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ROOT DISTRIBUTION OF SWEET CORN (*Zea mays*) AS AFFECTED BY MANURE TYPES, RATES AND FREQUENCY OF APPLICATIONS

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ABSTRACT

Manure applications can change soil porosity, bulk density, hydraulic conductivity, and nutrient availability, thus affecting root growth and distribution. Information on root distribution is important to developing more efficient irrigation strategies that meets crop water requirement and reduce excess irrigation. Two field experiments were conducted in Hawaii to study the effect of 1) types, 2) rates, and 3) frequency of manure application on root distribution of sweet corn (*Zea mays* cv. Supersweet 10). The studied variables were roots density, root percentage at 0-15 cm and 16-30 cm depths, and total dry roots per plant. The application of manures and their rates significantly increased the values of all the studied variables except the root percentage at 16-30 cm depth which was highest in the control treatment and was decreased by increasing the application rate. Two-time manure application significantly increased the values of the studied variables at both depths, except for the root percentage at the 16-30 cm depth which decreased under the two time application compared to the one-time application.

Keywords: Root distribution, Corn, Organic matter, Tropical

Abbreviations: CM (chicken manure); DM (dairy manure); OTA (one time application); TTA (two time application).

INTRODUCTION

Sweet corn (*Zea mays* L. subsp mays) is a popular and an economically important cereal crop worldwide (Akinrinde and Teboh, 2006; Reid *et al*., 2006). Sweet corn roots grow mostly in the top 15 cm of the soil profile and that might be due to its short growing season (Amos and Walters, 2006; Fritz *et al*., 2010). Different studies found out that 70-85% of total collected maize roots were found in the top 30 cm depth of the soil profile (Aina and Fapohunda, 1986; Crozier and King, 1993; Dwyer *et al*., 1996). Cherr *et al.* (2006) showed that up to 95% of sweet corn root system was found in the top 30 cm of the soil, and they found increase of the roots dry weight in the top 15 cm at the soil amended with green manure and green manure + chemical N produced compared to chemical N only by 54% and 44%, respectively. Applications of organic manures to soils, which usually occur at the plow layer, could improve soil aeration, soil water holding capacity, and nutrient availability to plants especially within the fertilized layer (Celik *et al*., 2004; Fares *et al*. 2008; Ibrahim *et al*., 2010; Ibrahim *et al*., 2011), and affecting roots growth and distribution pattern. The initial development of a crop root system, after seeds germination, in a uniform soil usually follows genetic patterns (Nielsen, 2010). The patterns are subsequently altered as roots interact with their environment in response to changes in soil conditions such as e.g. bulk density, and soil fertility (Coelho and Or, 1999; Bengough *et al*., 2001). Plant root biomass and distribution is affected by such factors as soil texture, bulk density, moisture content (Sarwar *et al*., 2010; Akhtar *et al*., 2013), crop and varietal characteristics, and management practices (Clothier and Green, 1994; Coelho and Or, 1999; Dexter, 2004; Tahir *et al*., 2013a; Tahir *et al*., 2013b). A study was conducted by Fares *et al*. (2008), using the same plots in this study, to measure changes in some soil physical and hydrological properties under different application of manure types, rates and frequency of application (Table 2). Their findings suggested a need to evaluate the effect of the study treatments on crop root distribution. The importance of information on root distribution under different organic amendment application is in developing more efficient irrigation strategies, which meets crop water requirement and reduce excess irrigation. Thus, the objectives of this study were to evaluate the effect of 1). manure types (chicken and dairy manure), 2). rates (0, 150, 300, and 600 total N equivalent), and 3). frequency (one- and two-time application) of application on root biomass distribution at two depths (0-15 and 16-30 cm) of sweet corn grown in Hawaii.

MATERIALS AND METHODS

This research was a part of a project to determine mineralization of three levels (150, 300 and 600 lb/acre Nitrogen equivalent) of organic manures (chicken and dairy) under sweet corn crop (*Zea mays* L. subsp. *mays)* at different environmental conditions in Hawaii. The study was conducted over two growing seasons at the University of Hawaii's research station at Waimanalo, Oahu, Hawaii. The soil at the study site is a Waialua silty clay (*very-fine, mixed, superactive, isohyperthermic pachic haplustolls*, and the changes in its physical properties under the study treatments are presented in Tables 1, and 2, respectively. Sweet corn (super sweet corn 10 variety) was planted in 2 by 18 m plots at a plant population of 15,000 to 17,500 plants ha^{-1} in rows spaced 65 cm apart, and with drip irrigation. Treatments for the first growing season were chicken and dairy manure applied at 0, 150, 300, and 600 kg ha^{-1} total N equivalent arranged in a RCB Design with three replications (block). In the second growing season, each plot from the first growing season was split in half (2 by 9 m plots) and one half of the plot was left untreated, so called one time application (OTA) while the other half received additional manure to make up for the mineralized portion of the manure during the first growing season, so called two time application (TTA). During the second growing season the experimental design was factorial within strip plot replicated three times, and same planting density and rows spacing were used as the first growing season. The manures were applied on April 25th and November 25th, 2006, seeding was done on June 6th and December 15th, 2006 and harvesting on August 24th, 2006 and March 20th, 2007 for the first and second growing season, respectively. Nutrient content of the chicken and dairy manures for both growing season are presented in Table 3. Daily rainfall and temperature data for the two growing seasons were collected from the weather station # 22503 of National Climatic Data Center (NCDC) at Waimanalo research station. Total precipitation was 218 and 624 mm with daily average of 1.5 mm and 4.1 mm, and average daily temperatures were 23.6 and 23.2 ºC, for first and second growing seasons, respectively. Temperature fluctuation was within the range of 20-27 ^{o}C irrespective of the cropping season along with a substantial variation in precipitation. At harvest, a few preliminary soil cores (15 cm long and 5 cm width) were randomly collected from three depths 0-15, 16-30, and 31-45 cm during the two growing seasons, using AMS soil core sampler (AMS Inc, American falls, ID, USA). The initial results revealed that there were no visible roots below the 30 cm depth, and that might be related to different factors, i.e. the application of manures were in the top 15 cm of the soil layer, which increased soil fertility and water holding capacity for the top soil layer, and/or to the crop short growing season (2-3 months). Therefore, one random plant from each plot was selected to study the root biomass distribution at only 0-15 and 16-30 cm depths. Soil core sampler (AMS Inc, American falls, ID, USA) was used for root sampling and six soil core samples were collected around each plant stem (soil cores were collected from 3 sides or directions, and few centimeters from the plant stem), 3 samples from 0-15 cm and 3 samples from 16-30 cm). Samples were secured in plastic ziplock bags and transferred to the lab where the air dried soil's weights were recorded. Roots were collected from each sample after washing them free of soil with tap water. All roots were collected and placed in an oven on 70 ºC for 72 hours and their weights were recorded. All measured variables in this study were based on roots collected from the soil cores, although they may only represent a fraction of the plants roots system, they would show the relative root distribution at two depths. Root density in milligram per gram of soil was calculated for each sample at both depths, total dry root weight in the six samples per plant in grams, and root distribution percentage at the two depths were calculated. SAS program (SAS Institute, 2003) was used to conduct analysis of variance (ANOVA) on the collected data. Also, Duncan's multiple range tests were performed on the treatment means if ANOVA showed significance.

RESULTS AND DISCUSSION

Analysis of Variance Results: During the first growing season there was a highly significant ($p<0.01$) effect of type and rate of manure application and the interaction between the two factors on total dry roots per plant (Table 4). There was also a significant ($p<0.05$) effect of type of application on root density (mg g^{-1}) at 0-15 cm, percent root at 0-15 cm, and 16-30 cm depth. During the second growing season there was a highly significant ($p<0.01$) effect of the level of application on all the variables, except root density which had a significant ($p<0.05$) effect (Table 5). Type of manure application had a highly significant ($p<0.01$) effect on root density and percent root at 0-15 and 16-30 cm depths, and significant ($p<0.05$) effect on the rest of the variables. Manure application rate had a highly significant ($p<0.01$) effect on root density at 0-15 cm, and percent root at 0-15 cm, and percent root at 16-30 cm, and a significant ($p<0.05$) effect on root density at 16-30 cm and total dry root per plant. There was a significant ($p<0.05$) interaction between type and rate on percent root at 0-15 and 16-30 cm depths, that might be related to the increase in nutrient availability in soil due to increase in the amount from the manure that releases nutrient faster (Ahmad *et al*., 2009). The interaction between application frequency and manure type was highly significant for root density at 0-15 and 16-30 cm depths. However, it was significant for the rest of the variables. The interaction between application rate and frequency was significant for all the variables except total dry root per plant which was not significant.

Root Density (mg g^{-1}) at 0-15 and 16-30 cm Depths

Effect of manure application types: In general, the application of both CM and DM amendments compared to the control treatment increased the root density at the top 15 cm of the soil during the two growing seasons. For the first growing season, there was a significant effect of the manure types on increasing root density at 0-15 cm depth compared to the control treatment, but there was no significant difference between the CM and DM treatments (Fig. 1). For the second growing season, the results followed the same trend as in the first growing season, where the application of manure amendments increased root density compared to the control treatment. The roots density at 0-15 and 16-30 cm depths significantly increased under the application of both CM and DM compared to the control treatment. The highest means were with the CM application, but there was no significant difference between the manure types (Fig. 2). That effect might be related to (1) increasing manure application rate increased nutrient availability in the top soil layer, also (2) increasing organic content in soil increased water holding capacity for the soil and especially at the application layer (Celik *et al*., 2004), which reduced the need for roots to expand and grow deeper in search of nutrients and water. Ahmad *et al*. (2009) on the same study site, collected whole roots and shoots of sweet corn plants, and analyzed for macro- and micro-nutrients content in roots and shoots, found a significant increase in roots growth and its content of macro- and micro-nutrients under CM application compared to DM and control treatments.

Effect of manure application rates: In general, increasing the manure application rate increased root density at both depths (0-15 and 16-30 cm) and during the two growing seasons (Fig. 2). For the first growing season, the root density at 0-15 cm depth significantly increased with increasing manure application compared to the control treatment, there was no effect for increasing the application rate from low to high on the root density. There was no significant effect of manure type and rate on root density at 16-30 cm depth. The results showed the same trend in the second growing season as the first. Root density at the 0-15 cm depth increased significantly with increasing the application rate, there was a significant difference between the high and medium rates with the low and control treatments, and there was a significant difference between the low and control treatments (Fig. 2). For root density at the 16-30 cm depth there was an increase in the means which reached a significant level between high and other application rates, these differences might be related to the significant increase in plant growth with increasing the application rate of manure (Valenzuela *et al*., 2000; Ahmad *et al*., 2009).

Effect of application frequency: Two-time application (TTA) of manure significantly increased root density at both depths compared to OTA (Fig. 3). The increase in root biomass distribution under TTA compared to OTA might be related to the decease in soil bulk density under TTA compared to OTA as reported by Fares *et al*. (2008) for work at the same site. In fact, Amato and Ritchie (2002) reported of a significant increase in maize roots with reducing soil bulk density. The increase in root density under the applications of CM and DM compared to the control might be related to the decrease in soil bulk density due to the animal manure application, which allows the roots to grow deeper (Celik *et al*., 2004; Prevost, 2004; and Fares *et al*., 2008). The decrease of root density at the 16-30 cm depth might be related to the increase in soil bulk density with soil depth, which may reduce the root development and growth (Amato and Ritchie, 2002). Also, the increase in the roots biomass distribution under manure applications might be related to the increase in plant growth as a response to the manure application (Valenzuela *et al*., 2000; Ahmad *et al*., 2009), where there is a positive significant correlation between sweet corn shoots and roots growth as reported by Amato and Ritchie (2002). Also, these findings agree with what reported by Cherr *et al*. (2006) who found a significant increase in sweet corn root at the 0-15 cm depth under the application of green manure compared to the control (Farid *et al*., 2013).

Total Root dry weight per Plant

Effect of manure types: The total root per plant significantly increased under the application of CM compared to the DM and control treatments (Fig. 4). Root weight in the DM treatment was significantly higher than the control treatment in the second growing season. The increase in total root per plant might be related to significant increase in plant growth under the application of CM and DM compared to the control treatment (Ahmad *et al*., 2009).

Effect of manure application rates: In general, total root per plant significantly increased with increasing the manure application rates (Fig. 5). The increase in root biomass with increasing the application rate might be related to the decrease in bulk density at the top 15 cm where the manure applied and incorporated (Fares *et al*., 2008). Amato and Ritchie (2002) reported significant increase in maize root with decreasing soil bulk density. Also, such increase in root biomass might be related to the significant increase in plant growth as a respond to the increase in manure application rates (Ahmad *et al*., 2009).

Effect of manure application frequency: Total root per plant under TTA was around 24% higher compared to OTA (Fig. 6). Decreased soil bulk density was the likely cause and/or it was related to the increase of nutrient available for plant due to the extra manure application (Celik *et al*., 2004, Fares *et al*., 2008). Ahmad *et al*. (2009) on the same study site, found a significant increase in total root weight under TTA compared to OTA, when they collected whole plant root using a big shovel.

Percentage Root at 0-15 and 16-30 cm depths

Effect of manure types: The root percentage at the 0-15 cm depth under the CM and DM treatments was highest (Fig. 7). However, the root percentage at the 16-30 cm depth was highest under the control treatment. The increase in root biomass at 16-30 cm depth under the control treatment compared to the CM and DM treatments might be related to the increase in roots growth to seek water and nutrients beyond the top 15 cm soil in the control treatment compared to the conditions under manure application, where nutrient and water holding capacity increased (Dong *et al*., 2005).

Effect of manure application rates: For the two growing seasons, there were more roots at the top 15 cm, and there were more roots in the second growing season than in the first growing season (Fig. 8). It might be because of better plant growth during the second growing season (Ahmad *et al*., 2009). However, the root percent at 16-30 cm for the two growing seasons was highest in the control treatment (Fig. 8). The reversed increase in roots percentage at 16-30 cm depth under the control treatment was probably caused by water and nutrients availability and soil bulk density at the two depths, as previously discussed, and mentioned by (Celik *et al*. 2004; Dong *et al*. 2005; Fares *et al*., 2008).

Effect of manure application frequency: Percentage root was significantly higher under the TTA than the OTA at the top 15 cm depth, while it was opposite (significantly higher under OTA) at the 16-30 cm depth (Fig. 9). The reversed effect of OTA at the 16-30 cm depth might be related to the decline of fertility at the top 15 cm of soil due plants uptake and nutrient lose from the first growing season, which forced the roots to grow deeper to look for nutrient and water, while the addition of manure (TTA) into the field regain its top layer fertility and supported plant growth (Ahmad *et al*., 2009; Rehman *et al*., 2013).

Table 1. Physical properties of the Waialua silty clay soil used in the experiments

Site	Depth	Sand	Silt	Clay	OC	K_{sat}*	θ_{aw}	ρ_b	pH**
Waimanalo	**cm**		**%**			**m d^{-1}**	**cm^3 cm^{-3}**	**Mg m^{-3}**	**cm**
	0–38	11.2	42.9	45.9	1.94	2.44	0.13	1.20	6.68
	38–91	11.4	43.8	44.8	0.80	2.44	0.14	1.10	—

*Saturated hydraulic conductivity; θ_{aw} available water content; OC organic carbon; ρ_b bulk density, **pH at 1:1 H_2O and soil ratio.

Table 2. Changes in soil properties under the application of organic amendments

Treatment		Bulk Density ($_b$)	Porosity ( )	Saturated Hydraulic Conductivity
		Mg m^{-3}	**cm^3 cm^{-3}**	**(K_{sat})**
Application Type	Chicken manure	1.12 a	0.53 a	2.8 a
	Dairy manure	1.15 a	0.52 a	3.0 a
Application Rate	Control	1.23 a	0.50 c	1.1 d
	Low	1.18 b	0.52 b	2.1 c
	Medium	1.13 c	0.53 b	2.8 b
	High	1.11 c	0.57 a	3.2 a
Application Frequency	OTA	1.18 a	0.51 b	1.1 b
	TTA	1.15 b	0.55 a	2.5 a

* Data is reproduced from Fares *et al*. (2008). K_{sat} data are multiplied by 10^{-5} times to present more readable data.

Table 3. Nutrient content of the chicken and dairy manures analyzed in the beginning of first and second growing seasons, respectively

1st growing season	N	C	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	B
				%						**µg g^{-1}**		
Chicken manure	3.01	21.52	1.47	1.97	14.26	0.75	0.40	209	967	397	43	30
Dairy manure	1.84	15.09	0.49	1.88	2.05	1.02	0.52	4317	330	123	191	45
2nd growing season												
Chicken manure	2.21	19.34	1.82	1.31	10.57	0.62	0.21	2286	669	302	29	36
Dairy manure	2.46	11.66	1.04	4.16	2.89	1.54	0.91	13760	740	215	153	132

Table 4. ANOVA results showing significance level for the effect of type and rate of manure amendment on the studied root variables during the first growing season

SOV	D.F.	Mean Squares (M.S.)				
		Root density 0-15 cm	**Root density 16-30 cm**	**Total dry roots / plant**	**% Root 0-15 cm**	**% Root 16-30 cm**
Block	2					
Type	2	*	N.S.	**	*	*
Rate	3	N.S.	N.S.	**	N.S.	N.S.
T × R	6	N.S.	N.S.	**	N.S.	N.S.
Error	7					
Total	20					

SOV = sources of variation. D.F. = degree of freedom, NS, *, ** non-significant, significant and highly significant effect, respectively.

Table 5. ANOVA results showing significance level for the effect of type and rate of manure amendment on the studied root variables during the second growing season.

SOV	D.F.	Mean Squares (M.S.)				
		Root density 0-15 cm	**Root density 16-30 cm**	**Total dry Roots/plant**	**% Root 0-15 cm**	**% Root 16-30 cm**
Block	2					
Level	1	*	**	**	**	**
Error (A)	2					
Type	2	**	**	*	**	**
Rate	3	**	*	*	**	**
T × R	6	N.S.	N.S.	N.S.	*	*
Error (B)	14					
L × T	1	**	**	*	*	*
L × R	3	*	*	N.S.	*	*
L × T × R	3	N.S.	N.S.	N.S.	N.S.	N.S.
Error (C)	14					
Total	47					

SOV = sources of variation. D.F. = degree of freedom, NS, *, ** non-significant, significant and highly significant effect, respectively.

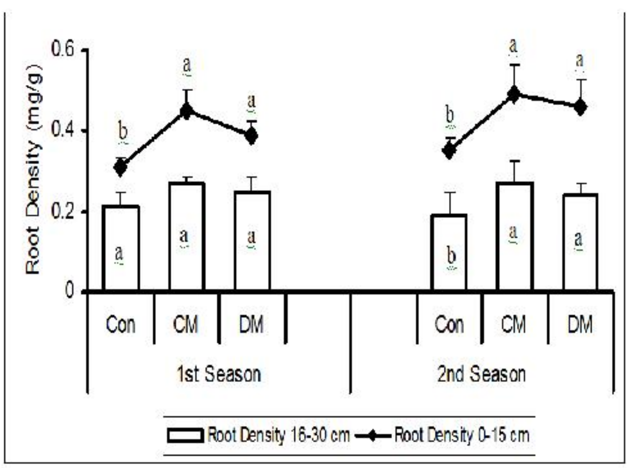

Figure 1. Effect of manure type on root density at 0-15 and 16-30 cm depths. Different letters within each depth indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

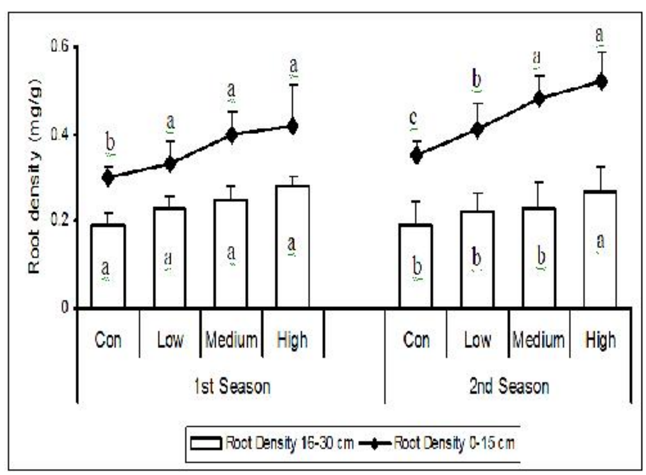

Figure 2. Effect of rate of manure application on root density at 0-15 and 16-30 cm depths Different letters within each depth indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

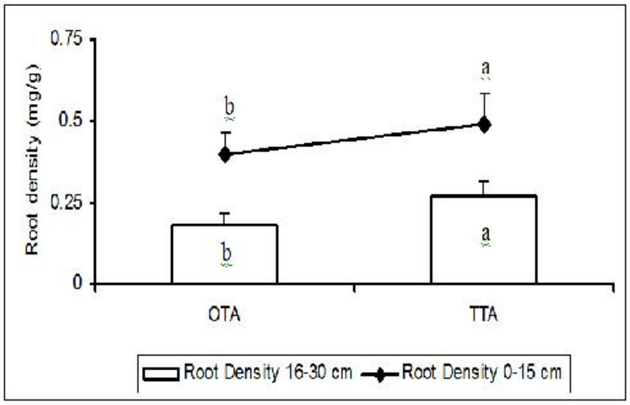

Figure 3. Effect of application frequency of manures on root density at 0-15 and 16-30 cm depths during the second growing season. Different letters within each application indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

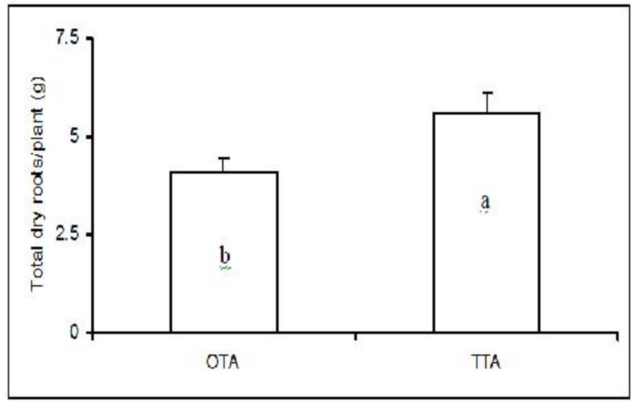

Figure 6. Effect of application frequency on total root dry weight per plant (g) during the second growing season. Different letters indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

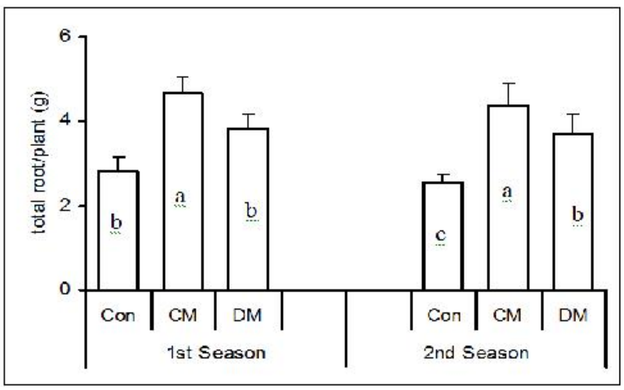

Figure 4. Effect of manure type on total root per plant in two growing seasons. Different letters within each depth and season indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

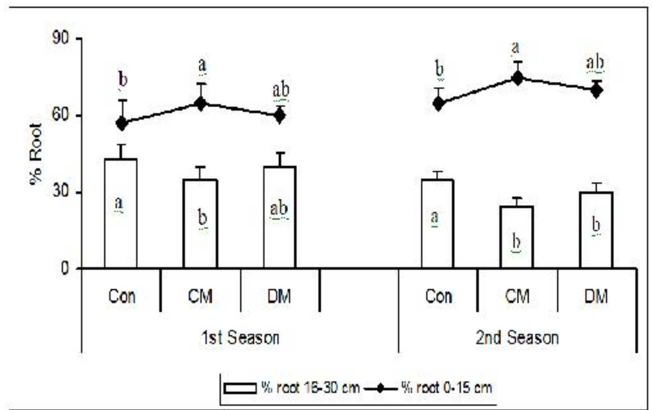

Figure 7. Effect of type of manure application on percent root at 0-15 and 16-30 cm depths in two growing seasons. Different letters within each depth and season indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

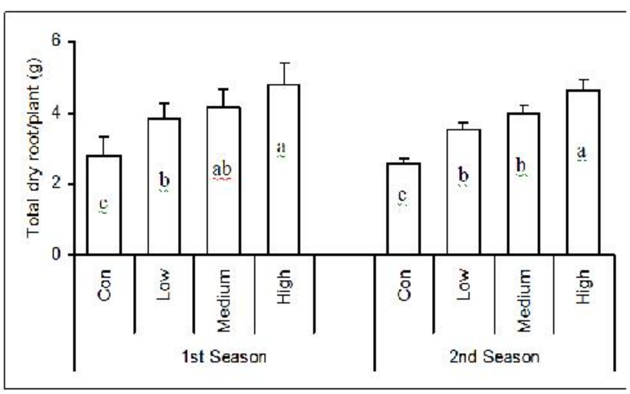

Figure 5. Effect of manure application rate on total root dry weight per plant (g) in two growing seasons. Different letters within each season indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

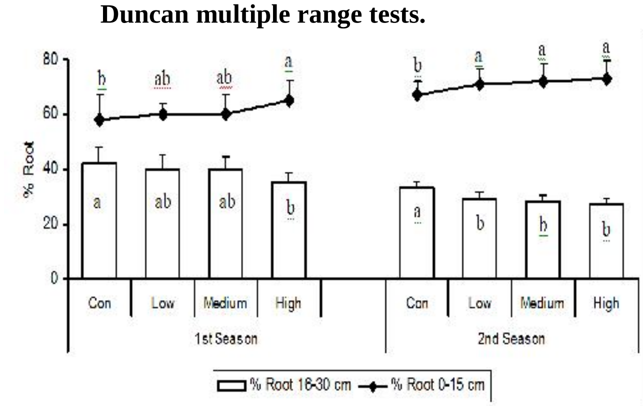

Figure 8. Effect of rate of manure application on percent root at 0-15 and 16-30 cm depths in two growing seasons. Different letters indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

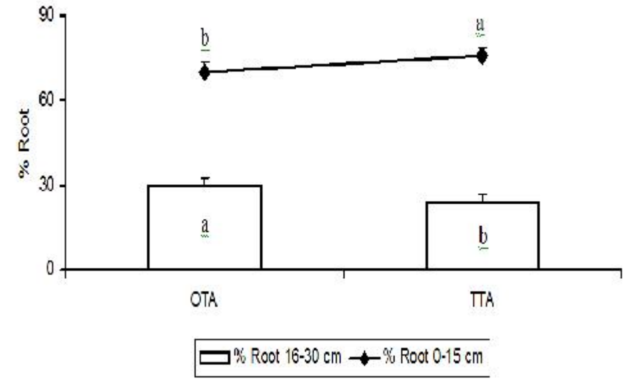

Figure 9. Effect of number of manure application (frequency) on percent root at 0-15 and 16-30 cm depths during second growing season. Different letters indicate statistical differences at 0.05 level according to the Duncan multiple range tests.

Conclusions: Chicken manure applications increased root biomass and the percentage of roots of sweet corn at 0-15 and 16-30 cm depths followed by the dairy manure relative to the control treatment. Higher application rates had more favorable effects on the root parameters measured, except the roots percentage at 16-30 cm depth, which followed an opposite trend. Two-time application had a significantly greater effect on all the studied variables than one-time application except the root percentage at 16-30 cm depth which increased under OTA compared to TTA treatment.

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