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Nitrogen, phosphorous, and potassium uptakes of organically grown sweet corn on coastal Entisols

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Abstract Results indicated that nutrient uptakes by organically grown sweet corn in coastal land of Entisols were very low; 0.44 to 0.67 g plant^{-1} for N, 0.35 to 0.61 g plant^{-1} for P, and 0.41 to 0.63 g plant^{-1} for K. In addition, nutrient tissue contents were also very low; 1.35 to 1.75 % for N, 1.18 to 1.58 % for P, and 1.29 to 1.68 % for K. It is concluded that after a one year of establishing organically growing environment on coastal Entisols, the use of LOF increased N and K tissue contents, but did not increase N, P and K uptakes, as well as P tissue content of sweet corn. For production purposes of sweet corn in coastal Entisols, it is imperative to pay attention to the amount of nutrient supply into the soil to assure sufficient nutrient availability for the plants.

Keywords: Liquid organic fertilizer; Nutrient uptakes; Organic sweet corn; Entisol; Coastal land

Introduction

Organic vegetable productions, including sweet corn, in coastal areas of Indonesia, are becoming significant interests of many parties due to declining arable land in highland production areas as well as increasing demand for organic vegetables (Golijan and Dimitrijevic, 2018; Halaye, 2019). Coastal agriculture lands in Indonesia are dominated by Entisols, characterized by the domination of coastal sands, coarse textures, easily cultivated and low water holding capacity, and excellent water permeability (Gunadi, 2002). Vegetable productions in Indonesian coastal areas have been increasingly practiced in many parts of the country, such as the production of shallots in northern coastal of Java (Hidayat, 2018), chili pepper in the coastal area of Bengkulu (Ganefianti and Fahrurrozi, 2018) as well as dragon fruits, shallots, and leafy vegetables in coastal regions of Yogyakarta Province (Ma'ruf, 2018).

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The use of liquid organic fertilizer (LOF) to compensate for the slow-released behavior of solid organic fertilizer availability for organic sweet corn (*Zea mays* L. var. Saccharata) production was reported to successfully serve as a complementary nutrient supply of solid organic fertilizing (Muktamar *et al.*, 2017). The effectiveness of tithonia-based LOF as supplementary nutrients for organically sweet corn production in highland areas was as effective as conventional production systems (Fahrurrozi *et al.*, 2016; Muktamar *et al.*, 2017). Efforts to extend the growing areas for organic sweet corn from high altitude areas to coastal areas require comprehensive understandings of how organic fertilizing interacts with coastal lands, including Entisols. Such soil in coastal land poses different biological, physical, and chemical properties from soils in highland areas. According to Stuart (2010), both location-specific and land uses pronouncedly impacted coastal ecosystems. Also, Awal (2014), agricultural practices in coastal areas are unstable since this ecosystem is frequently exposed to salinity changes, tidal processes, water stresses, and waterlogging.

Successful production of organic sweet corn on Entisols requires a consistent supply of nutrients, including the macronutrients of nitrogen (N), phosphor (P) and potassium (K), to ensure excellent growth and yields. Failure to maintain a sufficient supply of N, P, and K in organic production systems brings about a significant reduction in sweet corn growth and yields. However, to ensure excellent crop growth and yields, nutrient uptakes by a crop are likely more important to be disclosed than nutrient availability within the rhizosphere. Although there are growing interests in conducting vegetable production along the coastal areas in Indonesia, organic sweet corn production on the coastal land is limitedly practiced (Maroeto and Sasongko, 2004). The success of organic sweet corn production on Entisols requires a better understanding of nutrient dynamics in the rhizosphere since sweet corn consumes more nutrients than other vegetable crops. Plant-soil relationships could be reflected by the amount of nutrient uptakes by sweet corns, including N, P, and K since this figure determines further growth and yields of sweet corn. Nutrient uptakes reflect the amount of particular nutrients absorbed in a certain amount of plant dry weight (Havlin *et al.,* 2013). In addition, nutrient uptake efficiency described the ratio between nutrient uptakes and the amount of available soil nutrients. Turner and Hummel (1992) concluded that N, P, and K's nutrient uptake efficiency were 40-60%, 15-20%, and 40-60%, respectively.

Nutrient uptakes by organically grown sweet corn in highland areas of Indonesia's tropical ecosystems have been extensively studied. Fi'liyah *et al.* (2016) evaluated the effect of the nutrient amendment on soil nutrient contents and nutrient uptakes by corn on Inceptisols in the highland of Bogor, West

Java. Sofyan and Sara (2018) determined N, P, K uptakes of sweet corn on Inceptisols at 625 m above sea level grown under organic and conventional production systems. Other studies on nutrient uptakes (N, P, K) of organically grown sweet corn on Andisols in highland areas were conducted by Muktamar *et al*. (2016; 2017b) and Fahrurrozi *et al.* (2018; 2019a). In the medium highland of Bangladesh, Islam and Nahar (2012) evaluated nutrient uptakes (P, K, Ca, Mg, and Zn) by tubers and stems of organically grown potatoes on Sonatola soil. In a lower altitude of Indonesia (150 m above sea level), nutrient uptakes (N, P, K) under organic production systems of lemongrass on Ultisols were studied by Trisilawati *et al.* (2017). Although vegetable productions in coastal areas of Indonesia have been increasingly practiced, nutrient uptakes of organically grown sweet corn on coastal Entisols have not been well documented yet. This experiment aimed to determine the effects of LOF applications on NPK uptakes of organically sweet corn production in the Entisols of coastal areas.

Materials and methods

The field experiment was conducted on Entisols of coastal land from August to November 2019 at Kelurahan Beringin Raya, the City of Bengkulu at an elevation of 5 m above sea level (3°, 45’, 26.40” South Latitude and 102°, 15’, 41.78’’ East Longitude). This site, previously used for semi-organic vegetable production for two years, was cleaned, shallow plowed, harrowed, and applied with 10 ton ha^{-1} of vermicompost afterward. Soil-beds of 1.5 m × 4.0 m were established, and each of the beds was separated by 1 m within the block, and each block was separated by 1.5 m away. In each plot, sweet corn (a hybrid organic cultivar of CAPS5×6) was planted at 0.25 m × 0.75 m to make 30 plants per plot. Three weeks after planting, an additional 5 ton ha^{-1} of vermicompost was uniformly applied to the plants in the experimental site. This vermicompost contained 255.6 g kg^{-1} of organic-C, 21.5 g kg^{-1} of total nitrogen, 2.4 g kg^{-1} of phosphorous, and 5.5 g kg^{-1} of potassium (Muktamar *et al.*, 2017b). The experiment was arranged in a randomized complete block design with three replicates. Treatments were tithonia-based liquid organic fertilizer (LOF) concentrations consisted; (1) without LOF (control), (2) 25% LOF, (3) 50% LOF, (4) 75% LOF, and (5) 100% LOF.

Production of LOF followed the method suggested by Fahrurrozi *et al.* (2017) by aerobically incubating cattle's feces, cattle's urine, topsoil, green mass of *Tithonia diversifolia*, solution of effective microorganism with the weight ratio of 2:4:1:2:4, respectively. Incubation was conducted in a blue plastic container to reach a volume of 200 L for five weeks. A 100 ppm of zinc

(Zn) solution was also added for the production of LOF. Lab analysis indicated that this LOF contained 0.37 % N, 0.18 % P, 0.87 % K, 0.72% organic-C, and 7.3 in pH.

Each sweet corn plant was uniformly sprayed, and the rest of the LOF was applied around the planting holes (Fahrurrozi *et al*., 2019b). The applications of LOF treatments were conducted at 14, 21, 28, 35, and 42 days after planting with a volume of 50, 100, 200, 300, and 350 ml for each plant. Sweet corns were watered every day since very few precipitations occurred during the experiment. Weed removals were conducted at 25 and 45 days after planting. Pest controls were achieved by using bio-pesticide Pestona® and bio-fungicide Glio ®.

Before vermicompost application, soil samples were compositely taken at 0-20 cm depth to determine pH, N-total, organic-C, available P, exchangeable K, and cation exchange capacity (CEC). Soil pH was measured using pH meter at 1:1 ratio of soil and distilled water. Oragnic-C was analyzed using Walkey and Black Method, available using Bray I Method, exchangeable K using extraction with 1N NH_4-acetate before determination using flame photomteter, and CEC using method as recommended by Balai Penelitian Tanah (2009). Leaf samples for nutrient tissue contents were taken from the third or fourth leaf of the uppermost fully developed leaves at 45 days after planting. All samples were sent to the Soil Analysis Laboratory of the Faculty of the Agriculture University of Bengkulu. Determination of plant nitrogen, phosphorous and potassium contents (%) was conducted using the wet destructive method (Yoshida *et al.,* 1976, Balai Penelitian Tanah, 2009). Nutrient uptakes by sweet corn were calculated as recommended by Muktamar *et al.* (2016) with the formula: nutrient uptake = PPC/100SDW, where PPC is plant nutrient (N, P, or K) content (%) and SDW is shoot dry weight per plant (g).

Effect of LOF applications on N, P, K contents in plant tissue and N, P, K uptakes by sweet corn were determined using SAS ($P \geq 0.05$). Trends of treatment responses were evaluated by using Polynomial orthogonal analysis (Gomez and Gomez, 1984).

Results

Environmental conditions

Laboratory analysis of soil samples revealed that soil of the experimental site was characterized by pH of 6.8 (neutral), N-total of 0.24% (medium), organic-C of 1.32% (low), available P of 3.31 mg kg^{-1} (very low), exchangeable K of 0.37 me $100g^{-1}$ (medium), and cation exchange capacity 14.28 me $100g^{-1}$ (low) (Sihotang, 2019). During the growing season, the experimental site received a very small rainfall, which presumably served as the primary stressor for sweet corn growth as the soil was highly permeable. However, air temperatures, air relative humidity, and solar radiation are within the acceptable ranges to support sweet corn growth and development. It was recorded that the averages monthly rainfall from August to November were low, *i.e.*, 7.8 mm, 58 mm, 42.2 mm, and 61.3 mm. Although the sweet corns were planted in the fourth week of August, headed to higher rainfall in the following months, the amount of rainfall was not likely enough to support sweet corn on growth and development. According to Davis (2019), organic sweet corn production requires a continuous moisture supply to ensure successful pollination and kernels' growth. For example, after the tasseling stage, sweet corn requires 25.4 to 38.1 mm of water each week (or 101.2 to 152.4 mm per month). Although sweet corns were watered every other day during the experiment, this irrigation might not be long-lasted in the soil beds since the Entisols is very permeable to water. The average minimum, maximum, and daily temperatures, relative humidity, rainfall, and solar radiation from August to November 2019 are presented in Table 1.

Table 1. Daily temperatures, relative humidity, solar radiation, and monthly rainfall of the experimental site from August to November 2019

Month (2019)	Daily					Monthly rainfall (mm)
	Air temperatures (^{o}C)			Relative humidity (%)	Solar radiation (hours)	
	Minimum	Maximum	Average			
August	23.32	30.82	26.10	82.19	7.44	7.8
September	23.40	30.97	26.19	83.33	7.93	58
October	23.84	30.28	26.12	86.13	6.17	42.2
November	24.20	31.82	26.92	83.87	7.58	61.3

Source: Meteorology, Climatology, and Geophysical Agency/BMKG, Stasiun Klimatologi Bengkulu (ID WMO: 96255)

Sweet corn nutrient contents and uptakes

The use of liquid organic fertilizer (LOF) significantly increased N tissue contents (P≥F=0.0400) and K tissue contents (P≥F=0.0001), but not P tissue contents (P≥F=0.3700) of organically grown sweet corn. Unlike sweet corn nutrient contents, LOF application insignificantly affects N uptakes (P≥F=0.2300), P uptakes (P≥F=0.1500), and K uptakes (P≥F=0.1500) of organically grown sweet corn. Effects of LOF application sweet corn nutrient contents are presented in (Table 2).

Table 2. Effects of LOF concentration on sweet corn nutrient contents and uptakes

LOF concentration (%)	**Nutrient tissue content (%)***			**Nutrient uptakes (g plant^{-1})**		
	N	P	K	N	P	K
0	1.07 b	1.18	1.17 d	0.38	0.41	0.42
25	1.35 ab	1.32	1.29 c	0.44	0.42	0.41
50	1.59 a	1.18	1.44 b	0.48	0.35	0.43
75	1.61 a	1.34	1.68 a	0.47	0.39	0.48
100	1.75 a	1.58	1.63 a	0.67	0.61	0.63

* Means in the same column followed with the same letter are not significantly different according to Duncan's Multiple Range Test at 5%

The response of N organically grown sweet corns on Entisols nutrient contents to LOF concentration was linearly significant ($P \geq F=0.00001$; $y=0.00065x+1.153$; $R^2=0.5313$-Figure 1-left). Meanwhile, Response of N uptakes by sweet corn to LOF concentration was linearly significant ($P \geq F=0.0001$; $y=0.0024x+0.3705$; $R^2=0.3405$-Figure 1-right). The response of P sweet corn nutrient contents to LOF application was linearly significant ($P \geq F=0.0001$; $y=0.00033x+1.16$; $R^2=0.2225$-Figure 2-left), and P uptakes to LOF application was linearly significant ($P \geq F=0.0001$; $y = 0.0014x + 0.37$; $R^2 = 0.1656$; Figure 2-right). Lastly, response of K tissue content to LOF application was linearly significant ($P \geq F=0.00001$, $y=0.00053x^2+1.182$ and $R^2=0.7465$ (Figure 3-left), while response of K uptakes to LOF application was linearly significant ($P \geq F=0.000001$, $y=0.0019x+0.3833$, and $R^2=0.363$ (Figure 3-right)

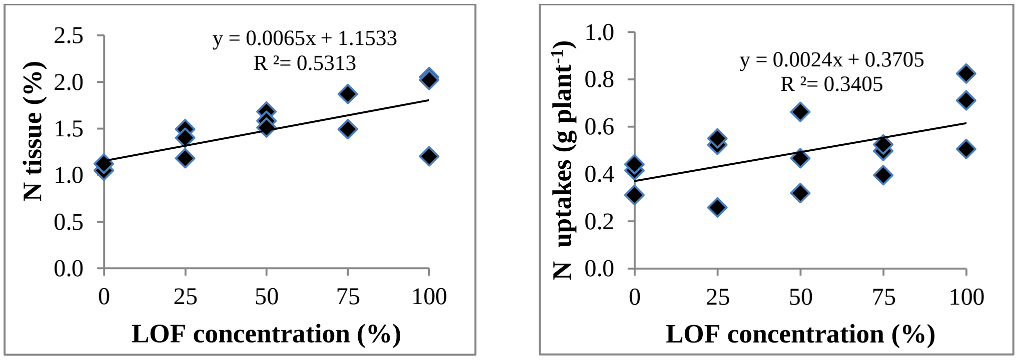

Figure 1. Relationship between LOF concentration and N tissue contents (left) and N uptakes (right)

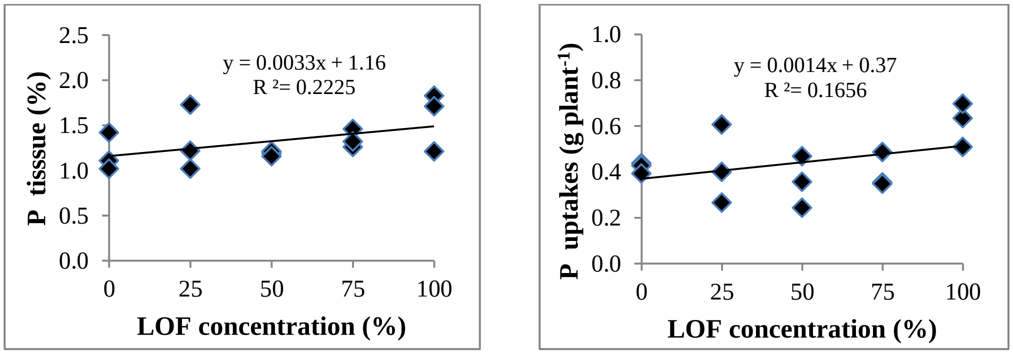

Figure 2. Relationship between LOF concentration and P tissue contents (left) and P uptakes (right)

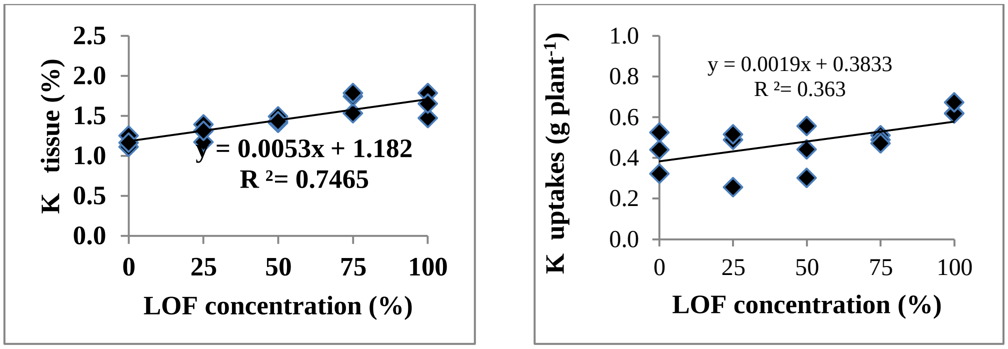

Figure 3. Relationship between LOF concentration and K tissue contents (left) and K uptakes (right)

Discussion

Like in any other crop, the nitrogen (N) concentration in sweet corn plant tissues determines plant growth and yield performances. When its amount goes below the critical range, it is considered deficient. If nitrogen concentrations in plant tissue increase and are able to support crop performance, they are deemed sufficient. However, at a certain point, beyond the sufficiency range, excessive nutrient concentrations can limit plant performance, which is considered the excessive or toxic range. This experiment indicated that the use of LOF significantly increased N tissue contents (P≥F=0.0400) (Table 1). The average increase in N tissue content in sweet corn was more than 47 % those of not fertilized with LOF. Such an increase might have attributed to additional N supply through LOF fertilizing, which later increased N absorption by sweet corn. Lab analysis indicated that LOF contained 0.37 % N. In addition, nitrogen from the soil (0.24%) and the vermicompost (2.15%) might have also contributed to such increased. Increased N content in plant tissues might be related to the stage of sweet corn growth and development. The response of N sweet corn nutrient contents to LOF concentration was linearly significant (y=0.00065x+1.153; R^2=0.5313-Figure 1-left), implying that 53.13% increasing N tissue content in sweet corn was attributed to LOF contribution. During the vegetative growth, sweet corn absorbs a large amount of N from the soil to support its early growth, and leaves serve as the major sink for N derived from fertilizing. According to Davis (2019), nitrogen deficiency during the early growth of sweet corn brought about the plant to get pale with spindly stalks and yellow leaf tips.

This experiment also revealed that N tissue content of organically sweet corn grown on the coastal area of Entisols was lower than N tissue content of organically sweet corn grown on the highland of sandy loam soil, the suborder of Andept (Muktamar *et al.,* 2016), and Ultisol (Pangaribuan *et al.,* 2019). It appeared that N stability in Entisols was pretty low since the Entisols have a coarse texture and low soil organic matter, leading to high water permeability and low water holding capacity. Soil organic matter mineralization is highly dependent on the moisture content of the soil, in which low moisture content restricts microbial activities (Salam, 2014). The inhibition brings about low organic matter mineralization (Tulina *et al.*, 2009; Curtin *et al.*, 2012; Wang *et al*., 2016), depressing the release of plant nutrients to the soil. Besides, watering the plants to compensate for the low rainfall during the early growth of sweet corn, N might have leached and eventually declined N availability in the soil. Volatilization of N might also be responsible for reducing the soil available N. Light-textured soil fertilized with farmyard manure had a significant amount of nitrous oxide emission (Buchkina *et al*., 2010). Harrison-Kirk *et al.* (2013) confirmed that the application of soil organic matter to soil emitted higher nitrous oxide even though continuously low content of soil water had lower emission. Higher soil temperature also accelerates N flux (Smith *et al*., 1998) as indicated by air temperature during the experiment, reaching a maximum of almost 32 ^{o}C.

Surprisingly, significant increased N tissue content was not followed by an increase of N uptakes by sweet corn. This result might have related to declining N availability in the soil (presumably due to leaching as previously discussed) and water-deficit stress experienced by sweet corns. According to Gastal and Lemaire (2002), soil mineral N availability and distribution, and on root distribution determined the magnitude of N uptakes by a crop grown under sub-optimal N supply. Reversely, under sufficient N supply, N uptakes largely depend on growth rate via internal plant regulations. The response of N uptakes by sweet corn to LOF concentration was linearly significant (y=0.0024x+0.3705; R^2=0.3405-Figure 1-right), which reflected that contribution of LOF brought about increased N uptakes was only 34.05%. It appeared that plants needed more N available in the soil to be absorbed. This experimental site was the first year experienced organic farming practices that might have contributed to such low N uptakes. A high supply of organic C from vermicompost (25.55%) was insufficient to hold N in the rhizosphere and to support N from LOF application in increasing N uptakes by sweet corn. It seemed that the availability of N in organic farming systems is not quickly established in the coastal soil environment. Diaz *et al.* (2012) concluded that the nitrogen supply applied in the first year was only detected in the second year, not in the third year after application. It is, therefore, certain years are required to establish an organically growing environment. According to the Indonesian National Standard (2016), it requires at least two consecutive years before the first planting to convert non-organic soil into organic production areas for short growing season crops.

The phosphorous (P) macronutrient plays a significant role in many plant metabolisms. A recent study conducted by Fahrurrozi *et al*. (2019a) concluded that P uptakes by sweet corn significantly increased leaf P content, shoot dry weight per plot weight of husked ear, the weight of unhusked ear and yield per plot as well as decreased days to the harvesting of sweet corn grown on Andisols in a highland organic environment. However, results from the coastal land of Entisols indicated that the application of LOF did not significantly increase P tissue contents of sweet corn. Nevertheless, P content in sweet corn was an average of 14.8 % higher than those not fertilized with LOF (Table 1). Insignificant effect of treatments to P tissue content in sweet corn might have attributed to low P exposed to sweet corns absorption systems in the soil since P content in LOF was considered low (0.18 %), soil P content was very low (3,31 mg kg^{-1}), and P content in vermicompost was also regarded as low (0.24%). In addition, other than the low organic matter mineralization of the soil, as indicated earlier, the neutral pH of Entisols (6.8) also made P in the soil became less available to the plants. According to Cerozi and Fitzsimmons (2016), increased pH decreased P availability to the plants due to P's binding events with several cations and brought about the formation of insoluble calcium phosphate species less available for the plants in the growing media. A previous study concluded that the use of LOF increased the P content of organically grown sweet corn on sandy loam soil with a pH of 5.5 (Muktamar *et al.*, 2017). Although the response of P sweet corn nutrient contents to LOF application was linearly significant, the contribution of LOF to increase P tissue content in sweet corn was only 22.25%.

The result also indicated that the average magnitude of P tissue content of organically grown sweet corn due to LOF application on coastal Entisols was 1.36%. This number was much higher than that reported by Muktamar *et al.* (2016), who reported the average P tissue content of organically grown sweet corn on highland Inceptisols was only 0.1375%. Fluctuated magnitude of P tissue contents might be derived from different soil types, local climatic conditions, as well as cultural management and practices.

The insignificant effect of treatments on P tissue content of sweet corn was followed by an insignificant effect of LOF application on P uptakes. Yet, P uptake in sweet corn was, on average, 7.9 % higher than those not treated by LOF (Table 1). According to Canatoy (2018), nutrient availability, including P in the rhizosphere, determined P uptake by sweet corn. Fahrurrozi *et al*. (2019a) concluded that increased P uptake by organically grown sweet corn was proportional to increased P tissue content. Results also suggested that LOF contribution in P uptakes in sweet corn was only 16.56%, though the response of P uptakes to LOF application was linearly significant. Similar results were reported by Muktamar *et al.* (2016), where LOF application did not increase P uptakes by organically grown sweet corn on highland sandy loam of Inceptisols. The average P uptake found in their research was slightly higher than of P uptake of organically grown sweet corn on coastal Entisols (0.4975 g plant^{-1} vs. 0.44 g plant^{-1}). A study conducted by Sofyan and Sara (2018) concluded that organic fertilizer increased P uptake by sweet corn grown on the highland of Inceptisols. However, the sweet corn plants in this experiment might be lacking P since the plant might have markedly removed P into generative organs (flowers and developing cobs). According to Khan *et al.* (2018), P uptakes in sweet corn were equally distributed into grain and stover.

In an organic farming system, potassium (K) deficiency becomes a significant problem for successful crop production. According to Mikkelsen (2008), failure to maintain sufficient K in the rooting zone of the organic crop production system caused poor water use efficiency, more severe pest problems, lowered harvest quality, and eventually reduced yields. The result indicated that the LOF application significantly increases K tissue contents of sweet corn. The response of K tissue content to LOF application was linearly significant, which implied that LOF controlled 74.65% of K tissue content in sweet corn. On average, increase K tissue content in sweet corn was more than 29.1 % those of not fertilized with LOF. Additional K supply from LOF fertilizing (contained 0.87 % K), vermicompost (contained 0.55 % K), and soil (contained 0.37 me 100 g^{-1} of exchangeable K) might have increased K tissue content in sweet corn. The previous study concluded that sufficient K availability in rooting zones increased K tissue content in sweet corn (Canatoy, 2018). This experiment revealed that the average magnitude of K tissue content of organically grown sweet corn on coastal Entisols soil was 1.51%. This number was much lower than the K tissue content of organically grown sweet corn on highland Inceptisols with an average of 2.39% (Muktamar *et al.,* 2016) and 2.19% (Fahrurrozi *et al.,* 2018).

The magnitude of K uptakes in organic sweet corn production is significant since it increased shoot dry weight per plant, weight husked ears, and yields per plot (Fahrurrozi *et al.*, 2018). According to Hartati *et al*. (2019), K uptake of rice grown on Entisols was strongly correlated with K tissue contents. Nevertheless, results from this experiment indicated that an increase of K uptakes did not follow increased K tissue content. It was also revealed that K uptakes of LOF fertilized sweet corns were, on average, 16.1% higher than their counterparts not treated with LOF. Muktamar *et al.* (2016) previously reported that the LOF application did not increase K uptakes of organically grown sweet corn on highland Inceptisols. However, the average K uptake found in their research was much higher than the K uptake of organically grown sweet corn on coastal Entisols (8.59 g plant^{-1} vs. 0.49 g plant^{-1}). Such discrepancy might have resulted from differences in soil characteristics, climatic conditions, altitude, and growing season. Although the effect of LOF application on K uptakes was insignificant, the response of K uptakes by organically grown sweet corns on Entisols to LOF application was linearly significant. It revealed that LOF controlled 36% of K uptakes of organically grown sweet corn on coastal Entisols. Canatoy (2018) also concluded that potassium availability in the rhizosphere of sweet corn determined potassium uptake by sweet corn.

In conclusion, after the first year of establishing an organically growing environment on coastal Entisols, liquid organic fertilizer (LOF) for organically grown sweet corn increased N and K tissue contents. Still, it did not increase P tissue content, N, P, and K uptakes. Increased N and K tissue contents did not increase N and K uptakes. The magnitude of nutrient tissue contents of organically grown sweet corn on coastal Entisols was also very low, 1.35 to 1.75 % for N, 1.18 to 1.58 % for P, and 1.29 to 1.68 % for K. The nutrient uptakes were very low, ranged from 0.44 to 0.67 g plant^{-1} for N, 0.35 to 0.61 g plant^{-1} for P, and 0.41 to 0.63 g plant^{-1} for K. A careful attention on soil nutrient management for newly organic farming practice is necessary to assure the nutrient availability for the plant. The further experiment should be conducted in the same growing site to evaluate the nutrient dynamics of coastal Entisols, nutrient uptakes, and organically grown sweet corn's physiological and biochemical responses.

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