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Recirculation Compost in Composting Process and Nutrients Accumulation

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ABSTRACT

The soil was the primary material for the food waste composting process, and the problem of compost product qualities, especially nutrients, was lower than standard. This study investigated the role of compost utilization as a cover material by using compost as a soil substitute for scarce land areas and study nutrient accumulation when recirculation compost products. The research aimed to study phenomena of SO_4^{2-} and nutrients accumulation and also study supporting factors. The experiment was three varied treatments with cover materials: T1 was only soil covered, T2 was using the compost product from T1 mixed with soil in ratio 1:1, and T3 was using the compost product from T2 mixed with soil in ratio 1:1. The research was stimulating from the concrete box composting under the nature-by-nature concept. The results found that compost product recirculation over one time in the composting process promotes sulfate reduction, affecting negative Eh value. The change in physical and chemical properties found that alkalinity pH helped to inhibit the substrate precipitation in entirely anaerobic conditions. The compost qualities indicated that TN and TP from T3 treatment were higher than others, but TK and sulfate were decreased by nutrient leaching on unsuitable conditions. In the second crop, the use of compost products as cover materials was associated with a fivefold increase in sulfate accumulation in the compost, but this relationship was changed in the third crop. Alkalinity and pH, both of which can enhance reduction conditions, were influencing factors. Sulfate-rich accumulations and nutrient productivity, on the other hand, demonstrate a non-relative relationship.

***Key words** : Compost, Cover material, Sulfate accumulation, Electron acceptors, Nutrient production*

Introduction

Municipal solid waste in Thailand had a high organic composition of about 64% by weight of all waste, including food waste, yard waste, and agricultural waste. These are highly moisture, rich in organic substances, and easy for digestion, so wildly utilization such as animal feed, biogas, and others (Silapasuwan, 2014; WMHM, 2018). Organic waste disposal by composting technology was suitable and has been published widely due to composting as the natural degradation process. Nutrients are recycling into humus and inorganic matter. They always use soil as the electron acceptors for the process, which has affected odor reduction while depleted oxygen within the anaerobic condition. Soil utilization in composting is an efficient technic for the degradation process but seems to be high cost and rarely soil function.

Moreover, compost products from organic or food waste had low nutrients, and the qualities are under the standard. Therefore, the adaptation by using compost as cover material for substitute soil may influence to promote the nutrients productivity (Buaprom *et al.*, 2020). By the way, sulfate accumulation would release gases, solvent, and colloid particles by the intense reduction reaction to effect releasing compound to the system which enhanced by pH higher (Vityakon, 2004; Chueawong *et al.*, 2019). Nowadays, there have been many studies on fertilizers for agricultural productivity; no clear data shows the effect of high sulfate fertilizer on soil properties. On the other hand, it might lead to soil toxicity and also nutrient fixation of a plant (Gao *et al.*, 2004). Therefore, the organic decomposition process mechanism is shortened and promotes a higher nutrient by the phenomena of sulfate accumulation is an influencing factor. Accordingly, this research focuses on applying compost for solving environmental problems with the resource circulation concept by using the compost from the previous crop as a covered material to replace the soil, whereas considering the quality of compost needs for eco-friendly and sustainable.

This research would be studying the phenomena of organic carbon elimination by the sulfate accumulation, which uses an electron acceptor that the primary acceptor in the decomposition process and the nutrient production.

Materials and Methods

Experimental unit

The experiments were conducted by simulates concrete boxes technology of the King's Royally Initiated Laem Phal Bia Environmental Research and Development Project,which was the one of organic composting technology in Thailand by down unit scale to 1: 1000. The experiments were done in rectangular plastic boxes (length x width x height equal 15.5 x 25 x 17 cm). The experiments were laid out in randomized complete block design (RCBD) with three treatments by varied cover materials with three replications. The first treatment (T1) was control by using only soil as cover materials, the second treatment (T2) was compost product fromthe first crop or T1 treatment mixed with soil in ratio 1:1, and the third treatment (T3) was compost product from second cropor T2 treatment mixed with soil in ratio 1:1.

Each unit's material contains 2 kilograms of organic waste divided intothree layers (660-670 g per layer) and covered by varied materials and the treatment. Cover materials were separated into three layers by the 1st and 2nd layer was 210 g, and the 3rd or top layer was 630 g. Organic waste consisted of rice, chicken, cabbage, and banana peel. The unit's bottom was perforated, and put some pieces of charcoal cover the hole to absorb leachate odor before release to a plastic bottle. Then put the sand and spread it over the unit's bottom, the thickness about 1 cm. After that, put organic wastes, then covering by materials alter for all three layers. After finish, spray 60 ml of water every week. This experiment was investigated for 21 days. This study has been researching at The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Chaipattana Foundation in Thailand in June 2020.

The 5 g of samples were taken every two days for determining pH, redox potential (Eh) by ORP meter, EC, SO_4^{2-}, OC, and nutrients.

Sample Analysis

Materials were analysis of properties for soil, compost product from 1st and 2nd crop, and organic waste such as soil texture, total phosphorus (TP), total potassium(TK) and sulfate (SO_4^{2-})(LDD, 2010); pH and electrical conductivity (EC) (Jackson, 2005); organic carbon (OC) (Walkley and Black, 1934); cation exchange capacity (CEC) (USDA, 1999); total nitrogen (TN)with Kjeldahl method (Steven *et al.*, 2000); also electron acceptors (EA) such as nitrate, active Fe(III)and active Mn(IV) (Teerajindakajon, 2009; Mckeague and Day, 1966). The properties of materials were shown in Table 1. The results were analyzed statistically using one-way analysis of variance (ANOVA) and Tukey's test with the SPSS 17 version at the significant level of 5% probability.

Results and Descriptions

Characteristics of paddy soil, compost product, and organic waste

Paddy soil was clay texture, OC, nutrients, and EC as low, pH as neutral. However, electron acceptors in paddy soils such as NO_3^-, MnO_2, Fe_2O_3, and SO_4^{2-} shown function in anaerobic respiration, especially iron oxide was highest that sensitive in mediating

Table 1. Physical and chemical properties of paddy soil, compost product, and organic waste

Parameters	Paddy Soil	Organic waste	1/T1	2/T2
pH (1:10)	6.8	5.7	7.1	7.7
EC (dS/m)	0.31	1.93	1.83	1.02
OC (%)	0.62	48.76	2.16	4.98
Total N (%)	0.03	2.21	0.22	0.78
Total P (%)	0.02	0.10	0.05	0.08
Total K (%)	0.04	0.78	0.73	0.81
C/N ratio	17.87	22.06	10.82	6.66
SO_4^{2-}- S (mg/kg)	22.85	54.92	31.95	162.70
NO_3^-- N (mg/kg)	151		110	320
MnO_2- Mn (mg/kg)	1,400		1,200	870
Fe_2O_3- Fe (mg/kg)	6,700		6,400	5,600
CEC (cmol/kg)	15.64		24.15	24.52
Texture Clay				

Remarks:
1/T1: compost product from the first crop which uses only soil as covered material;
2/T2: compost product from 2nd crop by using the ratio of T1: paddy soil at 1:1as covered material

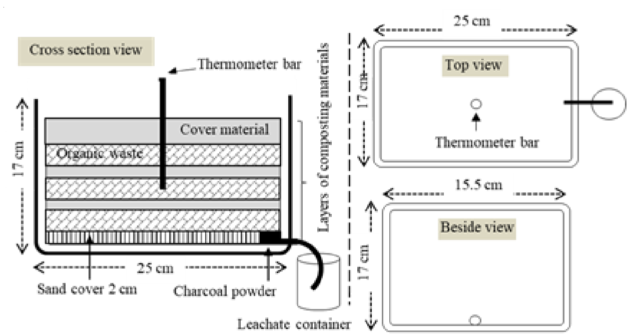


Fig. 1. The experimental unit box which simulated and downscaled from concrete box technology at 1:1000

biogeochemical redox reaction (Ponnamperuma, 1972; Nurmi and Tratnyek, 2002; Huang *et al.*, 2010) and also the all of the manure compost was shown as T_1 and T_2.

Sampling Technique

Period of the organic waste composting process, temperature, and moisture content were collected every day at 7 am at each centre of unit.

The properties of T1 were similar to paddy soil due to it was the product from composting process by using only paddy soil as cover materials. However, the nutrients and SO_4^{2-} concentration was higher than paddy soil. Evidence was shown in redox potential properties, including the reversibility of electron transfer from organic matter and electron acceptor and electron donor capacities (Bauer *et al.*, 2007; Huang *et al.*, 2010; Yuan *et al.*, 2011). When used T1: soil in ratio 1:1 as cover material, then got T2 product, it was found that sulfate value of T2 was 162.70 mg/kg, which approximately five times of T1 with the same trend to other nutrients. It has shown that when using soil recirculation in composting process, EC decreased, and pH was neutral.

In this experiment, compost product (T2): soil in ratio 1:1was used in T3 experiment. When compared T1 and T2, it was found that T2 contained rich-sulfate and NO_3^- bynutrient trapped in clay particles. To reduce nutrient loss and nutrient degradation via immobilization (DSS, 1987) and supported for the buffer as pH resistance when it was no stable (Ratneetoo and Wongkrachang, 2013; Jacoby *et al.*, 2017). C/N ratio in organic waste was 22.06, enough to make high-quality compost (Eiland *et al.*, 2001; Tang *et al.*, 2007; Rich *et al.*, 2018). Organic wastes were found pH was 5.7 bitter acids and OC and SO_4^{2-} loading would show relatively high from cabbage.

Temperature and moisture

The relationship between temperature and moisture during the composting process played a vital role in SO_4^{2-}accumulation. In this description, compost products from the previous crop had high SO_4^{2-} when used compost product mixed with soil as cover material and combined the organic waste as rich humus, the results were a rich nutrient product. However, they showed a slow degradation process due to the organic acids gained from the humic substance with extremely hydrophilic as polar functional to compost water holding capacity (Mankarnde *et al.*, 1985; Yuan *et al.*, 2018). Compost products from T2 and T3 experiment were high moisture content, indicating that soil water holding was increased (Al-Wabel *et al.*, 2015). As a result, the temperature reached the optimum point at 42.6 °C, ashift from the mesophilic phase (27 to 29 °C), and moisture was 40 to 47.3%. Then, the Sulphate-reducing bacteria (SRB) could tolerate temperatures from 5 to 75 °C, and it could adapt quickly to survivein all temperatures (Cocos *et al.*, 2002). However, the optimum of SRB community in the organic biodegradation was 28 to 30°C and at least at 20 °C (Sagemann *et al.*, 1998). The moisture condition and rich OC had enough for the promoted reduction reaction. Ehvalue wascontinuously decreased since in earlier state, which was effected to flocculate and decompose in completely anaerobic condition by substitutive moisture in macropore. Therefore, there were the reasons for accumulate SO_4^{2-} by physical factors had appropriated (Riddech, 2013) and also an electron acceptor (EAs) released through as microbial energy source (Prabuddham, 1985). Also, it was indicated the relationship between Eh and humus formation which the organic acids and Eh decreased in the similar direct variation (Kappler *et al.*, 2004). The temperature was significantly different during the composting process by using compost as cover material with physical and chemical properties (Fig. 2).

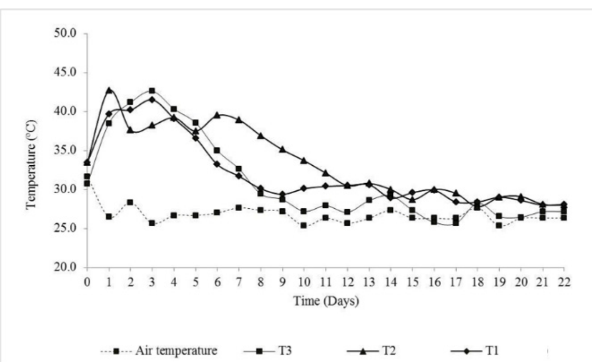


Fig. 2. The relationship between temperature and moisture content in compost product

Sulfate accumulation

The biodegradation process influenced sulfate; when concentration was higher than 21 mg/kg, it can inhibit the degradation process, moisture content related to OC removal on the 8th day. The trend of SO_4^{2-} accumulate was found in the highest range at 118.42 mg/kg on the 20th day, indicating that FeS was oxidized by the aerobic state afterward resulted in the compost's maturity, as shown in Table 2 (Samudro and Hewmana, 2007; Chueawong *et al.*, 2019). The relationship between SO_4^{2-} and redox potential (Eh) was significant to the organic degradation process inrich moisture conditions, so it was supported to redox-active reaction.Eh started at 144.6 mV then decreased continuously. This experiment was investigated to study SO_4^{2-}accumulate phenomena related to organic compounds as colloid forms in soil or compost products. Colloid particles had all other surface areas enough to trap SO_4^{2-} and oxide compounds by covalent bonds such as Fe_2O_3 or $Fe(OH)_3$, MnO_2. These had much in clay particles for crystalline form an amorphous form (Ponnamperuma, 1981). The composting had ion-exchange by electrostatic force from the redox reaction in electron exchanging, which contained positively or negatively charged sites that can attract anion from a surrounding solution (Swartzen-Allen and Matijevic, 1974) which active to substitute SO_4^{2-} at ligand point, then had sulfate reduction at furthest was -329.7 mV on 6th days. Sulfate reduction and methane reduction were -85.5 to -314.2 mV during 8th to 16th days, as shown in Fig. 3. The Eh was generally reduced and show negative according to the thermodynamic sequence of the microorganism's activity, which depends on temperature, pH,OM, and electron acceptors. At the end process, Eh increased from the ability of MnO_2 to resist redox potential and suppress the toxicity of substances when the richmoisture content in compost product (Ponnamperuma, 1972; Attanandana, 2007). However, each treatment was not significantly differentin sulfate and Ehvalues. SRB reduced in T3 from containing of cellulose in compost that could be shown hydrogen sulfide sediment and volatile fatty acids (VFAs) in alkaline condition (Kanjanaratand Ratanatamskul, 2010). Also, there would react to iron compounds in the reduction (sulfide formation) form resulting iron sulfide (FeS) that would lead to leachate be black and intense odor (Ponnamperuma, 1981; Xia *et al.*, 2017) and also has impacted on slow down the biochemical process led to a decrease in the degradation rate (Bitton, 2005; Ivan *et al.*, 2019) which shown in equations.

$$Fe(OH)_3 + SO_4^{2-} + CH_2O \rightarrow FeS + 2HCO_3^- + CO_2 + H_2O$$

$$SO_4^{2-} + \text{Organic matter} \rightarrow HS^- + H_2O + HCO_3^-$$

$CH_3COO^- + SO_4^{2-} \rightarrow 2HCO_3^- + HS^-$

$SO_4^{2-} + 10H^+ \rightarrow H_2S + 4H_2$

pH and EC

The pH is the main factor to accumulate SO_4^{2-} and also important to facultative anaerobe growth. Compost products of T2 and T3 gained significant differences resulted in greater pH compared with each treatment during a period of pH levels. pH value was range 5.7 to 8.4 from using compost product as cover material found the highest at 8.4 regarding the reactant properties had rich in organic matter, SO_4^{2-} and other EAs in wet solution. Fig. 3 changes in chemical properties during composting (A) EC (B) Relationship between Eh and pH and (C) Comparing Eh each treatment

The relationship between pH and nutrients was indicated to release free-proton when SO_4^{2-}, Fe^{3+} and Mn^{4+} were reduced for anaerobic respiration. In case of a decrease in OC degradation and releasing (Ebid *et al.,* 2007). The OC value began to decline on the 4thday. So, the treatment which used compost product as cover materials was reported that organic substances affect to elevate pH value. Due to strong alkaline pH can absorb substances by ionic bond from exchangeable cation and active iron to active-reaction and then precipitation of iron in an alkaline condition which described to reduction reaction by organic substances added (Mankarnde *et al.,* 1985). The changes in pH and EC value related to the activity of SRB in each process at its stage as shown in Fig. 3, during the period between the 4th to 10th days indicated that EC releasing the nutrients (Fageria *et al.,* 2011) on the substrate had high SO_4^{2-} at least 20.99 mg/kg. The reactant of SO_4^{2-} content resulted in the total OC increased from the compost product amendment layer. The organic matter was conserved more competently and kept SRB or facultative anaerobes for degradation (Méndez *et al.,* 2012). It is essential the nutrients in compost and hydrogen sulfide production by using hydrogen ions (H^+) and produced hydroxide ions(OH^-) it could be alkalinity (Sakunphanichai and Ratanatamskul, 2006). During the 18th to 20th days, the energy source decreased but remained carbon substrate of cellulose content which OC slightly increased. In case, compost product with high content of NO_3^- reduced to $NH4^+$ lead to the reduction and also $(NH_4)_2SO_4$ being an oxidizing acid compost, can reduce the soil pH and increase the availability of compounds in the soil (Kelley and Stevenson, 1987; Eriksson, 1990; Woro *et al.,* 2020). Therefore, pH 7 had the most degraded OC, which promoted anaerobic microorganism activity related to sulfate reduction and OC removal when pH value more than 8. It was found that SO_4^{2-} hadsome potential to suppress CH_4 productions because SRB competed with methanogens in using carbon substrates (Ro *et al.,* 2011). Simultaneously, SO_4^{2-}reduction was almost completed significantly and positively correlated with OC, pH, and EC.

Nutrient's production

Accumulate SO_4^{2-} and the nutrients such as TN TP and TK, which were not significantly different due to it related to EC and pH in all composting periods. TP had a strong signification than TK and TN, respectively, and tended to decrease in the maturity stage. The nutrients have arranged the order by re-

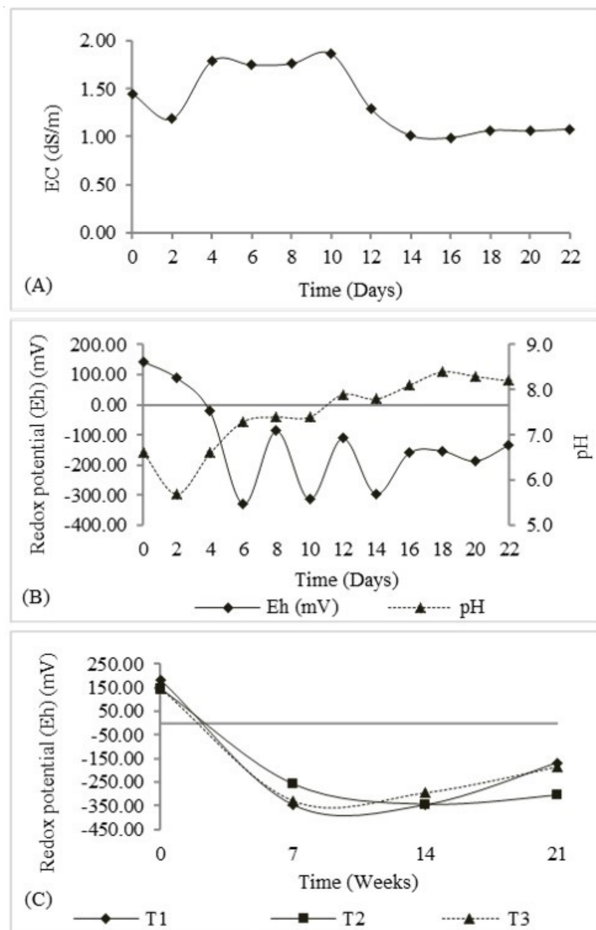


Fig. 3. Changes in chemical properties during composting process (A) EC (B) Relationship between Eh and pH, and (C) Comparing Eh in each treatment.

leasing step as TN> TK> TP, which could indicate that the nutrient had no relationship to inhibit SO_4^{2-} an accumulation while it had resulted in anaerobe microorganism activity shown in Fig. 3 (A).

Total nitrogen (TN) was significantly different ($p<0.05$) during composting, which had a lower initial statedue to nitrogen was essential to microbe activity and had a relation to TN, OC, and C/N ratio. Soil and compost treatment helped promote nitrogen releasing to microbe's utilization in 6th days, which almost inorganic nitrogen as NH_4^+ and NO_3^- forms, it would instead be altered slow. Nitrogen could not deliver at all, but that was slow down by mineralization which had greater in moisture 30 to 40%, the temperature at 25 to 30 °C, EC had lower than 1 dS/m and pH as 6 to 7 (Castellanos and Pratt, 1981). The relationship between sulfate, iron, and nitrate could explain by feammox and anammox to active-reduction in alkaline as a resulted co-reaction to compounds precipitation in the optimum stage, pH value at 7.0 to 8.5 that microorganisms had NH_4^+ as EAs and produced N_2 and SO_4^{2-} by-products (Wu *et al.*, 2020; Nie *et al.*, 2021). As a result, TN had not sufficient enough and decreased in the 18th to 20th days. Also, loss of nitrogen by denitrification and other factors such as moisture, pH, and texture mean that nitrogen mineralization is low when it contains high clay particles (Christianson *et al.*, 1979; Chae and Tabatabai, 1986) as shown in Fig. 4 and Table 3.

Total phosphorus (TP) was significantly different ($p<0.05$) during composting (Table 2), due to low in the initial 4th days as demand for microbe's growth (Liddle *et al.*, 2020), then phosphorus tend to increase since 6th day to the end with phosphate (HPO_4^{2-}) forms by released to alternative for balancing HPO_4^{2-} couples. Compost products created chelate on surface area for substrate compounds by chelation reaction such as iron oxides, aluminum oxides and clay particles insoluble HPO_4^{2-} (Dulai, 1977; Bloom, 1981; Tan, 2003), which almost absorb more than 90% on colloids as humus, sesquioxides and microbial biomass in paddy soils (Vityakon, 2004; Jeong *et al.*, 2009). The pH level was promoted HPO_4^{2-} in alkaline at 7 to 9, pH 7, if pH value more nine it would have HPO_4^{2-}, accumulate rich TP as shown in Fig.4 (A)(B) and Table 3.

Total potassium (TK) was significantly different ($p<0.05$) during composting (Table 2). However, it was not significantly different in the initial 2nd to 4th days as potassium was easily leached by the loss of water-soluble nutrients from the soil or moisture content. Potassium could be exchangeable and absorb on oxide compounds such as iron, manganese, and complex humic substances (Tessier *et al.*, 1979; Darmawan and Wada, 1999). Potassium had the highest absorbed on compost product of T2 since the OC quality was more accessible structure to digest than T3, which had OC removal rate at least, and then TK incompost product of T1 and T2 were not significant different. Therefore, compost products influenced potassium changes that were lost by nutrient leaching during composting (Tùma *et al.*, 2011) and created chelate on colloid surface area for substrate compounds by exchangeable potassium that beneficial to microorganism. According to the description, the evolution of total potassium in soil solution could also impact exchangeable K for bal-

Table 2. Accumulate SO_4^{2-}, the nutrients and chemical properties during composting in T3, n=3

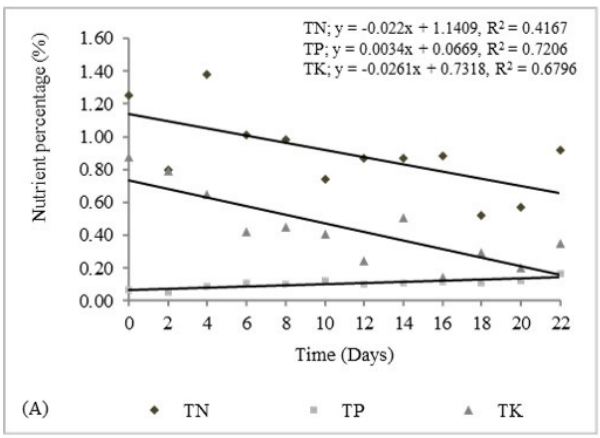
Time (Days)	pH	EC (dS/m)	OC (%)	TN (%)	TP (%)	TK (%)	SO_4^{2-} (mg/kg)
0	6.6^{e}	1.44^{c}	9.67^{a}	1.25^{a}	0.064^{bc}	0.875^{a}	50.39^{bc}
2	5.7^{f}	1.19^{e}	8.60^{ab}	0.80^{bc}	0.051^{c}	0.792^{ab}	52.66^{bc}
4	6.6^{e}	1.79^{b}	7.70^{abc}	1.38^{a}	0.090^{ab}	0.647^{ab}	65.60^{bc}
6	7.3^{d}	1.74^{b}	7.21^{bc}	1.01^{b}	0.106^{a}	0.420^{ab}	85.31^{ab}
8	7.4^{d}	1.76^{b}	5.58^{c}	0.98^{b}	0.099^{a}	0.451^{ab}	20.99^{c}
10	7.4^{d}	1.86^{a}	6.56^{c}	0.74^{cd}	0.120^{a}	0.408^{abc}	25.54^{c}
12	7.9^{c}	1.29^{d}	7.39^{bc}	0.87^{bc}	0.100^{a}	0.246^{c}	75.46^{ab}
14	7.8^{c}	1.01^{ef}	6.71^{bc}	0.87^{bc}	0.110^{a}	0.509^{abc}	43.92^{bc}
16	8.1^{b}	0.99^{f}	7.68^{abc}	0.88^{bc}	0.113^{a}	0.148^{c}	20.13^{c}
18	8.4^{a}	1.07^{ef}	7.43^{bc}	0.52^{e}	0.108^{a}	0.293^{bc}	86.36^{ab}
20	8.3^{ab}	1.06^{ef}	6.81^{bc}	0.57^{de}	0.125^{a}	0.199^{c}	118.42^{a}
F - Test	*	*	*	*	*	*	*
CV (%)	11.20	25.15	14.59	28.68	23.04	52.74	53.14

Remarks: * = Statistical variances at a level of 95% confidence

Table 3 Comparing for the qualities of compost product all of treatment

1/Treatment	pH	EC (dS/m)	OC (%)	C/N ratio	SO_4^{2-} (mg/kg)	TN (%)	TP (%)	TK (%)
T1	7.1[c]	1.84[a]	2.16[c]	10.82[a]	32.34[b]	0.213[b]	0.047[c]	0.783[a]
T2	7.7[b]	1.04[b]	5.16[b]	6.66[b]	162.70[a]	0.780[a]	0.080[b]	0.811[a]
T3	8.2[a]	1.07[b]	7.32[a]	7.97[b]	36.45[b]	0.923[a]	0.164[a]	0.352[b]
F-Test	*	*	*	*	*	*	*	*
CV (%)	7.18	34.44	53.10	25.07	96.04	58.80	62.19	39.67

Remarks:
1/T1: soil; T2: compost productfrom T1 mixed with soil in ratio 1:1; T3: compost productfrom T2 mixed with soil in ratio 1:1,
* = Statistical variances at a level of 95% confidence



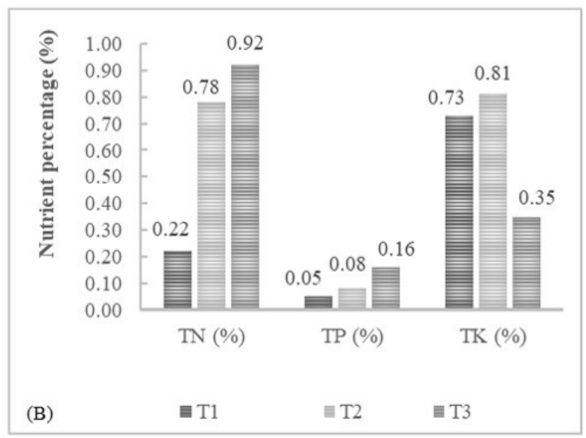


Fig. 4. The nutrient production in compost product (A) nutrients trend in composting process (B) The comparing of compost product nutrients in each treatment

ancing in the nutrient cycle, as shown in Fig. 4 and Table 3.

Conclusion

The nutrient accumulation incompost product from organic waste composting, it can conclude that the nutrients productivity was not significantly different and did not relate to inhibit or promote SO_4^{2-} due to microorganism's activities influenced it. Sulfate Accumulation factors were alkalinity pH, high moisture, low EC, reactant, texture, organic substrates, and electron acceptors such as iron and manganese. These were activated to sulfate accumulation in compost for a long time, and then it was precipitated with colloids by humus formation, which inhibited the acetate form of methanogens. The nutrients have arranged the order by releasing step from Nitrogen Potassium and Phosphorus, respectively. Recirculation compost in the second time, the system had iron cooperation, FeS and H_2S were madebad smell and compost turned to black color. Also, the quality of by-products was in standard and compared the nutrient production witha previous crop. There had higher TN and TP with relationship OC accumulation excepted TK had lower in second crop, so inappropriate condition to potassium leaching that indicated sulfate accumulation did not affect the nutrient contents. Sulfate concentration in the second crop of compost product recirculation was more than first crop approximately 5 times but low N and P. The third crop gained high TP and TN but Low in sufate and TK due to this compost product contained rich of S applied to soils which had the advantages of supplying multi-nutrient fertilizers. SO_4^{2-} was immediately available for plant uptake, and adjusted soil pH help improves harvest and plants' overall health.

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