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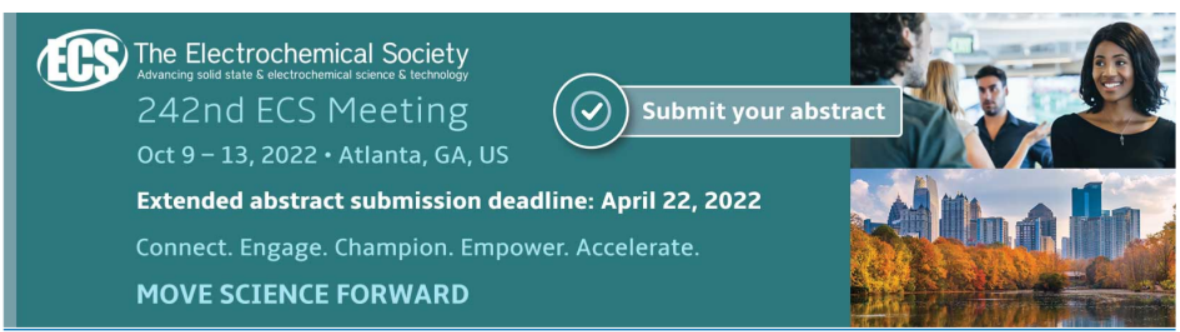

Root traits of sugarcane cultivated by monoculture system in three orders of soil

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Abstract. Sugarcane is a valuable crop and has been cultivated in Indonesia in a monoculture system since the Dutch colonial period. Cultivation of sugarcane in monoculture in the long term affects the condition of soil properties. This will affect plant growth, one of which is plant roots. This study aim was to determine the effect of long-term sugarcane monoculture on sugarcane root conditions in three different soil orders. The research was conducted using two factors oversite design, soil order and duration of monoculture system. The observed soil parameters included soil physical and chemical properties such as bulk density, percentage of sand, silt, clay, porosity, pH H_2O, organic matter, cation exchange capacity, NH_4^+, NO_3^-, Available P, Na, K, Ca, Mg, B and Zn. Root parameters observed were root fresh weight, the weight of root dry, root volume, the length of root, root cation exchange capacity and root surface area. The results showed that root volume, root length, root cation exchange capacity and root surface area were significantly impacted by the interaction of the soil order and the duration of monoculture system.

1. Introduction

The raw material usually used in the sugar industry is sugarcane [1]. Indonesia is known as the country with the 7th largest sugarcane harvested area in the world and the 11th sugarcane producing country in the world. Sugarcane cultivation in Indonesia is carried out using a monoculture system and is widely grown in Vertisols, Inceptisols and Entisols [2]. This monoculture system, if carried out in the long term, will have an effect on soil conditions, such as increasing soil density and decreasing soil aggregate stability [3], acidification of soil, decreased availability of nutrients Mg, Zn, Cu, Fe, decrease in available P content, decrease in exchangeable K, decrease in total N [4], as well as a decrease in the biological quality of soil [5]. Decreased yields and non-uniformity of plant growth can also be the result of a long-term sugarcane monoculture system [6].

Good root development will have a good influence on sugarcane productivity. The primary purposes of the sugarcane root system are water absorption, carrying and storing of water and nutrients, and maintaining plant growth [7]. The physical, chemical, and biological conditions of the soil greatly affect the roots growth and development, as well as varieties and management activities. The bigger root system of a plant, the better its capability to utilize the soil and take nutrients for its growth [8].

Indonesia has implemented a monoculture sugarcane cultivation system for a long time, but there is no further information about its effect on sugarcane roots, so the aim of this study was to verify the effect of monoculture sugarcane cultivation in the long term on the condition of sugarcane roots in three different soil orders.

2. Materials and Method

2.1. Research site

This study was done in three regencies, Purworejo, Magelang, and Kulon Progo, which have an Am climate type and used a two-factor oversite design, orders of soil and duration time of sugarcane monoculture as the factor. The soil orders used included Entisols, Inceptisols and Vertisols, and the duration of monoculture cultivation consisted of of 1–10, 11–20, and 21–30 years. Each treatment was repeated three times.

2.2. Analysis of soil and plant

Samples of soil and plant were taken when the plants on maximum vegetative phase (6 months old after harvest). Soil samples used a random sampling method (composite of three samples) at a depth of 0–30 cm. The physical properties of the soil analyzed include: bulk density (BD) with ring sample; soil porosity values and the percentage of sand, silt, and clay fraction [9]. The soil chemical properties analyzed were pH-H_2O, organic matter [10], cation exchange capacity (CEC) using ammonium acetate at pH 7 method [11], available P using Olsen extractor and Bray extractor if pH-H_2O <5.5 [12], Sodium (Na), Potassium (K), Calcium (Ca), and Magnesium (Mg) were extracted using NH_4Cl [3], Boron (B) was analyzed using the hot water method given Azomethin-H reagents [13],and Zinc (Zn) was analyzed using DTPA extract (diethylenetriaminepentaacetic acid) [14], ammonium (NH_4^+) and nitrate (NO_3^-) using Cottenie method. Analysis of sugarcane roots consists of: the weight of fresh and dry of root, CEC of root [15], root volume, length of root and root surface area.

2.3. Analysis of data

The analysis was accomplished using SAS 9.1.3. The data taken were analyzed using the analysis of variance (ANOVA) and then using Duncan's multiple distance test (DMRT) 5% to compare the effect of treatment. Correlation analysis was carried out with SPSS program.

3. Results and Discussion

3.1. Soil physical and chemical on research site

Sugarcane cultivation in monoculture in the long term has an unequal effect on the physical and chemical characteristics of the soil in each order. Soil physical properties on land with different soil orders and durations of monoculture system showed on Table 1. The bulk density of Entisols with 11–20 years of monoculture was higher than that of 1–10 years, but in Inceptisols and Vertisols, the bulk density value decreased with longer monoculture duration. The value of porosity in Entisols decreased with increasing monoculture duration, while in Inceptisols and Vertisols the monoculture duration of 21–30 years had a higher porosity value than 11–20 years and 1–10 years. Soil type affects the composition of the percentage of sand, silt, and clay in the soil. The average percentage of clay in Vertisols is higher than in Inceptisols and Entisols.

Table 1. Soil physical properties on land with different soil orders and durations of monoculture systems.

Soil physical properties	Location								
	E.D1	E.D2	E.D3	I.D1	I.D2	I.D3	V.D1	V.D2	V.D3
Bulk density (g cm^{-3})	1.11	1.36	1.30	1.33	1.27	1.29	1.37	1.37	1.36
Porosity (%)	58	51	52	44	45	47	34	34	35

Notes : E=Entisols, I=Inceptisols, V=Vertisols, D1= duration of monoculture 1–10 y, D2= duration of monoculture 11–20 y, D3= duration of monoculture 21–30 y.

The value of pH-H_2O, organic matter, cation exchange capacity (CEC) and availability of P were significantly affected by the interaction between soil type and duration time of monoculture (Table 2). The length of duration for monoculture sugarcane cultivation of up to 30 years caused the soil to have a lower pH-H_2O value in Entisols and Inceptisols. This is similar to several studies that have been carried out that sugarcane monoculture will result in soil acidification [16]. Long-term use of ammonium sulfate fertilizer is suspected to be the cause of the decrease in soil pH. Another reason could also be due to the leaching of NO_3^- and during leaching the cations will be replaced by H^+ ions, which accelerates the acidification process of the soil [17]. Soil order also significantly affected the value of soil organic matter, with the lowest values found in Entisols at 1–10 years of monoculture. This shows that land use and land management affect soil organic matter content [18]. Agregate stability [19] and soil texture [20] is also a factor that affects soil organic matter. For this three soil types, the duration of monoculture system of sugarcane up to 30 years did not cause any change in the character of the soil CEC in the three soil orders tested. However, soil CEC on Vertisols was significantly higher than Entisols and Inceptisols. This happens because the soil CEC in this condition is more influenced by mineralogy and soil texture factors in addition to organic matter content and weathering rates [21]. Vertisols have a parent material in the form of smectite which has a high CEC value, it will produce soil with a high CEC. The clay content in the soil also affects the CEC with the more clay content, the higher the CEC due to the higher surface area [22]. The duration for sugarcane monoculture up to 30 years did not change the character of soil phosphorus (P) in Entisols, Inceptisols, and Vertisols because phosphorus (P) is a nutrient that is difficult to leach. The availability of phosphorus (P) is influenced by soil texture and the type of clay mineral [23] and organic matter in Entisols is also low so that the available phosphorus (P) content is also low [24].

The Na, Ca, Mg, B, and Zn contents of the soil were significantly affected by the interaction among the soil order and duration of monoculture system. Soil Na in Vertisols was significantly higher than Entisols and Inceptisols at 21–30 years of sugarcane monoculture duration. Availability of Ca in Inceptisols and Vertisols was significantly higher than Entisols for all durations of sugarcane monoculture. Soil Mg in Entisols was significantly higher when compared to Inceptisols and Vertisols at all durations of sugarcane monoculture. Soil B value in Vertisols was significantly lower than Entisols at all durations of sugarcane monoculture. Soil Zn value in Inceptisol in monoculture duration 11–20 years had a significantly greater value than other treatments.

Table 3 provides information that soil NH_4^+, NO_3^- and K concentrations were not affected by the interaction between soil orders and the length of time for sugarcane monoculture. Sugarcane monoculture duration up to 30 years had no significant impact on soil NH_4^+ and NO_3^- concentrations. Duration for sugarcane monoculture up to 30 years had no significant impact on the K value of the soil even though the value had increased. Soil order did not significantly affect soil K, but the K value in Entisols was lower than Vertisols and Inceptisols.

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Table 2. pH-H_2O, organic matter (OM), cation exchange capacity (CEC), available P, Ca, Mg, Na, B and Zn of soil on different soil orders and durations of monoculture systems.

Treatments	pH-H_2O	OM	CEC	Available P	Available Ca	Available Mg	Available Na	Available B	Available Zn
E.D1	5.1 d	2.2 bcd	13.1 cde	10 d	4.80 c	1.46 a	1.68 e	0.28 bc	0.34 b
E.D2	4.7 e	1.9 cd	11.3 de	15 cd	4.90 c	1.39 a	1.52 e	0.40 a	0.22 b
E.D3	4.5 e	1.8 d	9.0 e	17 cd	4.91 c	1.23 b	1.54 e	0.34 ab	0.20 b
I.D1	6.0 c	2.4 b	17.9 bc	19 bc	17.70 b	0.49 e	4.23 c	0.35 ab	0.48 b
I.D2	6.9 b	3.3 a	22.2 b	11 d	22.03 a	0.29 f	4.64 b	0.19 cd	1.27 a
I.D3	5.3 d	2.3 bc	8.5 e	19 bc	7.00 c	1.41 a	1.62 e	0.16 d	0.25 b
V.D1	6.8 b	2.4 b	39.2 a	18 cd	17.50 b	0.59 de	4.20 c	0.11 d	0.44 b
V.D2	6.0 c	2.4 b	20.3 bc	28 ab	17.40 b	1.02 c	3.20 d	0.11 d	0.54 b
V.D3	7.4 a	2.7 b	45.3 a	38 a	18.70 b	0.64 d	5.13 a	0.19 cd	0.47 b
Interaction	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
CV (%)	4.24	9.03	11.7*	9.50*	10.31	6.89	6.63	3.56*	10.56*

Notes : E=Entisols; I=Inceptisols; V=Vertisols; D1= duration of monoculture 1–10 y; D2= duration of monoculture 11–20 y; D3= duration of monoculture 21–30 y; OM= organic matter (mg $100g^{-1}$); CEC = cation exchange capacity ($cmol^{(-)}kg^{-1}$); Available P (mg kg^{-1}); Available Ca, Mg, Na ($cmol^{(+)}kg^{-1}$); available B, Zn (mg kg^{-1}). (+) = interaction between treatments. Values accompanied by the same lowercase letters were not significantly different according to DMRT at 5%. CV= coefficient of variation. (*) shows data transformed using $\sqrt{x + 0,5}$.

Table 3. NH_4^+, NO_3^-, available K of soil on different soil orders and durations of monoculture systems.

Treatments	NH_4^+ (mg $100g^{-1}$)	NO_3^- (mg $100g^{-1}$)	Available K ($cmol^{(+)}kg^{-1}$)
Soil orders			
Entisols	55.3 a	75.9 ab	0.68 a
Inceptisols	45.5 a	61.9 b	0.81 a
Vertisols	58.1 a	85.7 a	0.76 a
Duration of monoculture			
1–10 y	50.6 a	73.9 a	0.70 a
11–20 y	54.5 a	81.6 a	0.79 a
21–30 y	53.7 a	67.9 a	0.77 a
Interaction	(-)	(-)	(-)
Coefficient of variation (CV)	12.16*	11.15*	18.23*

Notes : (-) = no interaction between treatments. Values accompanied by the same lowercase letters were not significantly different according to DMRT at 5%. CV= coefficient of variation. (*) shows data transformed using $\sqrt{x + 0,5}$.

3.2. Root traits of sugarcane

The weight of fresh and also dry weight of the sugarcane roots were significantly impacted by the interaction of the soil order and duration of monoculture system (Table 4). Root dry weight has a rather strong and significant correlation ($r = 0.410$; $P < 0.05$) to the soil CEC (Table 6). If the soil has a high CEC as in Vertisols, it will provide maximum root dry weight. CEC in Entisols and Inceptisols is lower than Vertisols because Vertisols has a parent material that has a high CEC and high organic matter content [25].

Table 4. Root fresh weight, root dry weight, and root cation exchange capacity (CEC) of sugarcane on different soil orders and durations of monoculture systems.

Treatments	Root fresh weight (gram)	Root dry weight (gram)	root CEC (cmol $^{(+)}$/kg)
E.D1	32.08 abc	4.93 bc	12.32 b
E.D2	47.05 ab	7.59 b	11.31 b
E.D3	32.96 abc	5.03 bc	18.41 ab
I.D1	33.23 abc	8.45 b	22.34 a
I.D2	9.42 c	6.98 b	18.66 ab
I.D3	29.49 abc	5.56 b	11.31 b
V.D1	55.90 a	17.92 a	21.99 a
V.D2	15.89 bc	1.99 c	16.62 ab
V.D3	13.57 c	6.25 b	20.28 a
Interaction	(+)	(+)	(+)
CV (%)	25.49*	18.02*	9.89*

Notes : E=Entisols; I=Inceptisols; V=Vertisols; D1= duration of monoculture 1–10 y; D2= duration of monoculture 11–20 y; D3= duration of monoculture 21–30 y. (+) = interaction between treatments. Values accompanied by the same lowercase letters were not significantly different according to DMRT at 5%. CV= coefficient of variation. (*) shows data transformed using $\sqrt{x+0,5}$.

Cation Exchange Capacity (CEC) of the root is an important parameter in observing the response of plants to existing environmental conditions. Nutrient absorption for plant growth is positively influenced by root CEC. Table 4 provides information that the CEC of sugarcane roots is significantly affected by interaction between treatment. CEC of plant roots has a strong and positive correlation significantly with pH-H_2O of soil ($r= 0.545$; $P<0.01$), soil CEC ($r=0.553$, $P<0.01$) and availability of Ca ($r=0.571$; $P<0.01$) (Table 6). The close correlation between soil pH and CEC of root has also been conveyed by previous researchers, that a positive relationship between soil pH and CEC of root is important in controlling plant growth and productivity [26]. A strong correlation relationship between root CEC and soil Ca has also been suggested by Ray & George (2011) in their research results. Root CEC is important in formulating a theory of plant nutrition and assessing soil fertility status [15].

Table 5. Root volume, length of root and root surface area of sugarcane on different soil orders and durations of monoculture systems.

Treatments	Root volume (cm^3)	Length of root (m)	Root surface area (mm^2)
Soil orders			
Entisols	35.0 a	4.44 a	108.6 a
Inceptisols	45.0 a	4.20 a	89.2 a
Vertisols	46.7 a	2.67 a	40.6 a
Duration of monoculture			
1–10 y	29.4 b	3.24 a	69.7 a
11–20 y	52.8 a	4.24 a	91.0 a
21–30 y	44.4 ab	3.83 a	77.7 a
Interaction	(-)	(-)	(-)
CV (%)	17.93*	23.95	52.35*

Notes : (-) = no interaction between treatments. Values accompanied by the same lowercase letters were not significantly different according to DMRT at 5%. CV= coefficient of variation. (*) shows data transformed using $\sqrt{x+0,5}$.

To be able to adapt to the environment, plants maximize the root system. Table 5 provides information that the volume of sugarcane roots were not influenced by the interaction between the orders of soil and duration of monoculture system. The volume of sugarcane roots planted in different soil orders also did not give a significant difference. Table 6 provides information that root volume has a strong and significant positive correlation with soil organic matter (r=0.448; P<0.05) and pH-H_2O of soil (r =0.393; P<0.05). A neutral pH-H_2O soil such as Vertisols will provide macro and micronutrients available for optimal plants, if the soil has an acid or alkaline pH, it will cause low nutrient availability for plants so that plants cannot grow optimally [27]. For chemical properties, the function of soil organic matter will influencing soil EC, pH-H_2O, availability of nutrient, improving soil physical characteristics, and improving the environment for soil microorganisms so that better soil conditions will provide more root volume [28]. Plants with high root volume are more resistant to environmental conditions [29].

The length and the surface area of sugarcane root were not influenced by the interaction between the orders of soil and duration of monoculture system (Table 5). Different soil orders have different porosity, and the length of sugarcane root and also the surface area of root (Table 6). The condition of the soil structure, which is also influenced by porosity, is responsible for plant growth and root development in taking water and nutrients for growth so that the easier it is to penetrate roots, the better root development [30]. Another concept regarding root length is that plants will expend energy for root growth with the aim of finding water availability, so sugarcane in Entisols have longer sugarcane roots because plants are trying to find the water needed for sugarcane growth. The surface area of sugarcane root is associated to the variety of absorption of water and nutrients on the growing medium by the root surface so wider the root surface area, the bigger capability of plant to absorb nutrients and water from the soil [31].

Tabel 6. Correlation between soil properties and root traits parameters.

Soil properties	Root fresh weight	Root dry weight	root volume	Length of root	root CEC	Root surface area
pH-H_2O	-0.289	0.314	0.393*	-0.402*	0.545**	-0.379
Organic matter	-0.303	0.094	0.448*	-0.064	0.214	-0.095
CEC	0.016	0.410*	0.213	-0.493**	0.553**	-0.458*
NH_4^+	-0.163	-0.143	0.123	0.028	-0.150	0.074
NO_3^-	-0.086	-0.162	0.273	0.129	-0.095	0.129
Available P	-0.286	-0.130	0.334	-0.301	0.171	-0.316
Available Na	-0.280	0.304	0.335	-0.461*	0.616**	-0.453*
Available K	-0.001	-0.157	0.145	0.068	0.258	0.077
Available Ca	-0.310	0.220	0.319	-0.395*	0.571**	-0.415*
Available Mg	0.196	-0.389*	-0.221	0.453*	-0.672**	0.443*
Available B	0.257	-0.108	0.018	-0.016	-0.086	0.015
Available Zn	-0.327	0.071	0.352	0.052	0.241	0.063
Bulk density	-0.097	0.193	0.395*	-0.390*	0.367	-0.431*
Porosity	0.113	-0.291	-0.224	0.487*	-0.527**	0.505**

Notes: CEC= cation exchange capacity; ** Correlation is significant at the 1% level (2-tailed); *. Correlation is significant at the 5% level (2-tailed).

4. Conclusion

The interaction between the types of soil order and the duration of monoculture sugarcane system affected by value of root volume, the length of root, CEC of root and root surface area significantly. CEC of soil, pH H_2O of soil, soil porosity and soil organic matter had a significant correlation with dry weight of sugarcane roots, CEC of plant roots, root volume and root surface area at various levels. Differences in soil property such as physical and chemical properties due to monoculture sugarcane cultivation with a long duration affect the development and growth of sugarcane roots wich will affect the production of sugarcane.

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