongo et al., 2007; Jiang et al., 2014), beet pulp (Stockdale et al., 2006), silage effluent (Zapata and Zaharah, 2002), rice straw (Zayed and Motaal, 2005a; Biswas and Narayanasamy, 2006; Nishanth and Biswas, 2008), wheat straw (Singh and Amberger, 1998) and other plant residues (Zayed and Motaal, 2005b; Walker et al., 2012; Korzeniowska et al., 2013). However, not enough information is currently available concerning the co-composting of rock phosphate with organic wastes and sulfur and the effect of both aspects, combined or not, on P availability.

On the other hand, green wastes, especially yard trimmings, constitute an important part of the municipal waste stream (López et al., 2010). This type of wastes is subjected to periodic production, which varies according to the season, also in terms of qualitative heterogeneity (Khalil et al., 2008). The management of these wastes is often difficult and expensive due to their low bulk density. Their principal cost arises from collection and transportation (Khalil et al., 2008; López et al., 2010), in some cases being burned or discarded in abandoned areas and in landfill. In this sense, composting is a viable option to manage and recycle these wastes (López et al., 2010). In addition, a positive aspect is that these wastes often show low contents in micro-pollutants. This aspect favors the obtaining of composts with adequate properties that fulfil the quality standards and utilization restrictions for compost use in organic farming systems.

Then, it was hypothesized that the co-composting process of rock phosphate with green wastes may enhance the availability of P form, further enhanced with the addition of elemental sulfur, which increases the water-soluble pool of P present in rock phosphate. Therefore, the main aim of this work was to study the viability of composting rock phosphate with green wastes as a treatment to increase P availability and studying the effect of sulfur addition on the process.

2. Materials and methods

2.1. Composting materials

The green wastes used in the composting mixtures were constituted by palm (*Phoenix* sp.) and *Washingtonia* sp.) prunings (PP), grass (*Lolium perenne* L.) clippings (GC) and a mixture (1:1) of olive tree (*Olea europaea* L.) and conifer (*Pinus* sp. and *Picea* sp.) prunings (MP). All these wastes were collected from the experimental farm of the Mediterranean Agronomic Institute of Bari

(IAMB-CIHEAM), placed in Valenzano, (Bari, Italy; 41°03'16"N, 16°52'45"E, elevation 72 m a.s.l.). These wastes showed high contents of organic C (PP = 42.7%; GC = 44.5% and MP = 50.2%) and low N contents, except for GC (PP = 1.95%, GC = 2.95% and MP = 0.76%). In addition, two additives were used in this experiment: rock phosphate (27% P₂O₅) finely ground in three different proportions (fresh mass basis): i) 0% rock phosphate, ii) 2.3% rock phosphate (equivalent to 0.27% P) and iii) 4.6% rock phosphate (equivalent to 0.54% P); and elemental sulfur powder in two different proportions (0% and 0.5% S fresh mass basis).

2.2. Experimental procedure

The experiment was arranged in a completely randomized factorial design with two factors (rock phosphate enrichment and sulfur addition) in triplicate. For this, six composts were elaborated at the compost facility of the Mediterranean Agronomic Institute of Bari (IAMB-CIHEAM) using the green wastes and the additives previously commented in the following proportions, on a fresh mass basis:

- CP0S0: 32% PP + 35% GC + 33% MP
- CP1S0: 32% PP + 35% GC + 33% MP + 2.3% rock phosphate
- CP2S0: 32% PP + 35% GC + 33% MP + 4.6% rock phosphate
- CP0S1: 32% PP + 35% GC + 33% MP + 0.5% sulfur
- CP1S1: 32% PP + 35% GC + 33% MP + 2.3% rock phosphate + 0.5% sulfur
- CP2S1: 32% PP + 35% GC + 33% MP + 4.6% rock phosphate + 0.5% sulfur

The mixtures (about 1200 kg each) were managed as trapezoidal windrows (about 2 m × 3 m base and 1.5 m high) and were mechanically turned every day for the first week of composting and twice a week during the rest of the thermophilic phase. The piles were turned to oxygenate the composting mixture and, during the active phase, to avoid excessive increase in temperature. The bio-oxidative phase of composting, which lasted 80 days in all the piles, was considered finished when the temperature was close to the ambient and re-heating did not occur. Then, composts were left to mature in static conditions over a period of one month, approximately. Throughout the composting process, temperature was monitored daily in five different positions in the heap core, at 40 cm depth. The humidity of each pile was kept at optimal level for microbial metabolism (55–65%), adding water at turning time.

Three fresh composting samples of approximately 1 kg were collected from each pile at the main phases of the composting process: initial phase (0 days), thermophilic phase (40 days), end of bio-oxidative phase (80 days) and maturity phase (120 days). The samples were taken by mixing until homogenization six sub-samples from six sites of the pile, from the whole profile (from the top to bottom of the pile). Each sample was oven dried at 50 °C, ground, sieved at 1 mm and stored for subsequent analyses. All the analyses were performed in triplicate.

2.3. Analytical methods

In the composting samples, electrical conductivity (EC) and pH were analyzed for a sample:water ratio of 1:10 (w/v). Total organic matter (OM) was assessed by determining the loss-on-ignition at 550 °C for 24 h, total organic C (C_{org}) was determined according to ISPR (2001) and total N (N_T) was analyzed by the Kjeldahl method. Water-soluble phosphorus (WSP) was measured in a 1:10 w/v water extract on a fresh weight basis. Organic and inorganic forms of phosphorus were determined according to the dry-combustion method described by Yokota et al. (2003). Briefly, micronized

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