Phosphorus Uptakes and Yields of Sweet Corn Grown under Organic Production System

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Abstract. Organic production system for sweet corn applied both solid and liquid organic fertilizer. The use liquid organic fertilizer potentially changes the availability of phosphorus for organically grown sweet-corn. Phosphorus absorption in sweet corn production determines the quality and quality of crop yields. This study aimed to determine the relationship between phosphorus uptakes and yields of sweet corn. A field experiment was arranged in randomized complete block design with three replications. Twenty sweet corn varieties were grown under organic environment where soil was fertilized with 30 tons ha\textsuperscript{-1} of cattle-based vermicompost. At 14, 21, 28 and 35 days after planting, each plant was additionally sprayed with thitonia-enriched liquid organic fertilizer of 50, 100, 200, 300 ml plant\textsuperscript{-1}. Observations were conducted on phosphorus uptakes by plant, leaf phosphorus content, shoot dry weight per plot, days to harvesting, weight of husked ear, and weight of unhusked ear as well as sweet corn yield per plot. Results indicated that phosphorus uptakes by sweet corn significantly increased leaf phosphorus content, (r=0.56), shoot dry weight per plot (r=0.83), weight of husked ear (r=0.60), weight of unhusked ear (r=0.56) and sweet corn yield per plot (r=0.70). Phosphorus uptakes by sweet corn also significantly decreased days to harvesting (r= -0.27). In conclusion, phosphorus uptakes determined growth and yields sweet corn grown under fully organic environment.

1. Introduction
Organic production of sweet corn (Zea mays var saccharata Sturt) is commonly limited to issues of soil fertility and pest management practices [1]. Research conducted by [2] suggested that the use of solid organic fertilizer was less effective to increased growth and yields of organically grown sweet corn and must be accompanied by the supplementary of liquid organic fertilizer (LOF). Previously, [3; 4] reported that the use of LOF in combination with solid organic fertilizer did not increase sweet corn yields. In the other hand, many reports claimed that soil amendment with organic fertilizer increased nutrient content in rhizosphere, including phosphorus [5].

Fertilizing sweet corn with organic fertilizers in organic production system might alter nutrient availability for this crop, including phosphorus. Such alteration might be related to the way of phosphorus uptakes by sweet corn which later determine phosphorus availability to sweet corn is how sweet corn uptakes this nutrient. Phosphorus is one macro nutrient and plays important roles as macro-molecular structures in nucleic acids [6]. In addition, ion uptakes by plant roots are influenced by influx to the apoplasm, pH, metabolic activities, ion interactions in the rhizosphere, external concentrations and plant nutritional status. The magnitude of this nutrient in plant tissues was also determined by its availability in rooting zones. It is therefore very important to understand how phosphorus uptakes by sweet corn under organic growing environment take place since this nutrient determines crop growth.
and yields. Unfortunately, most research on sweet corn fertilization has widely been focused on nitrogen and very little research with phosphorus fertilization [7]. Some relevant reports, however, concluded that the addition of compost extract could increase total available phosphorus, phosphorus uptakes and plant dry weight [8]. An experiment conducted by [4] concluded that sweet corn genotype significantly increased nitrogen uptake, but not phosphorus uptakes.

Successfulness of growing organic sweet corn requires consistent nutrient supply, including phosphorus, to ensure sweet corn to have high growth and yields. Failure to maintain sufficient supply of phosphorus in organic production system might bring about significant problems for crop growth and development. Nevertheless, studies on phosphorus uptakes by organically grown sweet corns are limited on determination of total removal by sweet corn for determination the amount of potassium fertilizer applied for sweet corn [8; 9]. Research on potato by [10] reported that potato tubers from organically fertilized soil had higher phosphorus uptakes than those fertilized with inorganic fertilizer. However, information how phosphorus uptakes by sweet corn grown under organic production system relate to yield components are very limited.

This experiment aimed to determine the relationship between phosphorus uptakes and yield components of organically grown sweet corn.

2. Materials and Methods

Field experiment was conducted from July to November 2015 at Air Duku Village, Bengkulu Province, Indonesia, at elevation of approximately 1.054 m above sea level (3°, 27', 30.38" South Latitude and 102°, 36', 51.33'' East Longitude). This site was previously used for organic vegetable production for four years and applied with 30 ton ha⁻¹ of vermicompost after site cleaning, ploughing and harrowing. Plant materials used in this experiment was twenty sweet corn varieties and arranged in randomized block design with three replicates. Each variety was planted in a soil-bed of 2.8 m x 3.0 m soil beds which was separated by 1 m within the block and each block was separated by 1.5 m away. In each plots, each sweet corn variety was planted at 0.25 m x 0.70 m. All plants were additionally fertilized with Tithonia-enriched liquid organic fertilizer (LOF), which was aerobically produced. Incubation of LOF materials, mixtures of 10 kg cattle’s feices, 20 l cattle’s urine, 5 kg of topsoil, 10 kg of Tithonia diversifolia (Hamsley) A. Gray), 20 ml EM 4, 0.25 kg white sugar with additional water to reach a volume of 200 l, was conducted in in the blue plastic container for four weeks. This LOF contained 3.36 %, 146 ppm, and 0.0325 % of N, P, and K, respectively. Each plant was fertilized with LOF of 50, 100, 200 and 300 ml at 14, 21, 28 and 35 days of after planting, respectively. Weed removals were conducted at 25 and 45 days after planting.

Soil samples were compositely taken before planting from 0-20 cm depth to determine the moisture content, pH, C-organic, N total, P2O5 and K. Laboratory analysis revealed that soil of experimental site was characterized by pH of 4.83, field capacity of 9.57%, N total of 0.19%, organic C of 2.05%, P2O5 of 5.54 ppm and K of 0.27 me/100g. Wet destructive method was used to determine plant phosphorus contents (%). Leaf samples for phosphorus content analysis were taken from the third or fourth leaf of upper most fully developed leaves. Five sample plants in each plot were used to determine weight of husked ears (g), weight of unhusked ears (g) shoot dry weight per plot (g). Weight of husked ears and unhusked ears were determined in fresh weight basis, whereas shoot dry weight per plot was calculated by weighing after the shoots were dried and put in oven for 48 hours with 65 to 70 oC. Total weight of all husked ears sweet corn in a plot (g) represented sweet corn yields per plot. The number of days for sweet corn in each plot to be ready for harvesting was a measure of days to harvesting (days). Phosphorus uptakes by sweet corn were calculated as PPC/100SDW, where PPC is plant phosphorus content (%) and SDW is shoot dry weight per plant (g).

Relationships between sweet corn uptakes with plant phosphorus content, weight of husked ears, weight of unhusked ears, shoot dry weight per plot, yields per plot and days to harvesting were determined by using Proc Reg SAS, meanwhile coefficient correlation between phosphorus uptakes by sweet corn and leaf phosphorus content, days to flowering, weight of husked ears, weight of unhusked ears, shoot dry weight per plot were determined by using Proc. Corr SAS. The magnitude of correlations were classified as suggested by [11] where 0 to 0.1 (trivial), 0.1 to 0.3 (small), 0.3 to 0.5 (medium), 0.5 to 0.7 (high), 0.7 to 0.9 (very high) and 0.9 to 1.0 (nearly perfect, perfect).
3. Results and Discussion

3.1. Phosphorus uptakes and leaf phosphorus content

Results indicated that phosphorus uptakes by sweet corn significantly correlated with leaf phosphorus content \( (p<0.0001, r=0.56) \) with linear relationships of \( y=0.367+2.015x \) (Figure 1). Although leaf phosphorus content is only 32 % controlled by plant uptakes, this relationship is considered high. Increased leaf phosphorus content might have resulted from relatively high P2O5 in the soil (5.54 ppm) and additional 650 ml of LOF in which contained 146 ppm P. Research conducted by [8] indicated that high organic phosphorus content in soil increased phosphorus uptake by sweet corn which eventually might increase leaf phosphorus contents.

![Figure 1. Relationships between phosphorus uptakes by sweet corn and leaf phosphorus content](image)

Most of the phosphate in the xylem of phosphorus-sufficient plants is transported to the younger leaves by root absorptions [12], which is eventually increased leaf phosphorus content. Increased leaf phosphorus content might be different among plant organs since this nutrient is required in all plant organs. According to [13] phosphorus concentration in the grain of maize was the highest among the organs, followed by stems, leaves, husks and cob cores. The fact that leaf organ was the second after stems where phosphorus was concentrated might explain the linear relationship between phosphorus uptakes by sweet corn and leaf phosphorus content.

3.2. Phosphorus uptakes and days to harvesting

It was revealed that phosphorus uptakes by sweet corn significantly correlated with days to harvesting \( (p<0.0402, r=-0.27) \) with linear relationships of \( y=90.92–7.695x \) (Figure 2). Although it is generally considered that sufficient phosphorus content in plant cells is necessary to hasten crop maturity [14], the magnitude of correlation between phosphorus uptakes by sweet corn and days to harvesting was classified small and phosphorus uptakes by sweet corn only contributed 7.1 % to decreasing of days to harvesting.
The fact that only 7.1% contribution of phosphorus to hasten sweet corn harvest might be acceptable since trait of days to harvesting is mainly controlled by genetic factor. Among many external factors, the major environmental factor to influence crop harvesting is the amount of heat received by particular plant which is often described as growing degree days.

3.3. Phosphorus uptakes and shoot dry weight
Phosphorus uptakes by sweet corn significantly correlated with shoot dry weight per plot (p<0.0001, r=0.83) with linear relationships of y=2.353+0.236x (Figure 3). This finding suggested that phosphorus uptakes by sweet corn control 69.2% of shoot dry weight and the relationship of sweet corn uptake and its shoot dry weight was very high. This result suggested that role of phosphorus very determinant in dry matter production of sweet corn. According to [15], phosphorus is the second most important nutrient (after nitrogen) in optimizing plant growth, crop yields and quality. This nutrient is responsible for a wide range of plant metabolic processes, including crop photosynthesis.

Crop dry matter production through photosynthesis is attributed to the light interception by leaf tissues and the rate of photosynthesis is influenced by the amount of phosphorus presence in the leaf tissues. According to [16] phosphorus uptake is proportional with dry weight increased. Recently,
increased phosphorus uptakes by sweet corn were reported to increase dry matter of sweet corn, especially sweet corn stover [5].

3.4. Phosphorus uptakes and weight of husked ears
Phosphorus uptakes by sweet corn significantly correlated with weight of husked ears (p<0.0001, r=0.60) with linear relationships of y=220.519+33.355x (Figure 4). Phosphorus uptakes by sweet corn control 36.4% of weight of sweet corn husked ears and the relationships of phosphorus sweet corn uptakes with weight of husked ears attributed to high correlation value.

![Figure 4. Relationships between phosphorus uptakes by sweet corn and weight of husked ears](image)

Increased phosphorus uptakes by sweet corn will eventually increase the weight of husked ears of sweet corn through its effects photosynthesis. Report by [17] concluded that phosphorus fertilization significantly increased canopy development and light interception in sweet corn which eventually increased sweet corn photosynthesis. Better canopy structure and increased light interception of sweet corn leaf might have led to higher photosynthesis rates which eventually increased weight sweet corn ears. Research conducted by [18; 19] indicated that phosphorus fertilizing organically grown sweet corn significantly increased weight of husked ears.

3.5. Phosphorus uptakes and weight of unhusked ears
Phosphorus uptakes by sweet corn significantly correlated with weight of unhusked ears (p<0.0001, r=0.56) with linear relationships of y=151.125+113.125x (Figure 5). Contribution of phosphorus uptakes to unhusked ears’ weight of sweet corn was accounted as much as 31.7% and is considered high as indicated by its correlation coefficient.

It seemed that increased of sweet corn’s unhusked ears was in line with increased of husked ears. Such trend was also reported by [19] where phosphorus fertilizing increased weight of husked and unhusked ears of sweet corn. Accumulation of phosphorus in sweet corn grain was accounted to 60-70 % of total crop phosphorus and the rest was distributed to other organs, including stems, leaves, husks and cob cores [13]. This might explain why weight of unhusked ears of sweet corn linearly increased with phosphorus uptakes.
3.6. Phosphorus uptakes and yield of sweet corn per plot

Results also indicated that phosphorus uptakes by sweet corn significantly correlated with yield of sweet corn per plot \( (p<0.0001, r=0.70) \) with linear relationships of \( y=1.686+9.560x \) (Figure 6). It was also suggested that yield per plot was 48.4 \% controlled by the phosphorus uptakes by sweet corn.

According to [20], yield of sweet corn was attributed to plant height, leaf number, stem diameter, ear diameter and number of kernel per row. Our data also suggested that increased sweet corn yield per plot was highly correlated to shoot dry weight \( (r=0.89, p<0.0001) \), weight of husked ears \( (r=0.72, p<0.0001) \) and weight of unhusked ears \( (r=0.61, p<0.0001) \). As previously been discussed, phosphorus plays significant roles in many plant metabolisms, from enzyme levels to photosynthetic activities. Increased dry matter production as resulted from active photosynthesis as well as increased on husked and unhusked sweet corn ears will eventually increase total yield of sweet corn. Report by [21] concluded that phosphorus significantly increased yields of maize. Furthermore, research conducted by [18] found that phosphorus significantly increased yields of sweet corn.

4. Conclusions

Under organic growing environment, phosphorus uptakes by sweet corn significantly increased leaf P content, shoot dry weight, weight of husked ear, weight of unhusked ear, and sweet corn yield.
addition, phosphorus uptakes by sweet corn significantly decreased days to harvesting. The magnitudes of relationships between phosphorus uptakes by sweet corn with shoot dry weight per plot, sweet corn yield per plot, weight of husked ears, weight of unhusked ears, leaf phosphorus content and days to harvesting were 0.83, 0.70, 0.60, 0.56, 0.56 and -0.27, respectively.

References
[1] Diver S, Kuepper G and Sullivan P 2001 Organic sweet corn production. ATTRA Cooperative Service USDA. 28 pages
[2] Muktamar Z, Sudjatmiko S, Chozin M, Setyowati N and Fahrurrozi F 2017 Sweet Corn Performance and Its Major Nutrient Uptake Following Application of Vermicompost Supplemented with Liquid Organic Fertilizer Int. J. Adv. Sci. Eng. Inform. Tech. 7 602-8
[3] Fahrurrozi, Muktamar Z, Dwatmadji, Setyowati N, Sudjatmiko S and Chozin M 2016 Growth and yield responses of three sweet corn (Zea mays L. var. saccharata) varieties to local-based liquid organic fertilizer Int. J. Adv. Sci. Eng. Inform. Tech. 6 319-23
[4] Muktamar Z, Fahrurrozi F, Dwatmadji, Setyowati N, Sudjatmiko S and Chozin M 2016 Selected macronutrient uptake by sweet corn under different rates of liquid organic fertilizer in Closed Agriculture System. Int. J. Adv. Sci. Eng. Inform. Tech. 6 258-61
[5] Canatoy RC 2018 Dry matter and NPK uptake of sweet corn as influenced by fertilizer application. Asian J. Soil Sci. & Plant Nutr. 3 1-10
[6] Marschner P 2012 Marschner’s mineral nutrition of higher plants 3rd ed. (London; Academic press) p 158
[7] Hochmuth G and Hanlon E 2016 A summary of N, P, and K research with sweet corn in Florida. The Institute of Food and Agricultural Services, University of Florida. 2016. #SL 326
[8] Darman S 2008 The availability and uptake of phosphorus nutrient by sweet corn in Palolo Oxic Dystrudepts added with extract of cacao fruit waste compost. J. Agroland 4 323-29
[9] Rahman IA, Djuniwati S and Idris K 2008 Effects of organic matter and NPK fertilizers on nutrient uptakes and yields of corn in Inceptisol Ternate. J. Tanah & Lingkungan 10 7-13
[10] Islam MR and Nahar BS 2012 Effect of organic farming on nutrient uptake and quality of potato. J. Env. Sci. & Nat. Res. 5 219-24
[11] Hopkins WG 1997 New view of statistics http://www.sportsci.org/resource/stats/effectmag.html
[12] Jeschke W, Kirkby E, Peuke A, Pate J and Hartung W 1997 Effects of P efficiency on assimilation and transport on nitrate and phosphate in intact plants of caator bean (Ricinus communis L.) J. Exp. Bot. 48 75-9
[13] Bak K, Gaj R and Budka A 2016 Accumulation of nitrogen, phosphorus and potassium in mature maize under variable rates of mineral fertilization. Fragm. Agron. 33 7-19
[14] Uchida R 2000 Essential nutrient for plant growth: Nutrient functions and deficiency symptoms. In: Plant Nutrition Management in Hawaii’s Soils, Approaches for Tropical and Subtropical Agriculture. JA. Silva and R. Uchida (eds). College of Tropical Agriculture & Human Resources. University of Hawaii at Manoa. Chapter 3. 31-55
[15] Schachtman D.P, Reid RJ and Ayling SM 1998 Phosphorus uptake by plants: From soil to cell. Plant Physiol. 118 447-53
[16] Alley MM, Mart Jr ME, Davis PH and. Hammons JL 2009 Nitrogen and phosphorus fertilization of corn. Virginia Cooperative Extension. Publication 424-027
[17] Fletcher AL, Moot DJ and Stone PJ 2002 Canopy development of sweet corn in response to phosphorus. Agron. New Zealand 32 7-15
[18] Geleta SB, Brinsfield RB, Mulford FR, Briand CH and O’Keefe JA 2004 Managing phosphorus for yield and quality of sweet corn on high phosphorus soils of Maryland’s Eastern shore. Canadian J. Plant Sci. 84 713-8
[19] Khan W, Singh V, Sagar A. and Singh SN 2017 Response of phosphorus application on growth and yield of attributes of sweet corn (Zea mays L., saccharata) varieties. J. Pharmacognosy & Phytochemistry. 6 2144-6
[20] Chozin M, Sudjatmiko S, Setyowati N, Fahrurrozi F and Muktamar Z 2017 Analysis of traits association in sweet corn inbred lines as grown under organic crop management. SABRAO J. Breed. & Genetics. 49 361-7

[21] Amanullah and Khan A 2015 Phosphorus and compost management influence maize (Zea mays L.) productivity under semiarid condition with and without phosphate solubilizing bacteria. Frontier in Plant Sci. 6. Article 1083

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