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Research paper

Biochar-ammonium phosphate as an uncoated-slow release fertilizer in sandy soil

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ABSTRACT

The objective of this study was to manufacture of a granular biochar-ammonium phosphate (BAP) as an uncoated-slow release fertilizer by using the reaction among biochar (derived from rice husk), phosphoric acid and ammonia gas for fertilization of sandy soil. In this study we assessed the influence of two types of BAP {1.5 mol $NH_3 + (0.76$ mol$H_3PO_4 + 150$ g biochar) BAP1and 1.5 mol $NH_3 + (0.76$ mol $H_3PO_4 + 220$ g biochar) BAP2} on nitrogen (N) use efficiency (NUE) and N losses in leachate water and compared them to a conventional mineral N fertilizer (ammonium phosphate, AP). Additionally the surface morphology of biochar, BAP1 and BAP2 was examined by scanning electron microscopy (SEM) and Fourier transfer infra-red (FT-IR). SEM and FT-IR confirmed the formation of ammonium phosphate inside the biochar's pores. Release of the available nitrogen (NH^{+4} -H and NO^{-3}- H) from both BAP1 and BAP2 fertilizers was detected to be slow and low compared with AP fertilizer. pots treated with either BAP1 or BAP2 demonstrated fundamentally higher ($p < 0.05$) N content and vegetative improvement compared with AP, however no critical difference ($p > 0.05$) were found among BAP1 and BAP2 fertilizers. Correspondingly, the synthesis of this new fertilizer using this technology provided a unique organic matter in the manufacture of uncoated-slow release fertilizer. Subsequently, BAP could be used as an uncoated-slow release fertilizer to maximize the functions of the nitrogen fertilizer when added to a sandy soil and minimize its environmental impact.

1. Introduction

Loss of fertilizers from agricultural soils is considered as a critical issue in crop fertility as well as a source of environmental problems. In the medium term, worldwide fertilizer consumption would indicate yearly growth of 1.8% to reach 199.4 Mt nutrients in 2019 [1]. Rises are anticipated for all three major nutrients (NPK), with usual yearly incremental rates of 1.5% for nitrogen, 2.0% for phosphorus and 2.9% for potassium [1]. However, only 33% of the total N applied for cereal production is actually removed by the crop [2] and the same fraction is found in vegetable crops [3]. This indicates a potential loss of 67% of the fertilizer applied. Pathways for N losses include ammonia as a surface volatilization, N from soils as nitrous oxide through nitrification and denitrification processes and N losses from leaching and drainage. The overall efficacy of N utilization for food production is considered to be low. At the same time, prices of nitrogen fertilizer continue to increase putting greater economic burdens of producers [5]. Slow releases fertilizer can be manufactured from the granules of the dissolvable fertilizers by covering them with coatings that do not allow for rapid release and thus minimize their dissolution rate. The slow release of a fertilizer throughout the whole growth season allows for an one time application, which reduces both time and fuel consumption [5]. The use of covering materials increases production costs and may act as a sources of soil contamination after their discharge into the soil. Their higher costs explain the main reason for their restricted application even though the slow release fertilizer can be applied for a lower rate [6]. Recent researches introduced a trend towards production of biochar-based fertilizers using a process of direct mixing, encapsulation and pelletizing [7–9]. Biochar is considered as a super carrier material to form nitrogen enriched with biochar of high-quality fertilizer enriched organic matter [10]. Among the agriculture products, biochar is a carbon-rich material attained from the pyrolysis of biomass in the absence of oxygen. Biochar application to a soil also to provide benefits of both soil fertility and plant productivity [11–13]. Many studies

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however suggest that some modification for this material should be done before being incorporated into the soil and these modifications may contain one or more advantages such as nutrients incorporated either by a mixing process, encapsulation and/or pelletizing or among others [14]. In this regard, we have developed a method which comprises the use of biochar (derived from fast pyrolysis process) enriched with nitrogen by the formation of an effective biodegradable uncoated slow-release fertilizer. Other studies have used peanut shell pyrolyzed under moderate conditions at 400 °C for forming a slow-release nitrogen fertilizer [8]. In addition to, biochar can improve several soil characteristics such as cation exchange capacity (CEC) and compensate soil organic carbon content [15,16]. Ammoxidation of biochar, which encompasses of the immediate response of dynamic carbons with the blend of air and ammonia can be used also to enrich the nitrogen content of biochar. Most of the researches study have worked on using biochar as supporting material for manufacturing of a controlled-release fertilizer used impregnation process (soaking the biochar powder with a commercial fertilizer solution). Unfortunately, this method results in a loss of around 50% of initial nitrogen content of its retention of biochar [17]. The formation of biochar-based releases nitrogen fertilizer using a chemical reaction between a nitrogen and lignocellulosic matrices was examined by several research groups [14,18,19,20]. Biochar-ammonium phosphate as uncoated slow release fertilizer is considered as an efficient method to increase the nutrients concentration in biochar. The objective of this study was to manufacture biochar related to high concentration of N and P in the form of biochar-ammonium phosphate fertilizer as an uncoated slow release fertilizer and to study its application on the growth, nutritional status and yield of Japanese mustard spinach grown in a sandy soil.

2. Materials and methods

2.1. Biochar production

Biochar was prepared by using rice husk as a raw material. Rice husk (Sakha 101 c. v, *Oryza sativa L.*) was collected in summer season, 2013 from rice hulling machine near to Kafr El sheikh city at the north part of Egypt. A pilot-scale electric pyrolyzer designed at the Agriculture Research Center, Egypt, with a maximum capacity to process 10 kg of raw material per batch was used to produce biochar. The pyrolyzer was filled to a full load and the air was replaced with nitrogen gas before starting the pyrolysis. Carbonization temperature was 420 °C. This temperature was selected because higher temperature may impact and decrease the functional groups of the structure of the biochar [20–22]. The temperature was elevated to a rate of 3.5 °C min^{-1} until the desired temperature (420 °C) was achieved and was held for 1 h. Biochar was then cooled to room temperature in stainless steel sealed container to prevent the biochar from exposure to oxygen.

2.2. Preparation of biochar-ammonium phosphate (BAP)

Biochar-ammonium phosphate (BAP) was prepared according to the reaction listed in Fig. 1; based on modifying only the amount of Biochar used. Biochar obtained was milled, and sieved to pass through a 0.5 mm using a 100-mesh sieve. The biochar was then washed twice with water in an ultrasonic bath and then the biochar was filtered using a Büchner funnel. Dry biochar (2–4% moisture mass fraction) powder was combined carefully with H_3PO_4 (85% of P2O5 obtained from Merck phosphoric acid, Sigma) in two mixtures [2 g/cm^3 of biochar (BAP1) and 3 g/cm^3 of biochar (BAP2)], then the mixture was reacted with ammonia gas in a closed container. Ammonia gas was carefully and slowly added through a tube to the mixture of the closed container with slow rotation during the reaction process to make round particles of the BAP and to avoid agglomeration. The granulation of BAP1 and BAP2 were carried out in a small stainless steel drum (inner diameter-17 cm, length-20 cm with a rotation of 33.3 Hz). Granules were air dried for at least 72 h at room temperature. The final granules with an ideal size of 3–5 mm were used for further trials. the manufacturing process was observed in Fig. 3. The chemical reaction for BAP1 & BAP2 as described in the follows reaction: (see Fig. 2).

Reac.1:1.5mol NH_3 + (0.76 mol H_3PO_4 + 150g Biochar)→248g Biochar $(NH_4)_2HPO_4$→**BAP1**

Reac.2: 1.5mol NH_3 + (0.76mol H_3PO_4 + 220g Biochar)→320g Biochar $(NH_4)_2HPO_4$→**BAP2**

In this operation, phosphoric acid is optionally reacted with part of the ammonia in a pre-neutralizer at mole ratio of 0.6 of ammonia to phosphoric acid to produce BAP. In this reaction enough ammonia gas was added to complete the reaction. Biochar-ammonium phosphate was formed when the ammonia gas was neutralized in the mixture (biochar + H_3PO_4). The final product had a crystallized shape of tetragonal prisms (Fig. 3).

2.3. Experimental details

Two glasshouse experiments were conducted at Tokyo University of Agriculture and Technology, Japan (first experiment in 2014) and at the Central Laboratory for Agricultural Climate, Egypt (second experiment in 2015). Japanese mustard spinach (Komatsuna Brassica rapa var) was used as the test crop. Pots of 2.2 L capacities were used in both experiments. The pots were arranged in the glasshouse as a randomized complete block design with four replications. The growing conditions in the glasshouse were adjusted 16 h of supplement light and a minimum temperature of 20 °C, but sunshine often raised the daytime temperature to 25 °C. The soil was used in this experiment was characterized as 100% sandy soil (Sieved with a 50 mesh sieve). In the first experiment, the soil was collected from Yamaguchi prefecture with precipitation average 236 mm annually. In the second experiment, the soil was collected at 20 cm depth of Markaz El-Hamam, Matrouh Governorate (29°59′02.0" N 29° 55′29.7" E) with annual precipitation about 1.8 mm, and mean annual temperature 19.8 °C. Air-dried sandy soil (2.1 kg in each pot) was placed in pots up to 3 cm below the rim. The soil and biochar used in both years were characterized as shown in Table 1&2. BAP1 (17.21 g), BAP2 (14.41 g) and AP (12.5% N, Sigma) (14.40 g) were thoroughly mixed with the soil to achieve 1.8 g of nitrogen in each pot in both years. Potassium fertilizer (5 g of K_2SO_4 per pot) was also applied. All pots were watered to field capacity. Eight seeds of Mustard Spinach were placed in each pot. The seeds were then covered with 2 cm of dry sandy soil. Five days after germination, two plants were left to grow in each pot. The soil was regularly watered with controlled volumes of irrigation water near to field capacity. Each pot was placed on a 200 cm^2 plastic tray to collect the leachates. To prevent the contact between plant roots and leachate, and to facilitate drainage system, all pots were placed 3 cm above the bottom of the plastic try. Three hours after each irrigation time, leachates from each pot were collected in a 100-cm^3 glass container. Leachate volume was determined and the sample was filtered and stored under refrigerated conditions (2 °C) until nitrate and ammonium analyses were conducted. Before analysis all leachate samples were carefully mixed then the available nitrogen (NH_4^+ -H and NO_3^-- H) in the leachate was analyzed by absorbance spectra measurements using the indophenol blue method on a combined fluorescence absorbance using a UV-2800 spectrofluorometer (Model Aqualog, Horiba Scientific, Edison NJ, USA), and NO^{-3} by ion chromatography (Model AC 861, Metrohm AG, Herisau, Switzerland). At the end of the experiment (45th day after seeding), some plant growth parameters were determined. Leaf chlorophyll content, an indication of N uptake by the plants, was determined using the Soil Plant Association Development, SPAD 502 m (Minolta Corporation, Japan). Plant fresh weights were determined at harvest and dry weights were subsequently determined after oven drying at 80 °C overnight. Leaf area was determined using a Li-Cor portable area meter (LI-3000).