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Influence of Phospho-Composting on Enhancing Phosphorus Solubility from Inactive Rock Phosphate

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Abstract: The direct application of insoluble rock phosphate increased globally due to the rapid expansion in the biological organic sector of agriculture and the need for inexpensive phosphate in developing countries. Therefore, the objective of this research work was to assess the effect of phospho-composting on increasing phosphorus solubility of inactive rock phosphate. To achieve this objective, P-rich rice straw compost was prepared using rice straw (RS), rock phosphate (RP) and sulfate of ammonia (SA) for P and N enrichment respectively and inoculated with *Aspergillus niger*, *Trichoderma viride* as a fungal activator and/or farmyard manure (FYM). The results showed that the duration of the composting cycle depends on the mixture of the substrate. The longest cycle (120 days) was observed with the mixture of rice straw + rock phosphate without inoculants of *Aspergillus* or FYM. The maximum amount of water soluble phosphorous (1041 ppm) was produced in composts received FYM and inoculated with *A. niger* + *T. viride*. Acidic conditions (pH 4.8–6.0) at the end of the composting cycle were obtained in all piles and there was a positive correlation between the amounts of water soluble phosphorus and the reduction in pH values. The C/N ratios ranged between 35.2 and 52.2 at the beginning and decreased notably up to 12.1 to 15.6 at the end of composting cycle. The ratio of NH_4/NO_3 increased over the composting progress cycle. Citric and oxalic acid registered higher in the treatment of RS + RP + SA and inoculated with FYM and *Aspergillus* as compare to other compost mixtures. These results conclude that a phospho-composted rice straw inoculated with FYM can be successfully utilized as alternative organic rich P fertilizer for increasing crop production. In addition, this can be proposed as an alternative waste management practices in developing countries.

Key words: Rice straw, rock phosphate, *Aspergillus*, soluble P, citric acid

INTRODUCTION

Phosphorus (P) is an element that is widely distributed in nature and occurs, together with nitrogen and potassium, as a primary constituent of plant and animal life. P plays a series of functions in the plant metabolism and is one of the essential nutrients required for plant growth and development. It has functions of a structural nature in macromolecules such as Nucleic acids and of energy transfer in metabolic pathways of biosynthesis and degradation. Unlike nitrate and sulphate, phosphate is not reduced in plants but remains in its highest oxidized form (Marschner, 1993). Phosphorus inputs are required for sustainable agricultural production in most acid soils of the tropics and subtropics. Rock phosphate (RP) and organic materials have been suggested as alternative P sources in these soils.

Compost as fertilizer or soil conditioner improves the soil quality by enhancing aeration, water status, macro and micro nutrients and aggregate stability which perk up plant growth (Amlinger *et al.,* 2007). The efficacy of inorganic additives (rock phosphate 5%, $FeSO_4$ 1%, and lime 0.63%) meant to perk up the Municipal Solid Waste composting process and to examine the physico-chemical parameters during composting in mechanical composter (Iqbal et al, 2010). They concluded that, composting process decrease the concentration of total carbon (TC), NH_4-N, C: N ratio, and increase the cation exchange capacity (CEC), humification index (HI), degree of polymerization (DP), humification rate (HR), phosphorous, potassium and total nitrogen.

High reactive Rp can be used in acid soil with similar agronomic efficiencies as superphosphates, but seldom in soils with pH values above 6.2 (Buresh et al. 1997). Bationo and Mokwunye (1986) had reported that in sandy soils of the Sahel, where both P sorption and P availability are extremely low, medium-reactive RPs applied at low rates (15 to 30 kg P ha^{-1}) having relative agronomic efficiencies of 68 to 104 % within 3-yr period.

Rock phosphate offers a good alternative or complement to superphosphate in volcanic soils of Chile and it is recommended to apply RP in combination with triple superphosphate because of the high P retention capacity of these soils. However, in Western Australia it has been shown that RP response is low. Possible explanations are slow dissolution of RP due to the moderately acid pH (5.5-6.5), Low pH buffering capacity, low calcium absorption in soil, which increase Ca concentration in soil solution and poor water holding capacity of these soil. The high cost of importing soluble P fertilizers is, therefore, forcing many developing countries to turn

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increasingly to using local rock phosphate resources to improve agricultural production (Buresh et al., 1997 and Van Straaten, 2002).

Several alternative approaches have been used or proposed to increase P availability in RP including: (1) incorporation of additives into RP, (2) partial acidulation of RP, (3) compaction of RP with water-soluble P fertilizers, and (4) microbial methods (Van Straaten, 2002). Composting manure and/or biological waste with RP has been shown to enhance the dissolution of the RP (Singh and Amberger, 1991) and is practiced widely as a low-input technology to improve the fertilizer value of manure (Mahimairaja *et al.,* 1995).

Therefore, the objectives were to assess the effect of composting on increasing phosphorus solubility from rock phosphate providing guidance for the materials to be combined with Rock phosphate for improving the Phosphorus availability in soil.

MATERIALS AND METHODS

To achieve the objectives of the studies, composting experiment were conducted in the greenhouse of the Japan International Research Center for Agricultural sciences (JIRCAS) at Okinawa Subtropical research station that was established on Ishigaki Island (24^0 N, 129^0 E) a core among the most southern Ryukyu Island. The climate is subtropical with winter and summer rainy seasons.

Composts were produced from rice straw enriched with rock phosphate, sulphate of ammonia and inoculated with *Aspergillus awamori, Trichoderma viride* and/or farmyard manure (FYM). Each treatment replicated trice. The treatment details used in this experiment presented in (Table 1).

Table 1: Treatment structure in compost experiment

Treatments designation	Abbreviations
Rice Straw (RS) + Burkina Faso rock phosphate (BRP) 10% + SA (2.0%)	C1
RS + BRP 10% + Farmyard Manure (FYM) (10%) + Sulphate of ammonia (SA) (2.0%)	C2
RS + BRP 10% + *Aspergillus*. (2.5 %) + SA (2.0%)	C3
RS + BRP 10 % + SA (5.0%) + *Aspergillus* (2.5%)	C4
RS+ BRP 10% + *Aspergillus* (2.5%) + FYM (10%) + SA (2.0%)	C5
RS + BRP 5% + *Aspergillus* (2.5%) + SA (2.0%)	C6

1. Rice Straw:

Air-dried rice straw used in this study was crushed into about 3–6 cm pieces using a shredding machine.

2. Microorganisms:

Cellulose degrading *Trichoderma viride* and phosphate dissolving *Aspergillus awamori* strains were obtained from the culture store of National Institute of Technology and Evaluation, Japan. The cultures were grown and maintained on potato dextrose agar slants.

3. Inocula Preparation:

A spore suspension was prepared by adding 3 ml of sterile distilled water to each slant and shaking vigorously for 1min. Cloth bags, each containing a mixture of 1kg of corn meal and 10kg of sand were autoclaved for 30 min. Each autoclaved wet (from contact with steam) corn meal–sand mixture bag was inoculated under aseptic conditions with 6 ml spore suspension of either *A. awamori* or *T. viride*. The inoculated corn meal–sand mixture was incubated at 30 ^{0}C for 5 days until the green spores of *Trichoderma* or the black ones of *Aspergillus* arise on the corn meal–sand mixture. These mixtures were used as inocula for compost preparations.

4. Preparation of Piles:

A plastic sheet was placed on the soil surface to control leaching from the piles. Dry shredded rice straw was enriched with rock phosphate, ammonium sulphate and the inoculants of farmyard manure, corn meal–sand mixture *T. viride* inoculum and corn meal–sand mixture *A. awamori* inoculum. Windrow piles each with 150 cm length, 80 cm width and 60 cm height were set up on the plastic sheet.

Moisture was maintained at 60 % (the moistening was considered satisfactory when a hand-full of composted materials would wet the hand but not drip). The fermentation was allowed to continue for 120 days. The piles were turned for aeration once a week and three replicate samples were taken from different spots in each pile at different time intervals for subsequent analysis. The initial data analysis of the material used and its abbreviations used in the composting experiment as followed in (Table 2).

5. Compost Aanalysis:

Sampling was done at 1, 7, 15, 30, 45, 60, 90 and 120 day of composting which named as S1, S2, S3, S4, S5, S6, S7 and S8. The collected samples analyzed for some chemical properties *viz.* pH, EC, TC, TN, TP, water soluble P, NH_4, NO_3 and organic acids. The results of the study are presented as follow.

Table 2: Initial data of material used in the Experiments.

Materials used	Abbreviated as	TP (%)	TN (%)	C/N
Rice Straw	RS	0.08	0.61	58.1
Farmyard Manure	FYM	1.68	1.97	19.3
Sulphate of ammonia	SA	-	21.5	-
Aspergillus awamori	Asprg.	P mobilizing fungi		
Tricoderma viridi	Trico.	Cellulose decomposer		
Burkina Faso rock phosphate (BRP) characterized by: Ca (%) 32.0; CO_2 (%) 1.0; K (%) 0.119; Na (%) 0.605; Mg (%) 1.06; Fe (%) 0.375; Al (%) 0.488; S (%) 0.025; Cl (%) 0.043; F (%) 3.2; total P (%) 10.69; soluble P (%) 0.032, PO_3/CO_3 = 23.				

5.1 Compost Temperature:

T Temperature was measured at the center of the compost heap every 10 minutes by a thermometer with temperature logger (UIZ3633, UIZIN, Tokyo, Japan)

5.2 Compost pH:

About 10 g of dried and powdered compost sample was stirred with 100 ml of distill water for one hour and pH of the suspension was measured using pH meter.

5.3 Compost EC :

About 10 g of dried and powdered compost sample was stirred with 100 ml of distill water, filter and EC of the filtrate was measured using EC meter.

5.4 Carbon: Nitrogen Ratio:

The total carbon and Nitrogen content of dried and powdered compost samples was determined by dry combustion method with NC analyzer (Sumigraph NC-95A, Sumika Chemical Analysis Service, Osaka, Japan).

5.5 Total Phosphorus:

The total phosphorus content of dried and powdered compost samples was determined by wet digestion method. A representative sample of exactly 0.1g was digested using sulphuric acid and hydrogen peroxide. The digest was quantitatively transferred into a 100-ml volumetric flask and made to volume by distilled water and 1ml was used for the colorimetric determination according to (Faithful, 2002).

5.6 Water soluble P:

Phosphorus was determined calorimetrically at a wavelength of 410 nm by the Vanado-molybdate reagent by (Faithful, 2002). In this method compost samples (about 100g) were collected from four different spots in each well-turned pile and thoroughly mixed. Ten gram of this mix was thoroughly mixed with 100 ml of distilled water at room temperature. The suspension was agitated for 1h, filtered using Whatman filter paper No. 15 and 1ml of the supernatant was used for phosphorus determination.

5.7 NH4 and NO3 Analysis:

Ammonia and nitrate in the aqueous extract of composted rice straw samples in some selected time and samples in (1:10) sample: water ratio was measured by HPLC. Isocratic HPLC (Waters) with software Millennium 32 equipped with a Photo Diode Array detector was used. A column of dimension 4.6 × 250 mm, X-Terra C-18, 5 μ, was operated at ambient temperature. Mobile phase consisted of 2.2 g of KH_2PO_4 per liter in HPLC grade water at pH 4.5 (adjusted with KOH).

5.8 Organic Acid Analysis:

The organic acids were extracted from decomposing rice straw by distilled water as described by Brinton (1998). The Determination was done in some selected sampling periods (S1, S2, S3, S5, S6 and S8) by using capillary electrophoresis (G1600A, Agilent Technologies, Santa Clara, CA, USA) Sieved (<2 mm) dried compost and distilled water (1: 10, v/v) was used. Standards and calibration curves were prepared for the following organic acids: Oxalic, Succucinic, Malic, Citric, Lactic and Acetic acids. The results were expressed on a dry basis.

6. Statistical Analysis:

Each compost parameter characterized was averaged from three analyses, where triplicate samples were each analyzed twice to measure the sampling and analytical error. Calculated using excel (Microsoft 2007), standard deviation was reported along with the average value. SPSS 11.5 was used for statistical analysis and the person correlation between water soluble P and the studied parameters was done also.

RESULTS AND DISCUSSION

1. Compost Temperature:

Temperature of compost pile increased rapidly within the first week of composting processes compare to room temperature (Rt). After 10 days of composting, temperature increased up to 57.2 ^{0}C in C2 which is sufficient to destroy pathogens in this thermophilic stage followed by C5 (54.1 ^{0}C) and the lowest 45.3 ^{0}C in C3 compost pile (Figure 1). Then the temperature gradually declined till 20 days and finally stabilized near the ambient temperature ranged from 25 to 35.7 ^{0}C throughout the composting period.

The results are in agreement with Strauch and Ballarini (1994) who find only the thermophilic range of 55 ^{0}C is sufficient to destroy pathogens. Throughout the experimental period, the ambient temperature ranged from 8 to 34.7 ^{0}C. Stentiford (1996) suggested that temperatures higher than 55 ^{0}C maximized sanitation, those between 45 and 55 ^{0}C maximized the biodegradation rates, and between 35 and 40 ^{0}C maximized microbial diversity in the composting process.

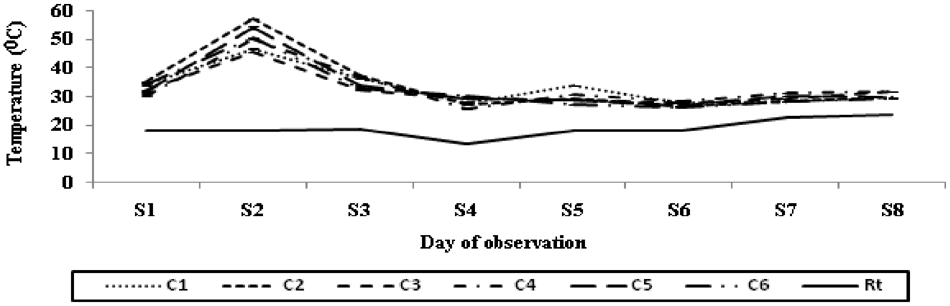

Fig. 1: Changes in Temperature during composting.

2. Compost pH:

The pH level is one of the important characteristics of the composting process. The data indicate that the highest pH values at 1 day of composting was noticed in C5 treatment (8.08), followed by C2 (7.38) due to application of farmyard manure and the lowest was in the treatment receiving 5% sulphate of ammonia C4 (6.39). During mineralization of organic nitrogen converted to ammonia nitrogen. This may increase pH values. Whereas, a decrease in pH may be caused by increased production of organic acids or increased nitrification. At 120 day of composting, the pH values were in the range of 4.75 to 6.02 and the highest was in C5 treatment and the lowest was in C4 treatment (Figure 2). Bertoldi et al. (1983) suggested that the optimum pH values for composting are between 5.5 and 8.0.

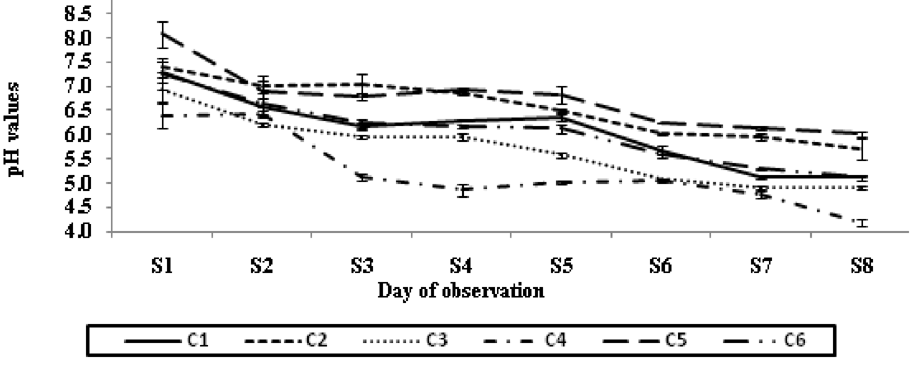

Fig. 2: Changes in pH values during composting

3. Electrical conductivity

The lowest electrical conductivity value was recorded in case C1 treatment (4.56 dS m^{-1}) and the highest was in sulphate of ammonia treatment C4 (7.60 dS m^{-1}) at 1 day of composting. However, at 120 of composting, the lowest electrical conductivity value was recorded in case C3 treatment (7.75 dS m^{-1}) and the highest was in treatment C4 (10.96 dS m^{-1}) due to application of 5 % sulphate of ammonia in (Figure 3). It means that, increasing or decreasing the EC values dependant on the component involved in each treatment.

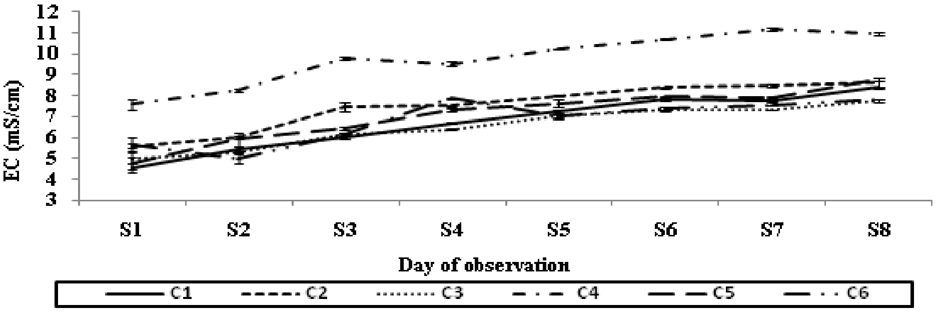

Fig. 3: Changes in EC values during composting.

4. Carbon: Nitrogen Ratio:

The C: N ratio of the compost at 1 day of composting varied between 52.2 in C1 treatment to 35 in C4 sulphate of ammonia treatment (Figure 4). With an increase in time, a decrease in C: N ratio was noticed in all the compost piles that were included for the study.

At 120 day of composting, the lowest C: N ratio (12.1) was noticed in the compost pile C4 that receiving 5% sulphate of ammonia, followed by C5 (13.4), C2 (13.8), C5 (13.9), C6 (14.9) and the highest in C3 (15.6). This is in agreement with Iqbal *et al.* (2010). The findings in the present study concurred with the results reported by (Satisha and Devarajan, 2007). During the composting process the biologically degradable organic matter is converted into volatile CO_2 and H_2O and is removed from the compost and the total N content increases which results in a C: N ratio decrease toward the end of composting (Day *et al.,* 1998).

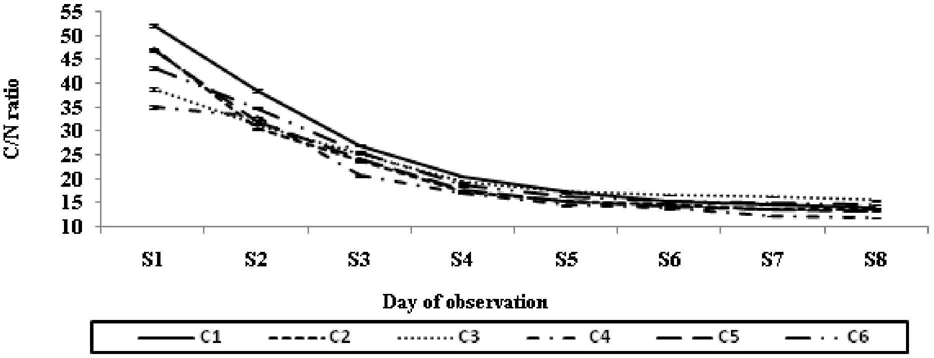

Fig. 4: Changes in C/N ratio during composting.

5. Total Phosphorus:

The highest total P content was registered in the C3 compost pile (0.97 %) followed by C4 (0.71 %) and the lowest value (0.54 %) was in the C6 pile receiving lower amount of rock phosphate (5 %). With increase in time till 30 days, an increase in total phosphorus was observed in all the compost pile mainly due to biomass loss. At 120 day of composting, the highest total P (2.09 %) was noticed in the compost pile C1, followed by C2 (1.97) and the lowest value (1.07 %) registered in C6 (Figure 5). Total P content increased on decomposition and the increase was proportional to loss in organic matter during decomposition. The phosphorous concentration increases due to the addition of rock phosphate as compared to untreated compost. Some studies reported the increasing trend by (Nishanth and Biswas, 2008).

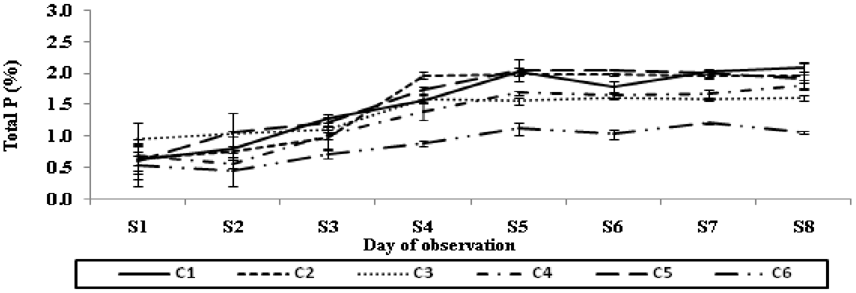

Fig. 5: Changes in total P during composting.

6. Water soluble P:

Particular interest has been paid to maximize the amounts of released phosphorus during the composting process of rice straw enriched with rock phosphate in this study. The data showed that water soluble P (WSP) ranged from 200 to 1000 mg kg^{-1} in different compost piles. At 1 day of composting, the highest (626.5 mg kg^{-1}) was recorded in FYM treatment C5, followed by C2 (542.1 mg kg^{-1}) and the lowest was recorded in C1 (220.9 mg kg^{-1}). With decreasing in compost pH, there were a significant increase in water soluble P up to 120 day of composting. The inoculation of rice straw–rock phosphate mixture with FYM was necessary to increase the amounts of soluble phosphorus. (Tengerdy and Szakacs, 2003) stated that inoculation with *A. niger* + *T. viride* under the same conditions represented the most suitable conditions for phosphate solubilization. The results showed that at 120 day the water soluble P was highest in the compost pile enriched with FYM (1041 mg kg^{-1}), followed by C2 and the lowest value (267.5 mg kg^{-1}) of water soluble P was observed in the treatment receiving 5 % rock phosphate as compare to other treatments (Figure 6).

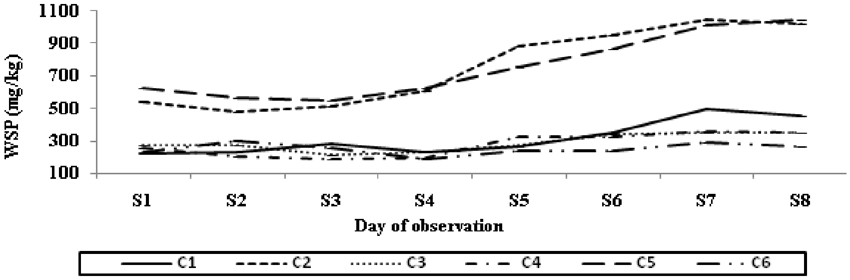

Fig. 6: Changes in water soluble P during composting.

The date in (Table 3) represents the percent increase in water soluble P significantly increased due to composting. The percent increase ranges from 12 to 50 %. The highest percent increase registered in C1 (50.1) followed by C2 (46.7) and C5 (40.0) and the lowest recorded in C6 treatment due to the lower application of rock phosphate (5 %). Phosphorus from rock phosphate could be solubilized and transformed into available forms when incorporated with rice straw during composting and the increasing phosphorus solubility may also due to the formation of humic substances.

Table 3: Apparent increase in water soluble P (mg/kg) during composting

Treatments	Water soluble P		Apparent increase
	1 day	120 day	(%)
C1	220.9 b	448.8 b	50.1
C2	542.1 a	1022.6 a	46.7
C3	271.3 b	369.9 bc	26.3
C4	251.3 b	352.8 bc	28.3
C5	626.5 a	1041.3 a	40.0
C6	232.3 b	267.5 c	12.3

7. NH4 and NO3:

The evolution of the different forms of nitrogen during composting depended on the material which supplied the nitrogen to the mixtures and the organic matter (OM) degradation rate during composting. The greatest concentration of ammonium was observed during the first two weeks of composting, coinciding with the most intense period of OM degradation, and ammonium then decreased gradually to reach final values of 480 and 420 mg kg^{-1} in C5 and C4 compost pile, respectively (Table 4).

The use of sulphate of ammonia as N source in the mixtures led to high NH_4 levels during the composting period as a result of its rapid hydrolysis. The nitrification process began only when the temperature of the mixtures had dropped below 40°C and its intensity depended on the quantity of ammonium present when the process began. The highest concentrations of NO_3-N were always produced at the end of maturation, reaching values of 1949, 1560 and 1043 mg kg^{-1} in the compost pile C3, C5 and C4, respectively.

The increasing concentrations of ammonia were due to the metabolism of protein by the microbial activity and decrease in NH_4-N was partly caused by volatilization of gaseous ammonia due to slight alkaline pH of the compost. However the major contribution of the removal of the NH_4-N shows the nitrification (Iqbal, 2010).

The ratio of NH_4-N and NO_3-N concentrations was shown to be a clear indicator of the maturity of the mixtures during composting, the final values of 0.22 and 0.31 for the compost mixtures C3 and C5 being equal to, or below the maximum value established as a maturity index in other materials.

Table 4: Changes in NO_3 and NH_4 (mg kg^{-1}) during composting

Treatments		NO3-N	NH4-N	NH4/NO3
S3	C3	0.97 b	805 b	838 b
	C4	0.78 b	6021 a	7769 a
	C5	5.43 a	602 b	114 b
S4	C3	73.2 b	609 b	9.40 b
	C4	4.46 a	4910 a	1123 a
	C5	2.59 b	529 b	209 b
S6	C3	1629 a	660 b	0.41 b
	C4	462 c	6053 b	13.1 b
	C5	1187 b	499 a	0.42 a
S7	C3	1949 a	420 b	0.22 b
	C4	1043 c	6313 a	6.06 a
	C5	1560 b	479 a	0.31 b

8. Organic Acids:

The production of organic acids and changes during decomposition of rice straw amended with Burkina Faso rock phosphate (BRP) was presented in (Figure 7). The organic acids detected during decomposition of rice straw at various sampling times were Oxalic, Lactic, Succucinic, Acetic, Citric and Malic acid. Oxalic acid were detected only at the beginning and it was higher (31 me/kg) at C4 treatment as compare to other treatment then disappeared on the other sampling times.

The higher concentration observed of Lactic acid and Acetic acid were (15 me/kg) and (5.0 me/kg), respectively after 60 day of starting the experiment. The maximum amount of Citric acid was (1.8me/kg) whereas, Malic acid (1.1me/kg) registered after two weeks of composting. Succucinic acid was below 1 me/kg in all treatments.

The higher concentration of Oxalic acid recorded in C4 treatment {RS + RP (10 %) + Sulfate of ammonia (5.0 %) + *Asp.* (2.5 %)}. Lactic and Acetic acids were higher at C2 treatment {RS + RP (10%) + SA (2.0 %) + Farmyard manure (FYM) (10%)} whereas, Citric, Lactic, Acetic and Malic acids were higher at C5 treatment {Rice straw (RS) + Burkina Faso Rock phosphate (BRP) 10% + Sulfate of ammonia (SA) (2.0 %)+(FYM) (10%)+Asperg.(2.5%)}.

Detection of these organic acids suggests their important role in increasing P solubility from rock phosphate. Kumari et al (2008) they found that citric, oxalic and malic acids were detected during decomposition of rice straw and maximum amounts were present on day 15. Citric and oxalic acids were responsible mainly for P solubilization from Tricalcium phosphate and Udapur Rock Phosphate; generally, citric acid was the most effective in P solubilization.

9. Correlation Study:

The data on correlation coefficient between the studied parameters at 90 day of starting composting are presented in (Table 5). The results of the investigation indicated that water soluble P significantly and positively correlated with total phosphorus (0.552*) and compost pH (0.924**). Highly significant and positive correlation was found between water soluble P and Citric (0.703**), Lactic (0.629**) and Acetic acid (0.768**).Total P also had significant and positive correlation with Citric acid (0.576*).

Table 5: Correlation between water soluble P and composting parameters.

	Water soluble P	pH	EC	Acetic acid	Lactic acid	Citric acid
pH	0.924**					
EC	0.006	-0.227				
Acetic acid	0.768**	0.944**	-0.513*			
Lactic acid	0.629**	0.768**	-0.138	0.751**		
Citric acid	0.703**	0.549*	0.229	0.351	0.833**	
Total P	0.552*	0.310	0.348	0.115	0.079	0.576*

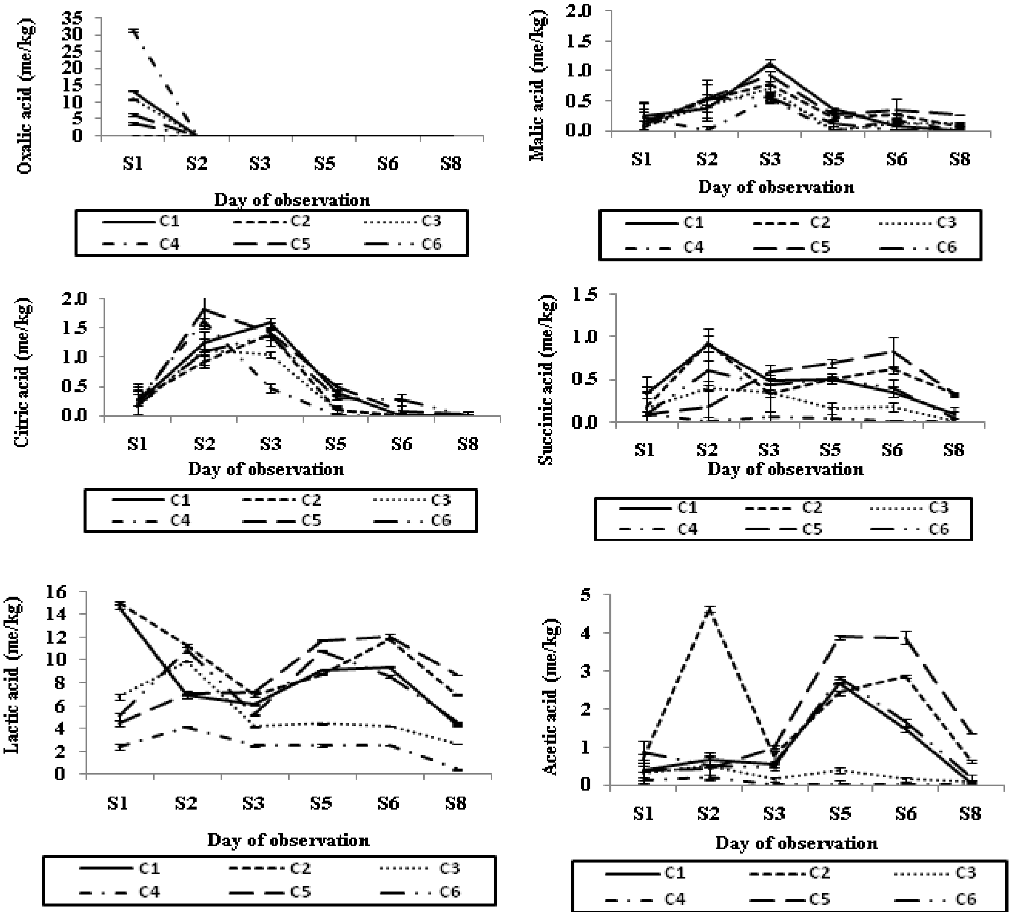

Fig. 7: Changes in organic acids during composting.

Conclusions:

Composting process of rice straw enriched with rock phosphate decrease the concentration of total carbon (TC), NH4 -N, C:N ratio, and increase the total nitrogen (TN), soluble phosphorous, and organic acid (Formic, Citric, Lactic and Acetic acids). Detection of these organic acids may indicate their role in P solubility. The phospho-composted produced with FYM enrichment can be considered a rich P fertilizer for increasing P solubility and crop production.

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