# Technology for the solubilization of phosphate rock and its advantages—Phosphate rock solubilization via rice straw composting

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## INTRODUCTION

The effect of phosphate rock (PR) direct application is inferior to that of water-soluble P fertilizer; however, the availability of PR to plants can be enhanced using many biological, chemical, and physical methods (FAO, 2004; Nakamura *et al*., 2013). Among the suggested technologies for PR solubilization, chemical and physical methods involve the use of fertilizers factories, whereas biological methods can be implemented by farmers. Chemical and physical methods cannot be afforded by small-scale farmers.

Biological methods promote the dissolution of minerals via the interaction between microbes and plants (Nakamura *et al*., 2013). Organic matter composting enriched with PR has been widely reported to accelerate the dissolution of PR with organic acid production during microorganism proliferation during the composting process. Recently, the inoculation of particular phosphate-solubilizing microorganisms has been investigated for preparing PR-enriched compost (Zayed and Abdel-Motaal, 2005).

In this study, the effectiveness of PR-enriched rice straw composting that can be possibly applicable for farmers was elucidated as a biological PR dissolution technology.

## MATERIALS AND METHODS

### *Research site*

The experiment was conducted at the Tropical Agriculture Research Front (TARF) of the Japan International Research Center for Agricultural Sciences (JIRCAS) at Ishigaki Island of Okinawa Prefecture.

### *Treatments*

The experiment was conducted for rice straw (RS) composting with PR yielded in Kodjari deposit in Burkina Faso. The RS were inoculated with Aspergillus niger at the initial (+ANi) and delayed timing (+ANd) of those composting process, and one treatment included no inoculation (Non-AN). A. niger which has been previously evaluated as the PR-solubilizing fungus by Hellal *et al* (2013), was selected and inoculated. The composts received 0 % (PR0), 5 % (PR5), and 10 %

(PR10) of PR against dry matter weight.

A. niger was pre-incubated on potato dextrose agar medium for 3 days. Next, the suspended culture was added to the medium consisting of 10 kg sea sand (Wako sea sand; 425–850 µm) and 1 kg wheat flour. The medium culture was incubated for 5 days in 30 °C. The inoculated medium was applied to RS at a rate of 25 g medium against 1 kg DM. Further, 150 g of ammonium sulfate was added to the compost for the acceleration of microbial activity. The treatments are listed in Table 1.

The water contents were maintained to approximately 60 % during composting. The composting trial was conducted for 56 days in the green-house of the Japan International Research Center for Agricultural Sciences (JIRCAS) at the Tropical Agricultural Research Front (TARF), at Ishigaki Island (24˚N, 129˚E). The composts were turned, and samples were collected once per week.

**Table 1** Treatments of rice straw composting experiment

| ID | Treatment | Rice Straw | *A.Niger* medium | Inoculation timing | PR | Ammonium sulfate | Initial P contents |
|---|---|---|---|---|---|---|---|
| | | g DM | | | g | | $mgP\ kg^{-1}$ |
| 1 | Non-AN PR0 | 7500 | 0 | None | 0 | 150 | 686 |
| 2 | Non-AN PR5 | 7500 | 0 | None | 375 | 150 | 7617 |
| 3 | Non-AN PR10 | 7500 | 0 | None | 750 | 150 | 13929 |
| 4 | ANi PR0 | 7500 | 187.5 | DAT 0 | 0 | 150 | 670 |
| 5 | ANi PR5 | 7500 | 187.5 | DAT 0 | 375 | 150 | 7443 |
| 6 | ANi PR10 | 7500 | 187.5 | DAT 0 | 750 | 150 | 13624 |
| 7 | ANd PR0 | 7500 | 187.5 | DAT 28 | 0 | 150 | 670 |
| 8 | ANd PR5 | 7500 | 187.5 | DAT 28 | 375 | 150 | 7443 |
| 9 | ANd PR10 | 7500 | 187.5 | DAT 28 | 750 | 150 | 13624 |

***Procedure on monitoring and chemical analysis***

The compost temperature was monitored using a thermocouple with a three-point averaging circuit placed at the center of the samples. Data were collected every 30 min. And the soil temperature were monitored as the reference. The compost samples for chemical analysis were sampled from three points of the container. Collected samples were oven-dried at 80 °C for 48 h and crushed (dried sample), or were stored at 4 °C and shredded to obtain approximately 5 to 10 mm long pieces by using hand scissors (fresh sample).

The total nitrogen and carbon were determined by using the dry combustion method by using Sumigraph NC-220 (Sumika Chemical Analysis Service, Ltd.).

Sequential P extraction was conducted as reported by Hedley *et al*. (1982) and Frossard *et al*. (1994). This sequential extraction can fractionate P into four fractions. The first step involved the extraction of the inorganic and organic forms of P with water. Next, $NaHCO_3$ (0.5 M at pH 8.5) was used to extract other labile forms of P (inorganic and organic); 0.1 M NaOH extracted the inorganic P absorbed on mineral and organic colloids and the organic P present in humic and fulvic compounds; and 1.0 M HCl solubilized the calcium phosphates. After each extraction, 2.5 M sulfuric acid was added to the extract, and inorganic P content was determined colorimetrically at 710 nm (Murphy and Riley, 1962). The precipitation was re-fused and diluted, and then P concentration in this solution was determined using inductively coupled plasma emission spectrometer (ICPE-9000; Shimadzu). In this study, precipitated P was defined as organic P form. And among the four fractions in sequential fractionation, authors defined sum of water soluble inorganic P and $NaHCO_3$ extractable inorganic P as plant available P. Water-soluble inorganic P concentration was measured for both dried and fresh samples.

## RESULTS AND DISCUSSION

### *General information about composting process*

The changes in C/N ratio are shown in Figure 1a. The C/N ratio of rice straw, which is the main material of compost, was 58.3 at the beginning of this study. But at 56 days after treatment (DAT), most of the composts showed decreased values around 15 to 17. It suggest that the samples in each treatment were successfully composted. Decreasing C/N ratio is one of the indices for composting stage of organic materials.

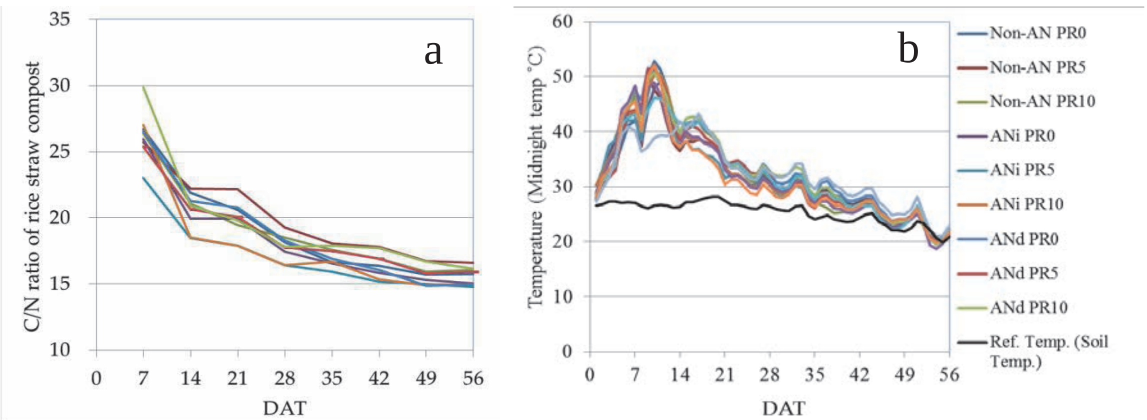


**Figure 1** Changes in C/N ratio (a) and compost temperature (b) during rice straw composting. Legends are common to a and b.

The temperature changes in compost samples during the composting period are shown in Figure 1b. Observed midnight temperature showed the highest value of over 50 °C at DAT 9 to DAT 11 and gradually decreased after DAT 30. Difference between sample and soil temperatures also gradually reduced after DAT 30. From these of C/N ratio and temperature, the composting process was thought to reach the peak of primary fermentation at almost 2 weeks after treatment, and the second fermentation was started almost after DAT 30. Therefore, days from initial to DAT 30 were defined as primary fermentation period, and days from DAT 30 to the end of composting were defined as second fermentation period in this trial.

### *Effect of rice straw composting on PR solubilization*

Results of P fractionation in the compost of DAT56 were shown in Table 2. Total P content and HCl extractable P content increased with PR addition rate. It means most of PRs remained as mineral form at DAT56, although available P content increased with PR application. On the other hand, available P content, which is sum of inorganic forms of water soluble P and $NaHCO_3$ soluble P were higher in PR5 and PR10 than those in PR0. PR was partly solubilized and became plant-available form through composting process. Furthermore, inorganic P in NaOH extractable fraction indicated clear increasing with PR addition. NaOH extractable fraction was not defined as plant available, because P in this fraction seemed complexed with mineral and/or organic colloids. But it also suggest that mineral form of PR was solubilized and complexed with colloids. Therefore, it can be considered that results suggested PR can be solubilized via rice straw composting.

**Table 2** P concentrations (mg P $kg^{-1}$) at DAT 56 in each fraction determined by Hedley's sequential fractionation method.

| Treatment | | Water | | $NaHCO_3$ | | NaOH | | HCL | Total P | Ava-P | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Inorg | Org | Inorg | Org | Inorg | Org | Inorg | | Ave. | S.E. |
| | | mg P $kgDM^{-1}$ | | | | | | | | | |
| Non AN | PR0 | 115.1 | 118.6 | 64.6 | 73.7 | 79.9 | 121.9 | 101 | 675 | 179.7 | 9.9 |
| | PR5 | 161.6 | 87.1 | 100.4 | 63.7 | 141.5 | 108.4 | 5762 | 6425 | 262.0 | 17.2 |
| | PR10 | 171.1 | 88.1 | 101.3 | 97.9 | 233.5 | 71.1 | 12493 | 13256 | 272.4 | 25.2 |
| ANi | PR0 | 97.9 | 117.0 | 69.2 | 79.3 | 83.5 | 102.6 | 146 | 696 | 167.1 | 22.0 |
| | PR5 | 129.7 | 118.5 | 99.0 | 49.7 | 193.0 | 133.9 | 6473 | 7197 | 228.7 | 23.0 |
| | PR10 | 164.2 | 126.2 | 102.7 | 98.7 | 258.3 | 105.1 | 9650 | 10505 | 266.9 | 14.1 |
| ANd | PR0 | 85.8 | 94.8 | 74.3 | 164.7 | 74.3 | 105.4 | 87 | 686 | 160.1 | 18.0 |
| | PR5 | 179.7 | 79.7 | 84.8 | 35.6 | 101.9 | 108.8 | 5177 | 5767 | 264.5 | 42.0 |
| | PR10 | 239.1 | 80.1 | 97.6 | 75.5 | 175.5 | 93.3 | 9984 | 10745 | 336.7 | 15.1 |

PR5 showed 1.46- and 1.37-times higher available P value than that at PR0, and PR10 showed 1.52 and 1.60 times higher available P values than those of PR0 (Figure 2). And the effect of initially inoculated A. niger was not observed. Conversely, for ANd, delayed inoculation with A. niger, relatively higher P was noted than that for other treatments, i.e., 1.66 times at PR5 and 2.10 times at PR10 higher than that at PR0 (Figure 2).

ANi did not affect PR solubility of the rice straw compost. It is well known that *Aspergillus spp*. becomes extinct around 60 °C (e.g. Fujikawa 2002), therefore *A. niger* applied in this trial might have been destroyed at 60 °C, and primary fermentation developed fever over 60 °C in this trial at daytime. Therefore, most of the applied microorganisms might have become extinct by high temperature during the primary fermentation, or by the reproduction of contaminated microorganisms. The spores of fungi can survive under this condition, but whether the growth stage of *A. niger* in compost already reaches the sporulation phase or abjection phase at DAT 9 to 11 when the maximum temperature was recorded is not known. The effect of *A. niger* application on PR dissolution needs to be determined. For example, the application timing might have to be changed to later such as that for the second fermentation period, for avoiding high temperature of primary fermentation.

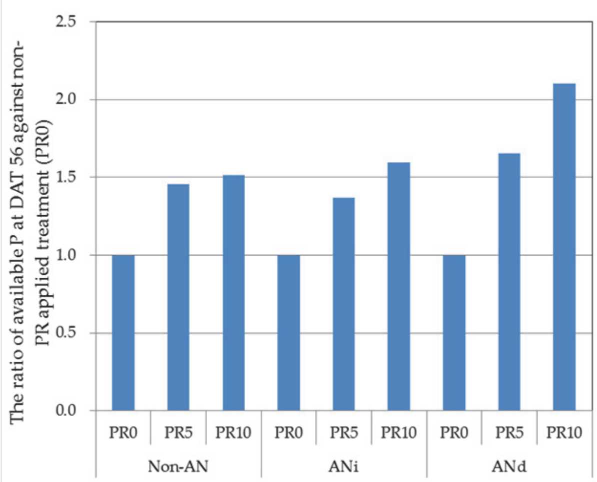


**Figure 2** The effectiveness of rice straw composting for PR solubilization at DAT 56
The ratio of available P at DAT 56 against non-PR applied treatment (PR0)

Inoculation of A. niger, as a microorganism producing organic acid, can contribute to the enhancement of PR solubilization in the case of delayed inoculation. The available P content of non-AN and ANi showed almost the same values, but ANd indicated higher available P than those in non-AN and Ani.

## CONCLUSION

In general, composting can be considered as an effective technology for Ghanaian rice production because of several reasons, such as mineral nutrient concentration, decreasing C/N ratio, and avoiding pest and disease risk. Furthermore in this study, authors suggested that the phosphate rock solubilization technology by using composting process is effective to dissolve phosphate rock even without the addition of microorganisms such as *Aspergillus niger*, but the inoculation of *A. niger* seemed to enhance PR solubilization. And we suppose that *A. niger* inoculation should be done after primary fermentation, to avoid extinction by high heat. In the rice straw compost, the final available P was increased with the PR application rate. The rice straw composting process might be considered to be useful as a PR solubilizing technology.

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