

Release of Various Elements from Organic Fertilizers Incubated in Organic and Non-organic Paddy Soils at Various Time Periods

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Abstract

Organic fertilizers often contain numerous elements beside nitrogen (N) such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na). In general, the application rates of organic fertilizer are based on N requirement which could result in extra amount of other elements i.e. P and Na which could negatively impact on environment. This study aimed to investigate the release of P, K, Ca, Mg, and Na using a batch technique from three organic fertilizers (e.g. cow manure, compost and sunn hemp) incubated in two paddy soils at various time periods (e.g. 0, 3, 5, 7, 14, 21, 28, 42, 56, 70, 98 and 120 days). A 2×4 factorial in completely randomized experimental design with three replications was employed. A factor A was type of paddy field (an organic paddy field (SO), and non-organic paddy field (SC)) and a factor B was four different organic fertilizers application type (control, cow manure compost and sunn hemp). Soil samples were collected to analyze soil pH, electrical conductivity, available P (Bray II), exchangeable K, Ca, and Mg and extractable Na at the end of each incubation time period. Results showed that the incubation time period did not play a role on the release of P, K, Ca, Mg and Na in soils. Release of P, K, Ca, Mg, and Na in SC was higher than SO. Release of P, K, and Na were highest in cow manure, while compost gave higher release of Ca and Mg. Electrical conductivity did not exceed safety levels with all treatments less than 0.50 mS/cm.

Keywords: organic fertilizer, phosphorus, potassium, calcium, magnesium, sodium
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1. Introduction

Organic fertilizer is sustained source of nutrients due to slow release during decomposition of plant materials and/or animal manures which often contains several elements. Increasing soil organic matter, improving soil fertility, and other essential plant nutrients can improve crop productivity [1]. However, organic fertilizer contains low levels of nitrogen (N) and accumulates some nutrients of essential and non-essential nutrients in soil [2]. The other essential plant nutrients in organic fertilizer are phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) as well as non-essential nutrients such as sodium [3]. Moreover, long-term organic fertilizer applications may result in calcium, magnesium and sodium accumulation in paddy fields [4]. Phosphorus, potassium, calcium and magnesium are essential nutrients for rice growth. Rice acquires these

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nutrients from both chemical and organic fertilizers [5]. In general, the application rates of organic fertilizer for rice plants are based on nitrogen requirements. Therefore, these elements can also accumulate in soils along with organic fertilizers application.

Accumulation of total phosphorus may benefit soils by decreasing the toxicity of aluminum, iron and manganese through phosphorus fixation [6]. However, phosphorus can be easily lost in paddy soil by runoff and transportation into water sources, thereby promoting eutrophication phenomena. High soil organic matter or sandy soil enhances high phosphorus leaching [7]. In addition, available phosphorus is a sensitive element and shows a positive correlation coefficient with soil pH. Phosphorus develops higher availability in submerged soils which are affected by iron reduction [8]. Historically, research has focused on the importance of inorganic phosphorus for plant nutrition. However, organic phosphorus usually accounts for 20-50% of the total phosphorus and mineralization of organic phosphorus to inorganic available forms plays an important role in soil phosphorus storage [9]. Accumulation of potassium, calcium, magnesium, and sodium are not affected by reduction conditions during paddy soil submergence but these sensitive elements determine soil electrical conductivity (EC). Organic fertilizer application increases soluble and exchangeable forms of Ca, Mg, K and Na, with higher release of soluble K and Na than exchangeable K and Na. However, release of exchangeable Ca and Mg is higher than soluble Ca and Mg [10]. Moreover, high accumulation of these nutrients may induce deficiencies of other nutrients such as high soil phosphorus may induce zinc deficiency in paddy soil [11]. In addition, if a plant uptakes potassium, this can induce calcium and magnesium deficiency with an antagonistic effect on the uptake of calcium and magnesium [12].

The release nutrients rate is depending on the component of the organic fertilizer [13]. Release of phosphorus, potassium, calcium, and magnesium is beneficial for rice growth. Continuous applications of organic fertilizer may induce accumulation of these elements while phosphorus and sodium can adversely impact on the environment. Manure applications might induce the risk of phosphorus, potassium and sodium loss to the environment [14].

Applications of organic fertilizers may improve all soil properties but continuous applications of the same organic fertilizer type may induce a negative effect. Accumulation of phosphorus, potassium, calcium, magnesium and sodium in the soil from fertilizer application adversely affects crop growth, the economy and the environment. Therefore, the purpose of this study was to investigate the release of phosphorus, potassium, calcium, magnesium, and sodium from different types of organic fertilizers in two different management paddy soils at various time periods.

2. Materials and Methods

2.1 Soil sampling

Two soil samples were collected from two rice fields as two paddy soils from an organic rice field by applying organic fertilizer more than 10 years (SO) and from a nearby rice field which used only chemical fertilizer (SC) in Nong Chok district, Bangkok. The soils were classified into Bangkok soil series (very-fine, smectitic, nonacid, isohyperthermic Vertic Endoaquepts). Each sample was collected at 0-15 cm depth, air-dried and passed through a 2-mm sieve prior to soil properties analysis.

Soil pH was determined at 1:1 ratio of soil to deionized water. Electrical conductivity (EC) was determined at 1:5 ratio of soil to deionized water. Soil pH and electrical conductivity were measured using a pH meter and an EC meter, respectively [15]. Soil phosphorus solution was extracted using 0.01M calcium chloride (CaCl_2) at 1:5 ratio of soil to solution, shaken for 15 min

and filtered through filter paper No. 42 [16]. Water extractable phosphorus was extricated using deionized water at 1:10 ratio of soil to water and shaken for 1 h [17]. Concentration of water extractable phosphorus was measured using an inductively coupled plasma optical emission spectrometer (ICP-OES). Available phosphorus was extracted using Bray II at 1:10 ratio of soil to solution. Phosphorus concentration was measured using the molybdenum blue method and determined using a spectrophotometer at wavelength 882 nm [18]. Total phosphorus, potassium, calcium and magnesium were digested with nitric acid (HNO_3); perchloric acid (HClO_4) at 2:1 ratio. Concentration of total phosphorus was measured using an ICP-OES [19]. Exchangeable K, Ca, Mg and Na were extracted using 1M ammonium acetate pH 7.0 and measured by an ICP-OES [20].

2.2 Organic fertilizer

Manure, compost and green manure are some of the major sources of N fertilizer for organic rice cultivation in Thailand [21]. In the study, three organic fertilizers were used including cow manure (CM), compost (CP) from a farmer in Nong Chok district, Bangkok, and sunn hemp (SH) from an extension plot at the Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand. Compost was prepared from the decomposition of cow manure and rice straw at a ratio of 1:3 by weight. Each organic fertilizer was ground and passed through a 2-mm sieve prior to analysis. The pH and electrical conductivity were determined at 1:5 ratio of organic fertilizer to deionized water. Concentration of total nitrogen was measured using dry combustion [22]. Total diphosphorus pentoxide (P_2O_5), total potassium oxide (K_2O), total Ca, total Mg and total Na were measured using dry ashing method and filtered through filter paper No. 5. Water extractable of P, K, Ca, Mg and Na were extracted using deionized water at 1:10 ratio of soil to solution. Each sample was shaken for 1 h and filtered through filter paper No.5 [17]. Concentrations of total and water extractable elements were measured using an ICP-OES.

2.3 Experimental design and incubation study

Batch incubation experiments were conducted in an incubator with a 2×4 factorial completely in randomized design with three replications. Factor A was two paddy soils from an organic rice field (SO) and a nearby rice field which used only chemical fertilizer (SC). Factor B was four different organic fertilizers consisting of control, cow manure, compost, and sunn hemp. The organic fertilizers were applied at the rate of 300 mg N/kg (based on total N in organic fertilizers) [14]. Soil with and without fertilizer was flooded with 200 ml of deionized water and incubated at 30°C for 120 days according to the rice growth cultivation. Other nutrient contents of organic fertilizers applied to meet nitrogen at the rate of 300 mg N/kg were shown in Table 1.

The release nutrients were released at the earliest stage of incubation [13]. Samples were collected at 0, 3, 5, 7, 14, 21, 28, 42, 56, 70, 98, and 120 days after incubation for analysis of soil pH, electrical conductivity, available P (Bray II), exchangeable K, Ca, Mg and Na extracted using 1M ammonium acetate pH 7.0 and measured by an ICP-OES [20].

2.4 Statistical analyses

All data were analyzed by analysis of variance (ANOVA) using a statistical software package. Mean comparison was analyzed using Duncan's multiple range test (DMRT) at a significant level of 95%.

Table 1. Nutrient content of organic fertilizers applied to meet nitrogen at the rate of 300 mg N/kg.

Organic fertilizer	Cow manure	Compost	Sunn hemp
Total nitrogen (mg/kg)	300.00	300.00	300.00
Total phosphorus (mg/kg)	480.24	230.68	252.48
Total potassium (mg/kg)	2,839.00	464.98	1,589.00
Total calcium (mg/kg)	2,346.00	709.00	753.00
Total magnesium (mg/kg)	481.95	303.76	517.65
Total sodium (mg/kg)	197.64	73.15	259.96

3. Results and Discussion

3.1 Soil and organic fertilizer properties before incubation

Physical and chemical properties of SO and SC were analysed as shown in Table 2. Both soils were clayey with an acidic reaction and soil pH at 6.10 and 5.30 for SC and SO, respectively (Table 2). Electrical conductivity (EC) of both soils did not exceed the safety level for rice growth (<2 mS/cm), while available phosphorus and exchangeable potassium, calcium and magnesium contents were high and adequate for rice growth. Exchangeable sodium of SC was higher than SO; however, organic matter and total nitrogen contents of both soils were not significantly different.

Organic fertilizer properties were presented in Table 3. The pH values of the three organic fertilizers as cow manure, compost, and sunn hemp were moderately alkaline (8.2), slightly acid (6.3) and strongly acidic (5.1), respectively. Electrical conductivities (EC) of cow manure and sunn hemp were higher than the regulations of the Department of Agriculture of Thailand (<3.5 mS/cm) [23]. Water soluble P, Ca, Mg and Na were highest in sunn hemp, while water soluble K was highest in cow manure.

3.2 Change in soil pH and electrical conductivity (EC)

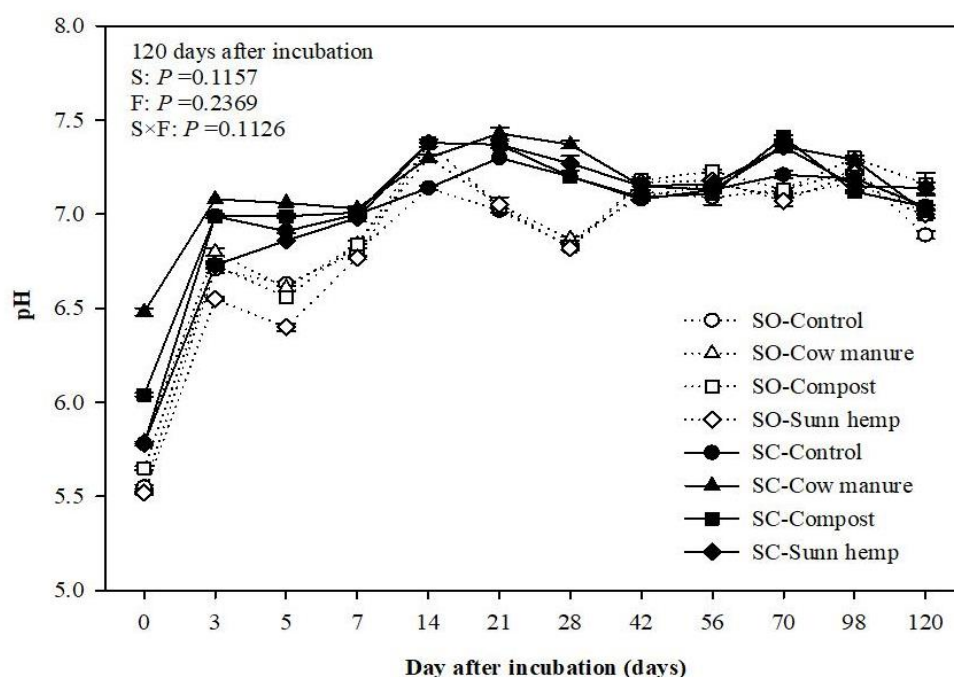
Results showed that the pH of each soil at initial was significantly different (Figure 1). The initial soil pH of both soils was acidic, with SC higher than SO. The two amended soils with cow manure had the highest pH followed by soils amended with compost. The pH of SO amended with cow manure at 0 day highest with 5.79 value, followed by SO with compost and sunn hemp at 5.65 and 5.52, respectively. The pH of SC amended with cow manure at 0 day was highest with 6.48, followed by SC with compost and sunn hemp at 6.04 and 5.78, respectively. Soil pH of all treatments increased rapidly to neutral within 3 days of incubation, with a slightly increase from 3-14 days after incubation and then became steady at neutral pH after 14 days of incubation. Soil pH of all treatments at 120 days after incubation showed no significant difference. This indicated that soil and organic fertilizer types did not affect soil pH changes under submergence. Soil pH of amended soil with organic fertilizer become neutral after 14 days as influenced by the reduction reaction [24]. It might be noticeable that the soil pH increased rapidly at the initial of flooding resulted by high organic carbon in soil and organic fertilizer [25].

Table 2. Soil properties before incubation.

Soil properties	Organic paddy field (SO)	Non-organic paddy field (SC)
pH (1:1 soil: water)	5.30	6.10
Electrical conductivity (1:5 soil: water) (mS/cm)	0.23	0.40
Soil texture	Clay	Clay
Sand (g/kg)	259.60	299.60
Silt (g/kg)	247.20	227.20
Clay (g/kg)	493.20	473.20
Organic matter (g/kg)	45.60	45.50
Total carbon (g/kg)	26.45	26.38
Total nitrogen (g/kg)	2.51	2.25
Total phosphorus (g/kg)	0.18	0.26
Total potassium (g/kg)	7.98	6.88
Total calcium (g/kg)	2.57	3.05
Total magnesium (g/kg)	3.83	3.08
Available phosphorus Bray II (mg/kg)	35.47	63.85
Available phosphorus Olsen (mg/kg)	8.96	15.43
Water extractable phosphorus (mg/kg)	0.28	0.24
Soil solution phosphorus (CaCl ₂ -P) (mg/kg)	0.68	0.71
Exchangeable potassium (mg/kg)	251.53	130.65
Exchangeable calcium (mg/kg)	2,343	1,838
Exchangeable magnesium (mg/kg)	661.99	226.32
Extractable sodium (mg/kg)	37.14	89.99
C/N ratio	10.54	11.71
Cation exchange capacity (cmol(+)/kg)	26.85	30.33

Table 3. Chemical properties of three organic fertilizer used in this study.

Organic fertilizer properties	Cow manure	Compost	Sunn hemp
pH (1:5 organic fertilizer: water)	8.20	6.30	5.10
Electrical Conductivity (1:5 organic fertilizer: water) (mS/cm)	10.48	2.94	10.23
Total nitrogen (g/kg)	7.80	19.40	23.20
Total P ₂ O ₅ (g/kg)	11.00	5.28	5.78
Total K ₂ O (g/kg)	65.02	10.65	36.40
Total calcium (g/kg)	23.46	7.09	7.53
Total magnesium (g/kg)	4.82	3.04	5.18
Total sodium (g/kg)	1.98	0.73	2.60
Water soluble phosphorus (mg/kg)	32.61	13.80	77.57
Water soluble potassium (mg/kg)	2,139.00	345.17	1,491.00
Water soluble calcium (mg/kg)	35.64	121.05	200.63
Water soluble magnesium (mg/kg)	17.92	126.50	325.92
Water soluble sodium (mg/kg)	305.40	65.56	361.92
C:N ratio	15.76	13.44	18.66

**Figure 1.** Changes of soil pH during incubation. S = Soil, F = Fertilizer, Error bar = Standard error of mean (SE), P -value = Significant at 0.01 and 0.05 level.

Soil electrical conductivity was highest at 3 days after incubation before decreasing dramatically and reaching steady state after 5 days of incubation, with a gradual decrease until the end of incubation (Figure 2). Results showed that EC of all treatments significantly differed during the incubation period. The electrical conductivity of SC amended with cow manure at 120 days was highest at 0.37 mS/cm, followed by SC with compost and sunn hemp at 0.24 and 0.22 mS/cm, respectively. The electrical conductivity of SC soil was higher than SO, while the application of cow manure significantly increased EC to higher than other organic manure. Meanwhile, the application of sunn hemp showed no significant difference with the control (Figure 2), possibly due to the high EC of cow manure to meet nitrogen rate which induced high quantities of cations. Electrical conductivity in all treatments did not exceed the safety level at the end of incubation (less than 0.50 mS/cm) [26].

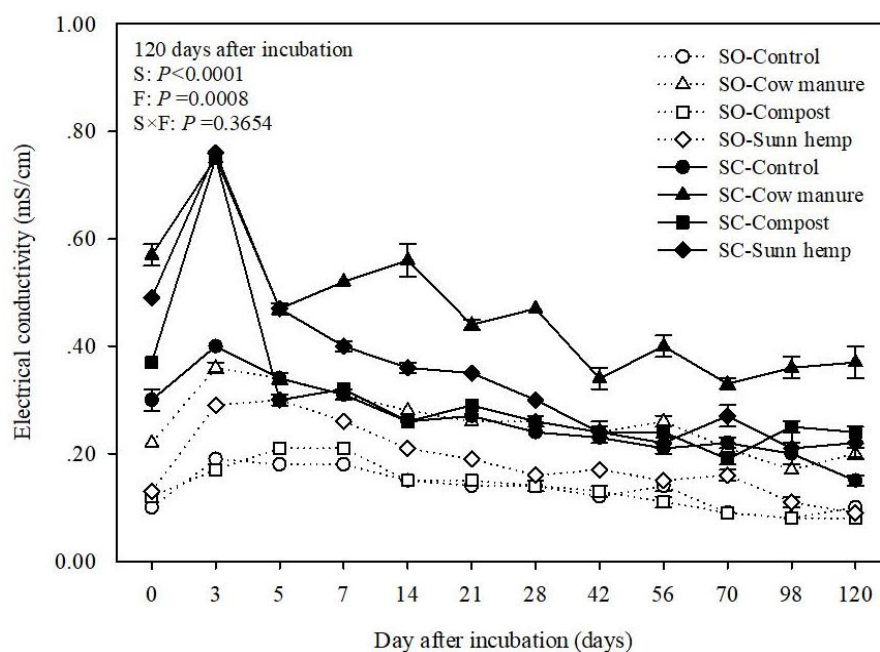


Figure 2. Changes of electrical conductivity (EC) during incubation. S = Soil, F = Fertilizer, Error bar = Standard error of mean (SE), *P*-value = Significant at 0.01 and 0.05 level.

3.3 Release of phosphorus

A release of phosphorus from organic fertilizers was calculated from the difference of available phosphorus (Bray II) in control and soil amended with the three organic fertilizers. Results showed that phosphorus release after incubation was higher for SC than SO. The SC with cow manure at 0 day released the highest phosphorus (14.12%), followed by SC with cow manure at 120 days (12.35%) (Figure 3). After incubation at 120 days, each soil and organic fertilizer type was significantly different (Figure 3). The amount of phosphorus in solution and available P was analysed. In both paddy soils, the highest amount of phosphorus in solution was found at the 120 days of incubation period amended with cow manure (0.28 and 0.34 mg/l in SO and SC,

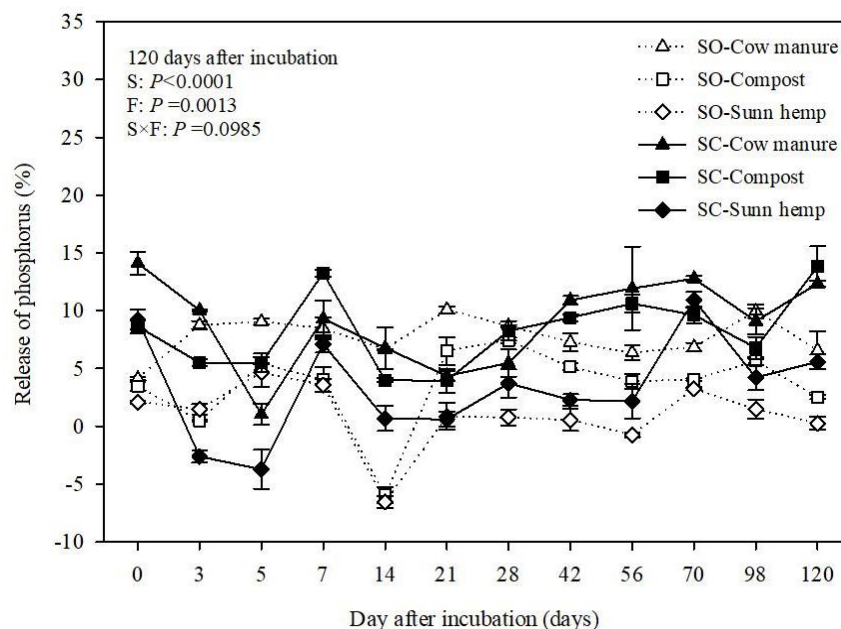


Figure 3. Changes of phosphorus release during incubation. S = Soil, F = Fertilizer, Error bar = Standard error of mean (SE), P -value = Significant at 0.01 and 0.05 level.

respectively, data not shown). Phosphorus in solution of both soils with cow manure was higher than the Department of Pollution Control of Thailand regulations (< 0.04 mg/L) [27]. Meanwhile, available phosphorus (Bray II) at 120 days after incubation of both soils amended with cow manure had the highest contents at 120.09 and 229.14 mg/kg for SO and SC, respectively. Available phosphorus of both soils amended with cow manure was higher than the critical value of phosphorus leaching risk at 43.85 mg/kg [7]. It might be due to high amount of the total phosphorus in cow manure (Table 2). These results showed that the total phosphorus amount is an important role in the release of phosphorus in submerged soil. This indicated that the amount of P release from paddy soils amended with cow manure could be potentially risk to the environment [28].

3.4 Release of potassium, calcium and magnesium

A release of potassium, calcium, and sodium from organic fertilizers was calculated from the difference of exchangeable potassium, calcium and magnesium in control and soil amended with the three organic fertilizers. Both soils amended with cow manure released the highest extractable potassium at 17.49 and 28.18% in SO and SC, respectively (Figure 4). Release of extractable Ca was 26.54% and 33.80% in SO amended with sunn hemp and SC amended with compost, respectively (Figure 5) while release of Mg in SO was slightly higher than SC, with little difference between the three organic fertilizers at 12.88-13.13% (Figure 6).

At the end of the incubation period, soil and organic fertilizer type strongly affected the release of K, while soil type influenced Ca and Mg release more than organic fertilizer, possibly due to high K content of cow manure. However, the repeating large amounts of manure build up increased high amounts of exchangeable Ca and Mg and decreased exchangeable K in soil [3].

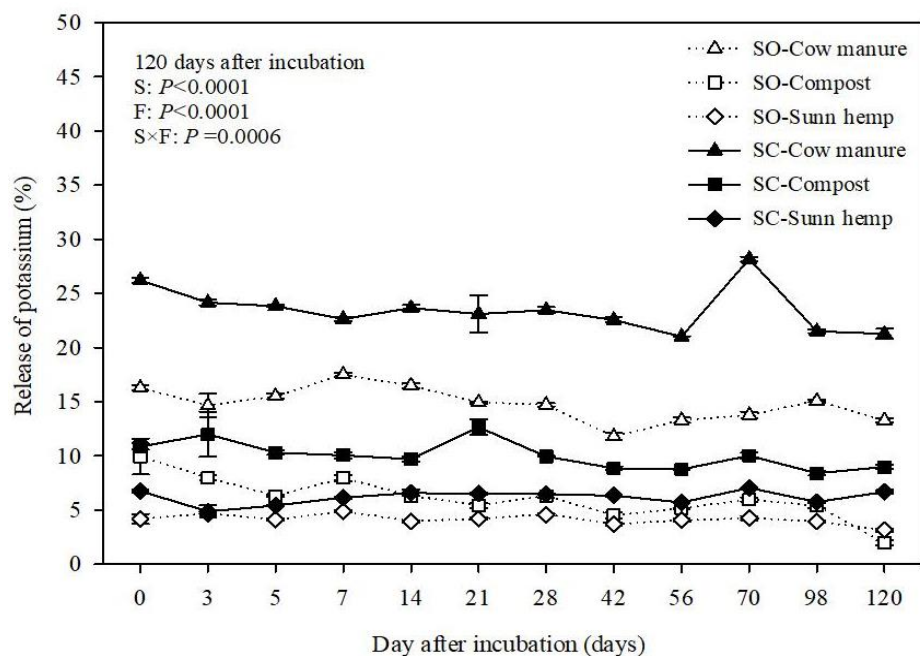


Figure 4. Changes of potassium release during incubation. S = Soil, F = Fertilizer, Error bar = Standard error of mean (SE), P -value = Significant at 0.01 and 0.05 level.

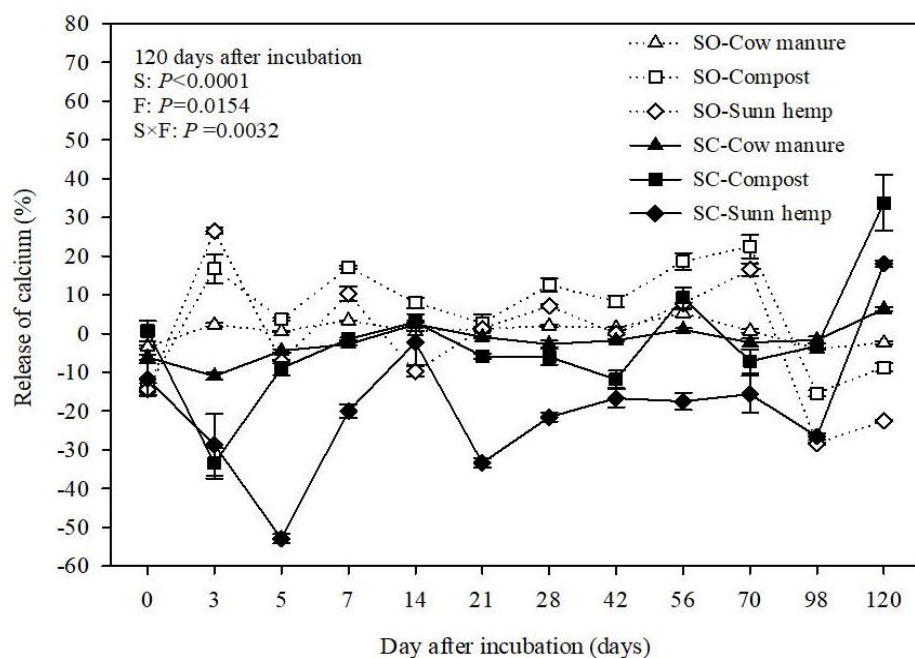


Figure 5. Changes of calcium release during incubation. S = Soil, F = Fertilizer, Error bar = Standard error of mean (SE), P -value = Significant at 0.01 and 0.05 level.

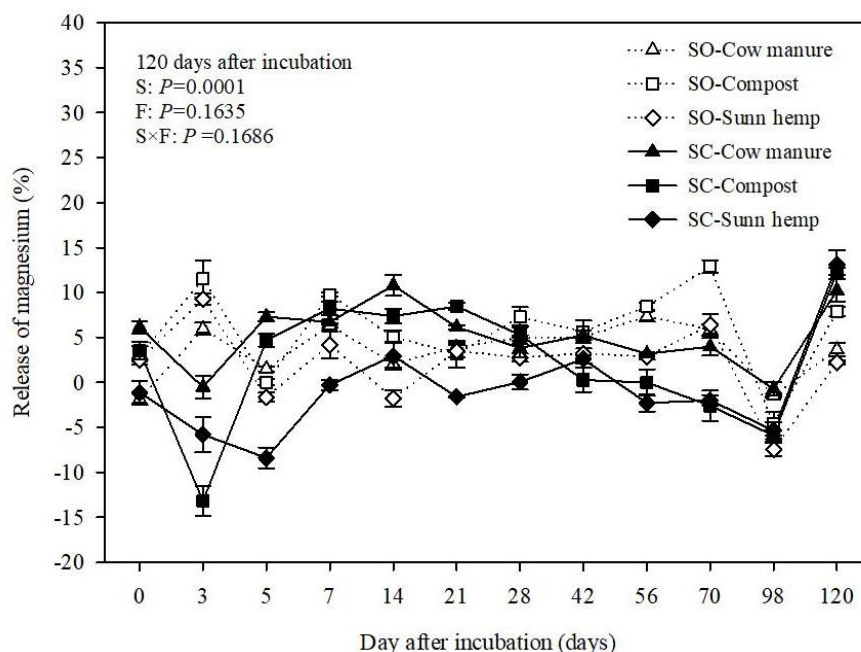


Figure 6. Changes of magnesium release during incubation. S = Soil, F = Fertilizer, Error bar = Standard error of mean (SE), P -value = Significant at 0.01 and 0.05 level.

3.5 Release of sodium

A release of sodium from organic fertilizers was calculated from the difference of extractable sodium in control and soil amended with the three organic fertilizers. Results indicated that sodium release after incubation of both soils showed no significant difference. The SO amended with cow manure released the highest sodium at 31.12%, 70 days while the SC amended with cow manure had the highest sodium at 42.19% at 0 day (Figure 7). After incubation at 120 days, sodium release of each soil and organic fertilizers type was significantly different. Sodium is not an essential nutrient for rice growth. Soil exchangeable Na increases when a large amount of manure is applied [3]. Sodium in solution at 120 days after incubation for both soils amended with cow manure was highest at 27.17 and 137.03 mg/l in SO and SC, respectively (data not shown). Meanwhile, exchangeable sodium at 120 days after incubation of both soils amended with cow manure was highest at 146.50 and 189.81 mg/kg for SO and SC, respectively.

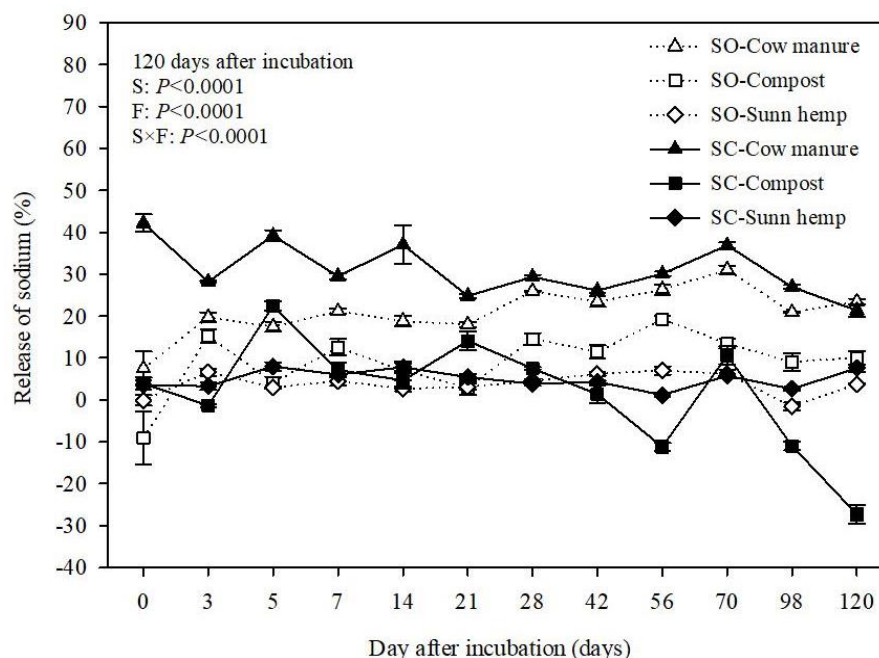


Figure 7. Changes of sodium release during incubation. S = Soil, F = Fertilizer, Error bar = Standard error of mean (SE), P -value = Significant at 0.01 and 0.05 level.

4. Conclusions

This study showed that the incubation-period did not play a role on the release of phosphorus, potassium, calcium, magnesium, and sodium in soil. Release of phosphorus, potassium, calcium, magnesium and sodium in non-organic paddy soil was higher than organic paddy soil. It was found that the release of phosphorus, potassium, and sodium was higher in both soils amended with cow manure. Phosphorus in solution of both soils with cow manure was higher than the Department of Pollution Control of Thailand regulations (< 0.04 mg/L). The available phosphorus (Bray II) was also higher than the critical value of phosphorus leaching risk at 43.85 mg/kg. The release of calcium and magnesium was higher in both soils amended with compost and sunn hemp. Electrical conductivity in all treatments did not exceed the safety level at less than 0.50 mS/cm. Soil and organic fertilizer types are important factors which have an effect on the release of phosphorus and sodium.

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