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Root traits and carbon input by sweet sorghum genotypes differs in two climatic conditions

Ibrahim. A. M. Ahmed[1], Ibrahim Ortaş[1*], Celal Yucel[2], Abdullah Oktem[3], Derya Yucel[2], Md Toufiq Iqbal[1,4*]

[1]Department of Soil Science and Plant Nutrition, University of Cukurova, Adana, Turkey
[2]Eastern Mediterranean Agriculture Research Institute, Adana, Turkey
[3]University of Harran, Department of Field Crops, Faculty of Agriculture, SanliSanlıurfa, Turkey
[4]Department of Agronomy and Agricultural Extension, University of Rajshahi, Rajshahi 6205, Bangladesh

***Corresponding author: toufiq_iqbal@yahoo.com**

Abstract

Response of sweet sorghum [*Sorghum bicolor* (L.) Moench] root traits and carbon (C) input under two different climatic condition is not well understood. The aims of this study were to characterize and compare root biomass and root traits of several sweet sorghum genotypes at field condition and to estimate their C input to into soil. Roots and shoots were analyzed for C concentration and CO_2 was calculated. Root samples were collected through monolith root sampling techniques. Root morphological characteristics like root surface area and root volume were differed between locations as well as locations × genotypes interactions. Root surface area varies from 423,800 to 887,800 m^2 ha^{-1} in Mediterranean soil and 339,100 to 579,600 m^2ha^{-1} for Harran soil. All sweet sorghum genotypes inputs root and shoot C as well as CO_2 higher in Mediterranean than Harran soil. Root C input varies from 140 to 386 Mg ha^{-1} in Mediterranean soil and 112 to 224 Mg ha^{-1} for Harran soil. A greater diversity of root traits was found on several sweet sorghum genotypes irrespective to plant biomass C inputs into the soil. However, compared to several sweet sorghum genotypes, their lower C input to soil needs to be recognized to ensure a balanced C budget. This study concluded that several sweet sorghum genotypes can be a good source of soil C sequestration under different climatic conditions of Turkey.

Keywords: Root morphology, C budget, C sequestration, Root and shoot C, Root and shoot CO_2.
Abbreviations: C = Carbon, CO_2 = Carbon di oxide

Introduction

Sweet sorghum [*Sorghum bicolor* (L.) Moench] are annual crops from which the sweet sap can be fermented to ethanol (Bernardes et. al., 2015). Sweet sorghum is a C_4 crop in the grass family and is characterized by its high photosynthetic efficiency (Sage, 2004). Sweet sorghum can also adapt a wide range of climatic and soil conditions (Wu et. al., 2010). Sweet sorghum cultivation and practices are simple and readily adoptable (Almodares et. al., 1997). Sweet sorghum is also a short day plant and most varieties require fairly high temperature to make their best growth (Mamoun and Salma, 2015).
Since studying root morphology is time-consuming and labor intensive (Costa et al., 2002; Dowdy et. al., 1998; Monti and Zatta, 2009; Nickel et. al., 1995). Little information exists on root morphological characteristics of sweet sorghum particularly under diverse field experimental conditions. Besides their role in nutrient uptake, roots constitute a major source of carbon (C) for soil (Rasse et. al. 2005) and root biomass might be a good indicator of crop C input to soil (Monti and Zatta, 2009). Soils contain the largest amount of C in the terrestrial ecosystem with roughly twice the amount of C stored in the soil as found in the atmosphere (Batjes, 1996;Powlson et. al., 2011). Sweet sorghum produces a net C flux from the soil to the atmosphere (Le Quéré et al., 2012). It is essential to estimate the ability of the soil to sequester C back from the atmosphere (Schulp et. al., 2008) and to mitigate the emissions of CO_2 into the atmosphere. Increasing soil carbon may play a critical role in mitigating CO_2 emissions. Consequently, relatively small changes to the soil C pool can influence the global C balance (McNally et al., 2015).
Little information exists on root morphological characteristics of sweet sorghum [*Sorghum bicolor (L.) Moench*] crops under field conditions, which can be a major determinant of C input to soil (Thivierge et. al., 2016). Our previous study evaluated dry weight and nutrient uptake of twenty one sweet sorghum genotypes grown in two separate locations of Turkey (Ibrahim et al., 2018). However, the influence of weather variation on root traits and carbon input by sweet sorghum genotypes is

poorly understood for Mediterranean and Harran soil. The purpose of the experiment was to screen the most suitable sweet sorghum genotypes or lines with root biomass production and their C input into the soil. We hypothesized that several sweet sorghum genotypes will be helped to accumulate C in soil.

Results

Sweet sorghum genotypes growth response

Sweet sorghum genotypes growth response varied differently irrespective to year and genotypes (Table 3). Plant height was higher in Sanliurfa than Adana location. The plant height varies 325 to 427 cm in the year 2016 at Adana location. Similarly, the plant height varies 313 to 425 cm in the year 2017 in same location. The plant height varies 352 to 446 cm in Sanliurfa location for the year 2016. Similarly, plant height varies 333 to 423 cm in Sanliurfa location for the year 2017. On average, shoot dry weight was higher in 2016 than 2017 in both locations. The shoot dry weight of several genotypes varies 29048 to 49175 and 31905 to 65011 kg/ha in the year 2016 and 2017 respectively in Adana location. The shoot dry weight varies 29968 to 42762 and 31683 to 54000 kg/ha in the year 2016 and 2017 respectively in Sanliurfa location. In general, root dry weight was higher in 2016 than 2017 for several sweet sorghum genotypes in Adana location. The root dry weight of several sweet genotypes varies 5510 to 8118 kg/ha in the year 2016 in Adana location. Similarly, the root dry weight of several sweet sorghum genotypes varies 5273 to 7875 kg/ha in the year 2017 in Adana location. The root dry weight varies 4512 to 7115 and 5119 to 7579 kg/ha in the year 2016 and 2017 respectively for Sanliurfa location.

Root morphological characteristics

Root morphological characteristics of several sweet sorghum genotypes vary among the genotypes and locations to locations. The root length of several sweet sorghum genotypes was higher in Şanlıurfa than Adana location except Nebraska sugarcane, P1579753, Wray, BATAEM-4 and Gülşeker genotypes (Table 4). The highest root length was found 235366 km ha^{-1} for Cowley sweet sorghum genotypes and lowest root length was found 139310 km ha^{-1} in Nebraska Sugarcane sweet sorghum genotypes at Şanlıurfa location.
Root surface area of several sweet sorghum genotypes was higher in Adana than Şanlıurfa except Cowley sweet sorghum genotypes except Cowley sweet sorghum genotypes (Table 4). The highest root diameter was 0.75 mm for P1579753 sweet sorghum genotype and lowest root diameter were found 0.54 mm for UNL-hybrid-5, Wary and Smith sweet sorghum genotypes at Şanlıurfa location.
Root diameter differ significantly ($P \geq 0.05$) among sweet sorghum genotypes (Table 4). However, locations as well as locations and genotypes interaction did not differ irrespective to root diameter of several sweet sorghum genotypes. The highest root diameter was found 0.68 mm for White Orn and lowest was 0.49 mm for P1579753 sweet sorghum genotypes at Adana locations.
Interestingly, root volume differs significantly ($P \geq 0.05$) between locations, among genotypes as well as locations and genotypes interactions (Table 5). The highest and lowest root volume for Wary and UNL-hybrid-5 sweet sorghum genotypes were 26.70 and 8.46 m^3 ha^{-1} respectively at Adana location. Likewise, the highest and lowest root volume for Wary and UNL-hybrid-5 sweet sorghum genotypes were 20.8 and 7.88 m^3 ha^{-1} respectively at Şanlıurfa location (Table 4).

Root C input in several sweet sorghum genotypes

Root C input was higher in Adana than Şanlıurfa locations (Figure 1a and Figure 1b). The root C input was higher in 2016 than 2017 in Adana location. The root C input varies 2616 to 4027 and 2275 to 3582 kg/ha in the year 2016 and 2017 respectively in Adana location (Figure 1a). Root C input varies 2217 to 3400 and 2290 to 3631 kg/ha in the year 2016 and 2017 respectively in Sanliurfa locations (Figure 1b).
Sweet sorghum genotypes root C inputs differ significantly ($P \geq 0.05$) between locations as well as locations × genotypes interactions. However, root C inputs did not differ among several sweet sorghum genotypes (Table 5). The highest root C input was found 386 Mg ha^{-1} in Wary sweet sorghum genotypes and lowest root C input was found 140 Mg/ha in UNL-hybrid-5 at Adana location. Likewise, the highest root C input was 224 Mg/ha for P1579753 sweet sorghum genotypes and lowest root C input was found 112 Mg/ha in smith sweet sorghum genotypes.

Shoot C input in several sweet sorghum genotypes

In general, two year average shoot C inputs were double in Adana locations than Şanlıurfa locations with some exceptions (Figure 2). Shoot C inputs significantly ($P \geq 0.001$) differed between two locations. However, the shoot C inputs did not differ among genotypes as well as locations × genotypes interaction (Table 5). The highest shoot C input was found 3334 Mg/ha for BATAEM-4 sweet sorghum genotypes and lowest shoot C was found 1007 Mg/ha for UNL-hybrid-5 genotypes at Adana locations. However, shoot C input varies 1014 to 1923 Mg/ha in several sweet sorghum genotypes at Şanlıurfa locations.

Root Carbon content converted into CO_2

After analyzing the root carbon content, total carbon dioxide was calculated. It seems that root carbon fixation was higher in Adana location than Şanlıurfa location except M81-E and P1579753 sweet sorghum genotypes (Figure 3). Root CO_2 fixation did not differ among genotypes. However, root fixed CO_2 differ between locations as well as locations × genotypes interaction (Table 6). The maximum root CO_2 was found 1417 Mg/ha for Wary sweet sorghum genotypes and minimum was found 515 Mg/ha for UNL-hybrid-5 sweet sorghum genotypes for Adana location. Similarly, the maximum root fixed CO_2 was

Table 1. Some Chemical and physical properties of soil at depths of 0–30 cm in Adana and Şanlıurfa Location.

Location	Adana	Şanlıurfa
pH (1:2.5 H_2O)	7.40	7.6
EC (dS/m) (1:2.5 H_2O)	0.18	0.2
OM (%)	1.16	0.67
Total N (%)	0.11	0.059
Available P (mg/kg)	0.63	0.39
CaCo3 (%)	30.3	40.8
Sand (%)	25.2	28.3
Silt (%)	42.0	26.7
Clay (%)	32.8	45.0
Textural class	clay loam	clay

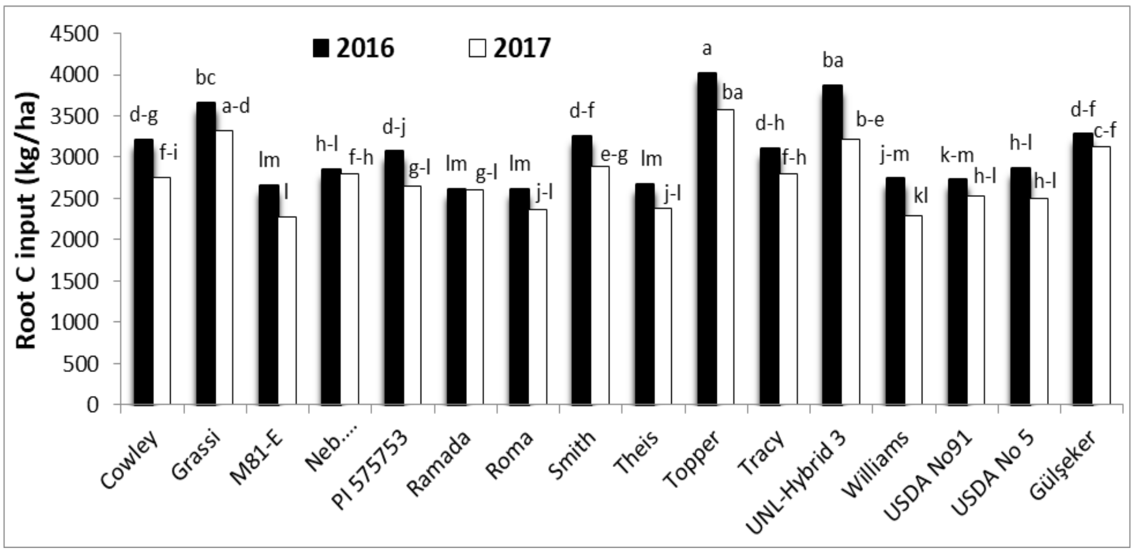

Fig 1a. Root C inputs in several sweet sorghum genotypes at a depth of 0-30 cm for Mediterranean soil (Adana location). Data were means of three replicates. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

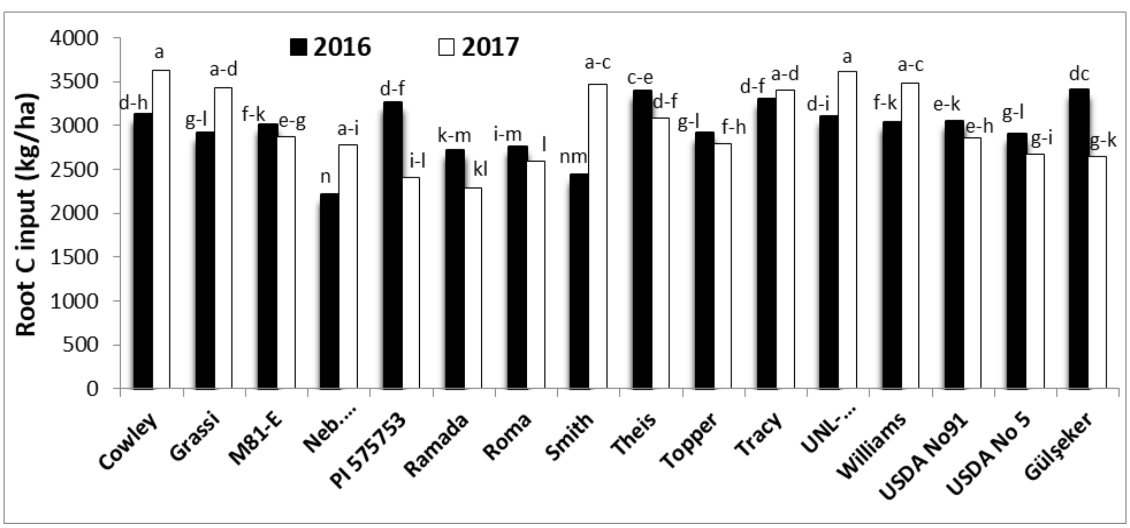

Fig 1b: Root C inputs in several sweet sorghum genotypes at a depth of 0-30 cm for Harran soil (Sanliurfa location). Data were means of three replicates. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

Table 2. Genotypes of sweet sorghum used in the study.

Genotype Name	Received organization
Cowley	The University of Nebraska /USA
Grassi	The University of Nebraska/USA
M81-E	The University of Nebraska/USA
Nebraska sugarcane	The University of Nebraska /USA
PI 575753	The University of Nebraska /USA
Ramada	The University of Nebraska /USA
Roma	The University of Nebraska /USA
Smith	The University of Nebraska /USA
Theis	The University of Nebraska /USA
Topper	The University of Nebraska /USA
Tracy	The University of Nebraska /USA
UNL-Hybrid 3	The University of Nebraska /USA
Williams	The University of Nebraska /USA
USDA No91	USDA (Originated from Taiwan) USA
USDA No 5	USDA (Originated from South America) USA
Gülşeker	Uludag University. Faculty of Agriculture, Turkey.

Prof. Dr. İsmail Dweikat, The University of Nebraska, Lincoln, USA, USDA, U.S. Department of Agriculture)

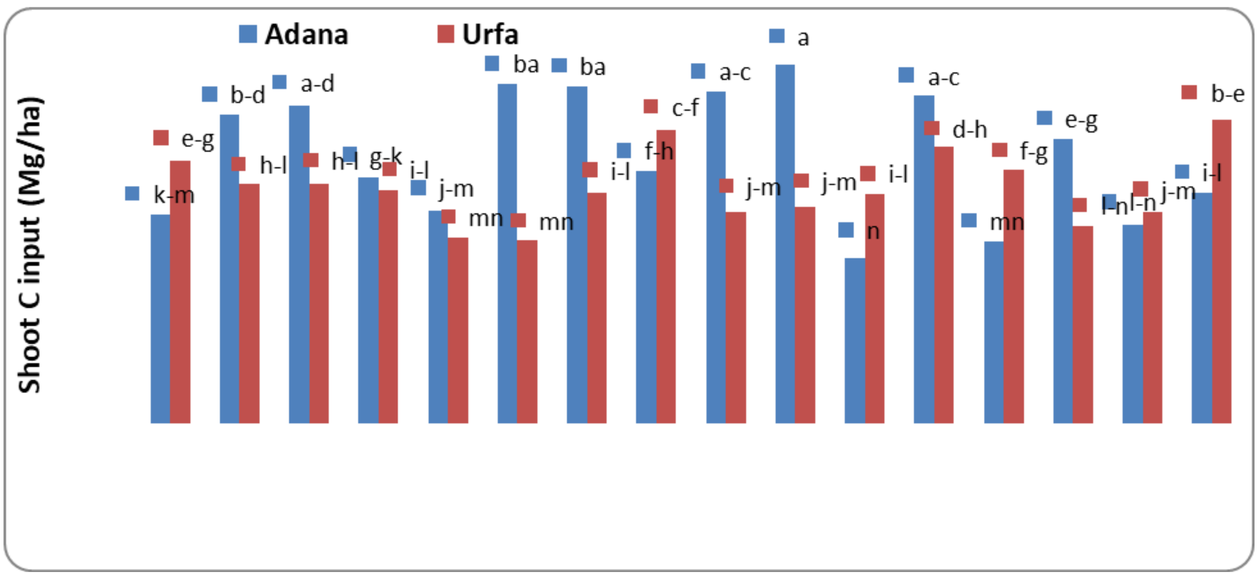

Fig 2. Shoot C inputs in several sweet sorghum genotypes for Mediterranean soil (Adana location) and Harren soil (Urfa location). Data were means of three replicates. Two year data (2016 and 2017) average. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

Table 3. Sweet sorghum genotypes growth response that grown in two years in two locations.

Treatment	Genotype	Plant height 2016	Plant height 2017	Shoot dry weight 2016	Shoot dry weight 2017	Root dry weight 2016	Root dry weight 2017
		cm	cm	kg/ha	kg/ha	kg/ha	kg/ha
Adana	Cowley	338nq	367hm	32381gl	36730jp	6395dg	6173ei
	Grassi	393ef	389ci	34730fk	54222bd	7578ba	7513ba
	M81-E	422dc	410ae	34825fk	57143bd	5515kj	5273jl
	Nebraska sugarcane	368il	393bh	37873b-g	43524gj	6159dj	5988ej
	PI 575753	347mp	337mp	29397kl	37651ip	6168di	5847fk
	Ramada	363jm	373fj	35714ej	59048ac	5510kj	5450il
	Roma	337oq	313 p	32794gl	60952ba	5669hk	5291jl
	Smith	367il	352ko	42095cb	45175eh	6780ce	6592ce
	Theis	408ed	412ad	30571jl	57905ad	5673hk	5401jl
	Topper	377fj	365hm	49175a	65016a	7982a	7875a
	Tracy	335oq	372fj	31778hl	31270p	6190di	6221eh
	UNL-Hybrid 3	437ac	425a	48603a	59778ba	8118a	7337ba
	Williams	330pq	325op	29048l	31905np	5578ik	4938l
	USDA No91	427bc	407ae	41841bd	52381ce	5669hk	5511hl
	USDA No 5	383fi	360in	38667bf	35937lp	5986gj	5635gl
	Gülşeker	325q	352ko	48540a	42317gl	6780ce	7164ad
Sanliurfa	Cowley	352lo	380ek	35524ej	46000eg	6695cf	7579ba
	Grassi	446a	413ac	30952il	43238gk	6077gj	7460ba
	M81-E	379fj	383dj	36857ch	42984gl	6135ej	6230eh
	Nebraska sugarcane	380fj	358jn	40762be	43016gl	4512l	5833fk
	PI 575753	442ba	405ae	32127hl	31683op	6807dc	5556gl
	Ramada	388gf	380ek	32921gl	34286mp	5697hk	5119kl
	Roma	367il	368gl	34063fl	38889go	5913gj	5873ej
	Smith	365jl	383cj	32730gl	54000bd	5142kl	7540ba
	Theis	352lo	338lp	34571fl	38984gn	7115bc	6508df
	Topper	370hk	333np	42762b	38222hp	6281dh	5952ej
	Tracy	383fi	423ba	29968kl	39683gm	6729ce	7103bd
	UNL-Hybrid 3	437ac	400af	36571dh	51270df	6655cf	7619ba
	Williams	365jl	398ag	34730fk	44540fi	6134ej	7262ac
	USDA No91	375gj	363in	36413di	36254kp	6497cg	6270eg
	USDA No 5	355kn	340lp	31873hl	37333ip	6185di	5556gl
	Gülşeker	386fh	427a	33778gl	54508bd	6671cf	6206eh

Data were means of three replicates. Means followed by the same letter within a column are not significantly differed at *P*≥0.05 based on the Tukey test.

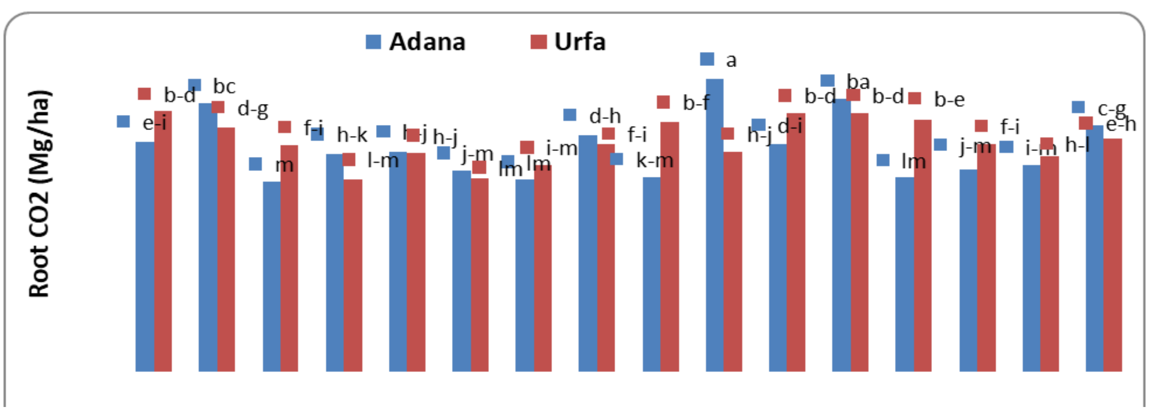

Fig 3. Root CO_2 in several sweet sorghum genotypes for Mediterranean soil (Adana location) and Harren soil (Urfa location).. Data were means of three replicates. Two years (2016 and 2017) average. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

Table 4. Root morphological characteristics of several sweet sorghum genotypes.

Several sweet sorghum genotypes	Root length (km/ha)		Root diameter (mm)		Root surface area (m^2/ha)		Root volume (m^3/ha)	
	Adana	Şanlıurfa	Adana	Şanlıurfa	Adana	Şanlıurfa	Adana	Şanlıurfa
Cowley	139740cge	235366cd	0.65c	0.62ab	447895.23g	579564.63kl	14.75bc	17.73de
Grassi	138430 cgf	171078c	0.66c	0.68ef	549622.23ij	348810.72aa	18.92kl	12.66bc
M81-E	174207ac	202176b	0.63b	0.57e	422856.69b	371600.95	10.74a	9.62bc
Nebraska sugarcane	153153bc	139310a	0.67a	0.69ef	458132.57a	247306.60a	16.27bc	9.32bc
PI 575753	200935de	153152ab	0.49ef	0.75gh	550684.58ef	344609.92ab	10.61a	15.12cd
Ramada	186145cd	190617	0.59gh	0.55d	520068.04gh	392090.51bc	14.31ab	10.44ef
Roma	156175bc	233922de	0.61f	0.63fg	661098.51ef	518219.02kh	18.53cd	16.04cd
Smith	175724cd	234245cb	0.56e	0.54cd	469776.27bc	356994.74a	11.39b	7.92a
Theis	191003a	201870ab	0.63e	0.59c	755373.46hi	561883.41k	22.92c	16.04cd
Topper	160420ab	192288ca	0.68e	0.55ab	578507.85gh	511824.50kh	20.97bc	12.39bc
Tracy	185311bc	198271bc	0.68e	0.66g	708831.96hi	593833.42ij	25.34cd	20.08ef
UNL-Hybrid 3	197027ef	158522cd	0.62e	0.54cd	887757.34kl	422017.87bc	26.70cd	9.47ab
Williams	166785bg	236614sf	0.56e	0.54cd	431053.48ab	339091.35a	8.46a	7.88a
USDA No91	201694de	188538cd	0.62e	0.61bc	772464.88hi	570889.84jk	23.09cd	16.99de
USDA No 5	189691ab	197391c	0.61ae	0.58de	753256.05	434041.31	22.25bc	11.47bc
Gülşeker	671951he	214499cdf	0.57c	0.60bc	749922.85	423806.67	18.93ab	14.40cd

Data were means of four replicates and the average value of two years (2016 and 2017) data.

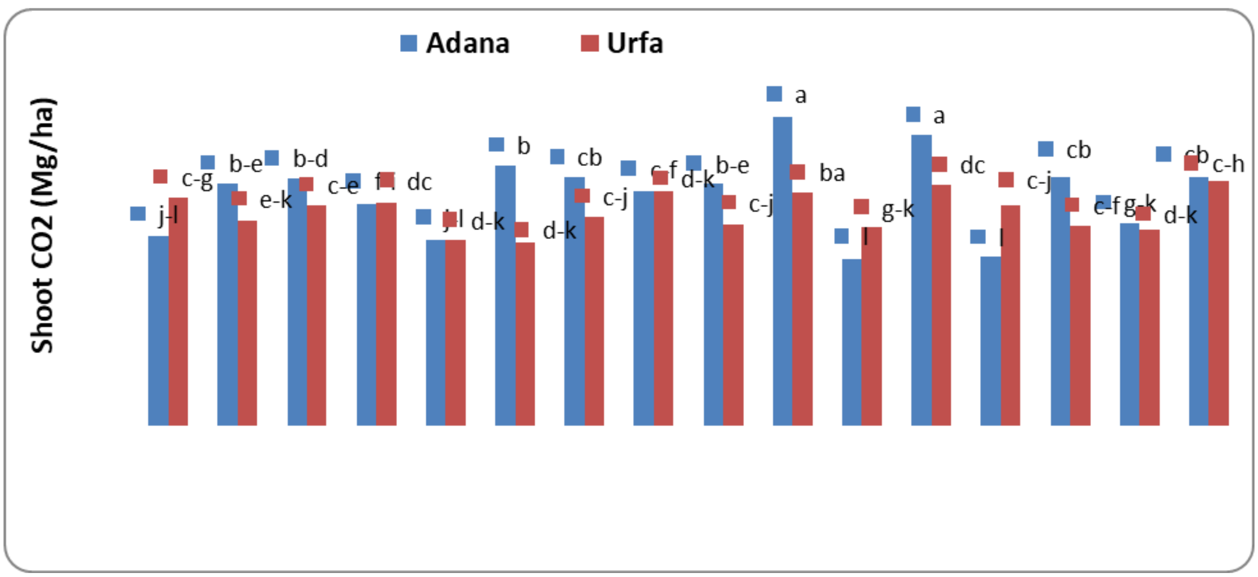

Fig 4. Shoot CO_2 in several sweet sorghum genotypes for Mediterranean soil (Adana location) and Harren soil (Urfa location). Data were means of three replicates. Two years (2016 and 2017) average. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

Table 5. Level of significance for the main and interactive effect on root morphological characteristics and root biomass of several sweet sorghum genotypes

Sources of variations	Root biomass	Root morphological characteristics			
		Root length	Root surface area	Root diameter	Root volume
Locations	***	n.s.	***	n.s.	***
Genotypes	n.s.	*	***	*	**
Locations × Genotypes	n.s.	n.s.	**	n.s.	**

Where n.s. * and ***represents probability of > 0.05, ≤ 0.01 and ≤ 0.001 respectively. Values were means of four replicates.

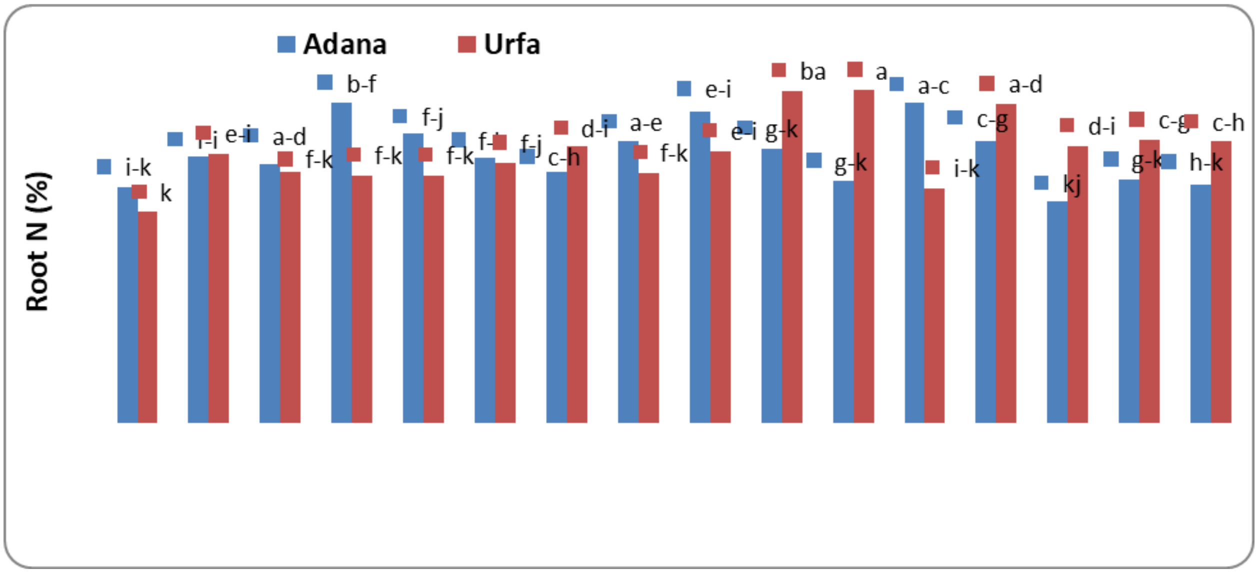

Fig 5. Root N in several sweet sorghum genotypes for Mediterranean soil (Adana location) and Harren soil (Urfa location). Data were means of three replicates. Two years (2016 and 2017) averaged. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

Table 6: Level of significance for the main and interactive effect locations and genotypes on root morphological characteristics of several sweet sorghum genotypes.

Sources of variations	Root C inputs	Shoot C inputs	Root CO_2	Shoot CO_2
Locations	***	***	***	***
Genotypes	n.s.	n.s.	n.s.	n.s.
Locations × Genotypes	**	n.s.	**	n.s.

Where n.s. ** and ***represents probability of > 0.05, ≤ 0.01 and ≤ 0.001 respectively. Values were means of four replicates.

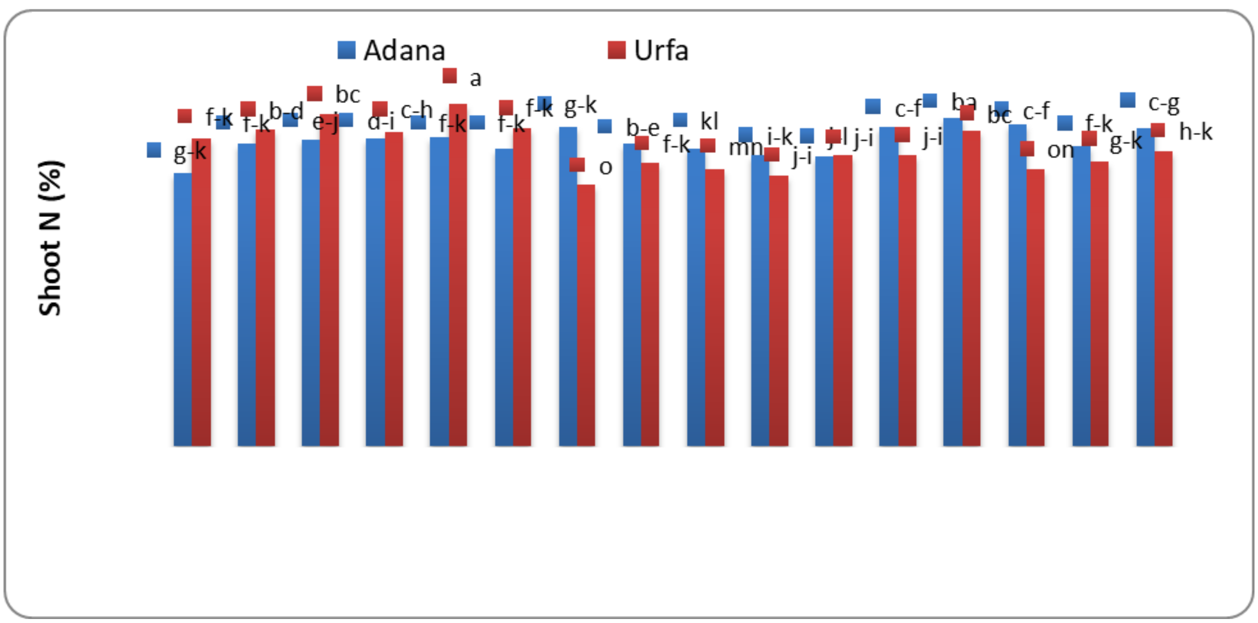

Fig 6. Shoot N in several sweet sorghum genotypes for Mediterranean soil (Adana location) and Harren soil (Urfa location). Data were means of three replicates. Two years (2016 and 2017) averaged. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

Table 7. Level of significance for the main and interactive effect locations and genotypes on root N, shoot N, soil C stock as well as soil N stock.

Sources of variations	Root N	Shoot N	Soil C stock	Soil N stock
Locations	n.s.	***	***	***
Genotypes	*	n.s.	n.s.	n.s.
Locations × Genotypes	**	*	n.s.	n.s.

Where n.s. ** and ***represents probability of > 0.05, ≤ 0.01 and ≤ 0.001 respectively. Values were means of four replicates.

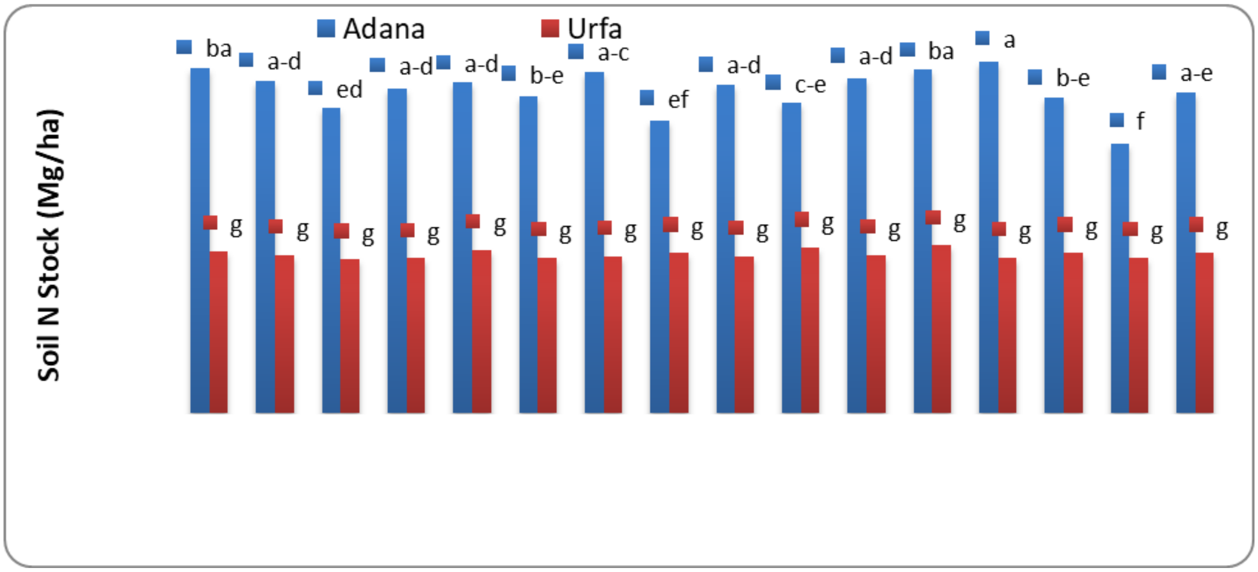

Fig 7. Soil N stock in several sweet sorghum genotypes for Mediterranean soil (Adana location) and Harren soil (Urfa location). Data were means of three replicates. Two years (2016 and 2017) averaged. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

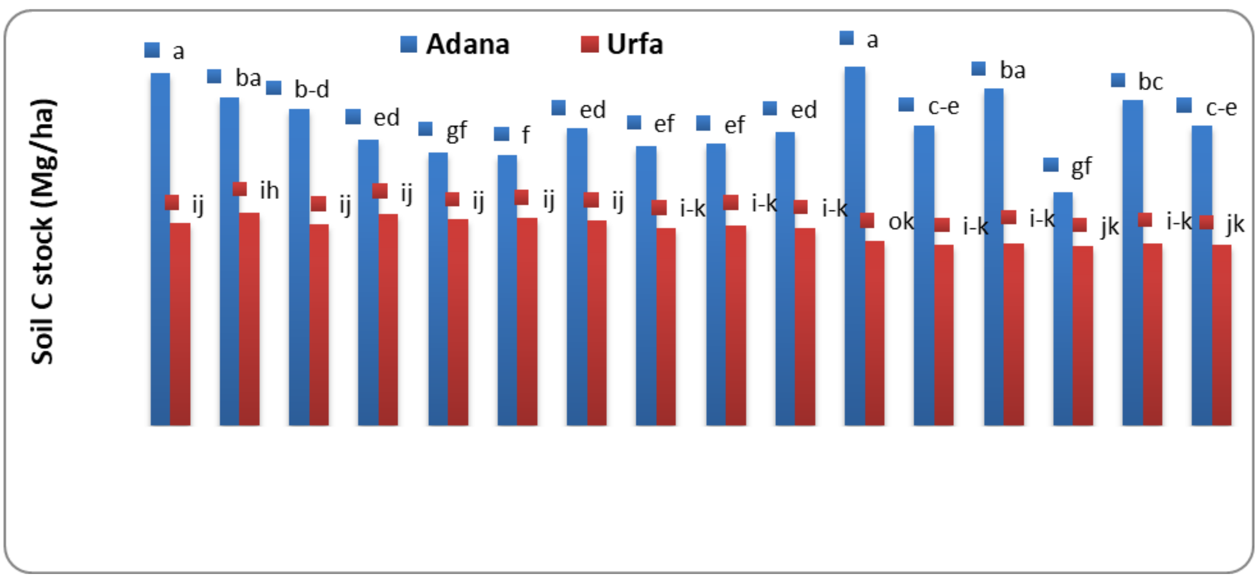

Fig 8. Soil C stock in several sweet sorghum genotypes for Mediterranean soil (Adana location) and Harren soil (Urfa location). Data were means of four replicates. Two years (2016 and 2017) averaged. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

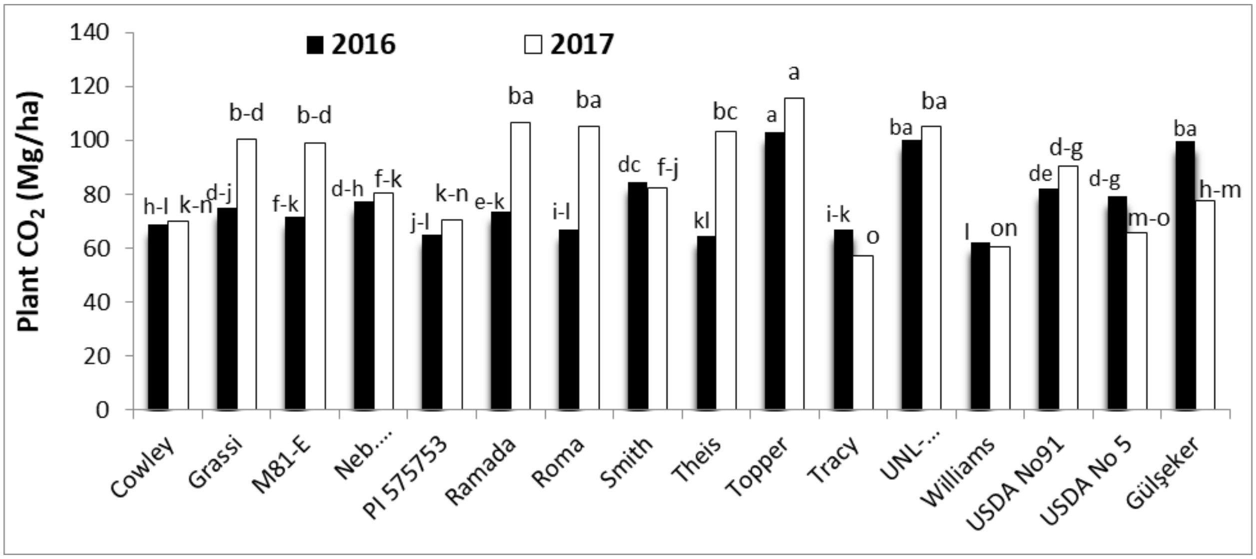

Fig 9a. Plant CO_2 in several sweet sorghum genotypes at a depth of 0-30 cm for Mediterranian soil (Adana location). Data were means of three replicates. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

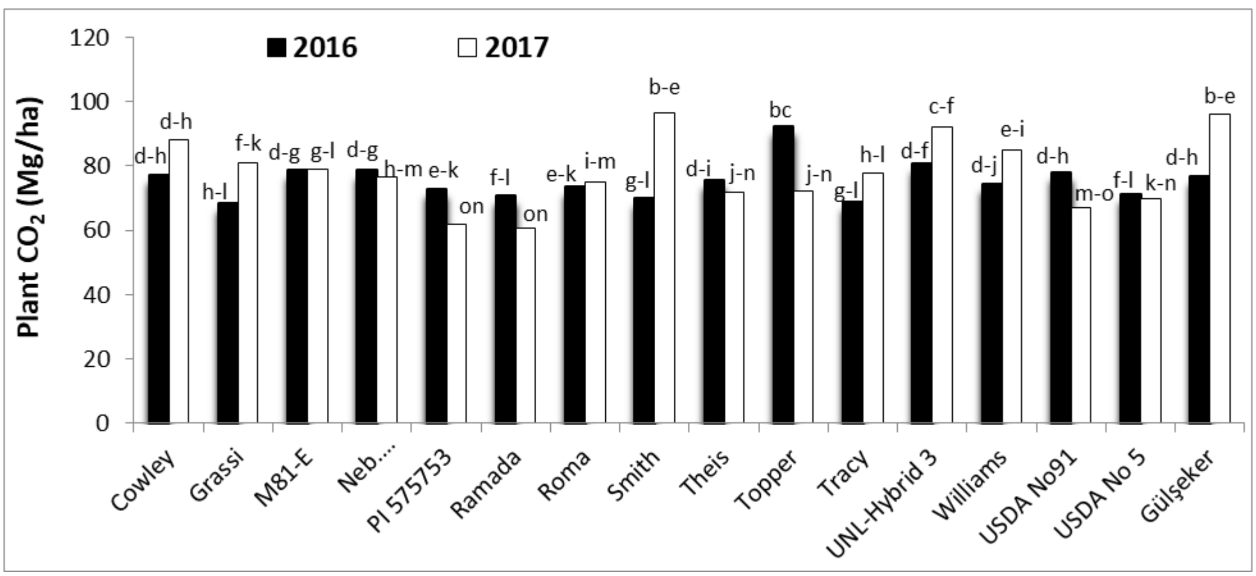

Fig 9b. Plant CO_2 in several sweet sorghum genotypes at a depth of 0-30 cm for Harran soil (Sanliurfa location). Data were means of three replicates. Means followed by the same letter within a column are not significantly differed at P≥0.05 based on the Tukey test.

found 824 Mg/ha for P1579753 genotypes and minimum root CO_2 was found 428 Mg/ha at Şanlıurfa location.

Shoot Carbon Fixation was Converted into CO_2

Shoot CO_2 fixation in several sweet sorghum genotypes in Adana than Şanlıurfa location (Figure 4). Several sweet genotypes shoot CO_2 differ significantly (P ≥0.05) differed between two locations. However, genotypes and locations × genotypes interactions did not differ (Table 6). The maximum shoot CO_2 fixation was found 12236 Mg/ha for BATAEM-4 sweet sorghum genotypes and minimum shoot CO_2 fixation was found 4584 Mg/ha for white Orn genotypes in Adana location. Similarly, maximum shoot CO_2 fixation was found in Nebraska Sugarcane 7059 Mg/ha and minimum hoot CO_2 fixation was found 3721 Mg/ha for Grassi sweet sorghum genotypes at Şanlıurfa locations.

Root N

Root N% was higher in Şanlıurfa than Adana location with some exception (Figure 5). The maximum root N% was found 1.90 for BATEM-5 and minimum root N% was found 0.78 for P1579753 sweet sorghum genotypes at Şanlıurfa location. The maximum root N% was 1.21 for P1579753 and Theis genotypes and minimum root N% was 0.86 for BATAEM- genotypes at Adana locations. Root N% differed significantly ($P \geq 0.05$) among genotypes as well as locations × genotypes interactions (Table 7).

Shoot N

Shoot N% was higher in Adana than Şanlıurfa location in several sweet sorghum genotypes (Figure 6). The maximum shoot N% was 1.93 in White Orn and minimum was 1.28 in Theis sweet sorghum genotypes at Adana location. Likewise, the maximum shoot N% was 1.29 for Tracy and minimum was 0.82 for Cowley genotypes. Shoot N differed significantly ($P \geq 0.05$) between locations as well as location × genotypes interactions (Table 7).

Soil C stock

Soil C stock by several sweet sorghum genotypes was double in Adana than Şanlıurfa location (Figure 7). The highest soil C stock was in White Orn 93 Mg/ha and lowest soil C stock was BATAEM-4 60.26 at Adana location. The soil C stock did not differ among sweet sorghum genotypes at Şanlıurfa location and it ranges from 47 to 55 Mg/ha.

Soil N stock

Soil N stock was 2-3 times higher in Adana than Şanlıurfa locations (Figure 8). Soil N stock varies from 3 to 4 Mg/ha at Adana locations. Likewise, soil N stock varies from 1.83 to 2.03 Mg/ha at Şanlıurfa locations. However, soil N stock did not differ among genotypes as well as locations × genotypes interactions at both Adana and Şanlıurfa locations (Table 7).

Plant biomass CO_2

On average, plant biomass CO_2 was higher in 2017 than 2016 in Adana location (Figure 9a). The plant biomass CO_2 varied 62-103 and 57-115 Mg/ha in the year 2016 and 2017, respectively at Adana location. In general, plant biomass CO_2 was higher in 2017 than 2016 in Sanliurfa location (Figure 9b). The plant biomass CO_2 varied 69-93 and 62-97 Mg/ha in the year 2016 and 2017, respectively at Sanliurfa location.

Discussion

Genotypic responses to root morphological characteristics

Several sweet sorghum genotypes responded differently irrespective to root morphological characteristics. Root volume was lowest in UNL-hybrid-5 sweet sorghum genotypes for both sites (Table 4). Root surface area and root volume among genotypes, location as well as location × genotypes interactions significantly ($p \leq 0.05$) differed at depth of 0-30 cm (Table 5). Our study showed that root length (0-30 cm) of several sweet sorghum genotypes varies from 139310 to 235366 km/ha (Table 4). Likewise, a study found that root length in 0-30 cm soil layer for sweet sorghum species varies from 31 to 46 m/g (Thivierge et. al., 2014). Furthermore, root diameter influences the decomposition and turnover of roots, where smaller fine roots (< 2 mm diameter) have a faster decomposition and turnover (Pacaldo et. al., 2014). The ratio of root length to root dry mass is a widely used indicator is the ability of crops to compete for below ground nutrients (Zegada et. al., 2012). There is no information about sweet sorghum root morphological characteristics, which is required to estimate the contribution of soil C and N inputs. However, some sweet sorghum genotypes had coarse root diameter in both sites that may contribute to soil C input into soil. Likewise, several studies have suggested that sweet sorghum C inputs into the soil could be explained by their root system architecture (Ceotto et. al., 2013). Our finding indicates scope for enhancing soil C sequestration by cultivating collected several USA sweet sorghum genotypes. Similarly, the longer and finer root system of sweet sorghum genotypes likely contributes to higher N uptake efficiency. Thus, not only higher N uptake efficiency but also morphological characteristics of roots should be taken into account when assessing C input from roots.

C and N stocks in root and soil

Shoot N concentration was higher than root N concentration (Figure 5 and Figure 6). Our study found that several sweet sorghum genotypes on soil N stock varies 1.83 to 4.16 Mg N/ha. Likewise, other study found that sorghum plant N stock in soil was 2.47 Mg N/ha (Das et al., 2016). Similarly, shoot C input was ten times higher than root C input (Figure 1 and Figure 2). Likewise, Shoot CO_2 fixation was 8 to 10 times higher than root CO_2 fixation (Figure 3 and Figure 4). Several sweet sorghum genotypes sequester too much C in soil as compared to N stock in soil. Besides their specific function in N uptake, very fine roots could also play a key role in soil C sequestration. This study confirmed that several sweet sorghum genotypes have the ability to C sink in soil. The amount of C stock in soil by several sweet sorghum genotypes depends on land-use change and management practices of several sweet sorghum cultivation (Tolbert et al., 2002).
Sweet sorghum genotypes have high shoot N than root N (Figure 5 and Figure 6). Shoot N varies from 0.82 to 1.88% and root N varies from 0.78 to 1.90%. This difference could be related to the stronger ability of sweet sorghum roots to secrete nitrification inhibitors that likely helped in competing for soil N and may have compensate lower root N than shoot N (Tesfamariam et al., 2014).

Root and shoot C input

Besides their role in nutrient uptake, roots constitute a major source of C for soil (Rasse et al., 2005). Root biomass i.e root volumes were high in several sweet sorghum genotypes in our study. Root volume varies from 7.92 to 26.70 m^3/ha in several sweet sorghum genotypes at both sites. Other study also opined that root biomass might be a good indicator of crop C input to soil (Monti & Zatta, 2009).

Root diameter of several sweet sorghum genotypes were low and did not differ location and location × genotype interaction (Table 4 and Table 5). This minimum root diameter may cause less C input in several sweet sorghum genotypes. A study speculated that roots become more numerous, longer, thicker, and faster growing in crops exposed to high CO_2 with increased root length in many plant species. Branching and extension of roots under elevated CO_2 may lead to altered root architecture and ability of roots to acquire water and nutrients from the soil profile with exploration of the soil volume. Root turnover is important to the global C budget as well as to nutrient cycling in ecosystems and individual plants. Agricultural management practices have a greater impact on root growth than rising atmospheric CO_2 since management practices influence soil physical, chemical, and biological properties of soil, consequently affects root growth dynamics in the belowground (Madhu & Hatfield, 2013).

Our results indicate that even though several sweet sorghum genotypes allocated less C into their root system than shoot (Figure 1 and Figure 2), they produce larger root volume (Table 4), which likely increased their competitiveness for nutrients. Likewise, a study speculated that smaller allocation of C to roots along with a high root length for greater investment of C to the shoot (Bonifas & Lindquist, 2009). This could explain the high C in shoot of several sweet sorghum genotypes in the present study.

Materials and methods

Experimental locations

Field experiments were located at the Eastern Mediterranean Agricultural Research Institute (Adana, 36°51' 35'' K and 35° 20' 43'' D) and GAP Agricultural Research Institute in Turkey (Şanlıurfa, 36º 42' K, 38º 58' D).

Experimental design

The experimental designs were 2 locations × 16 genotypes × 2 seasons. The sixteen sweet sorghum genotypes were evaluated as randomized complete block design with four replications. The locations were Adana and Şanlıurfa. The sweet sorghum genotypes growing season in Turkey is June to September. The experiments were conducted in the year of 2016 and 2017. The sources sweet sorghum genotypes used in this study was shown in Table 1. Most of the genotypes used in this study were collected from the Nebraska University, USA.

Soil and climatic conditions of experimental sites

in Table 2. Soil samples were taken from 0-30 cm depth from the experimental sites in the Adana location known as Mediterranean soils. Some of the best-known examples of Mediterranean soils are the famous “terra rossa” or the Rhodic and Chromic Luvisols the Rhodoxeralfs of Soil Taxonomy (Soil Survey Staff, 2006). The Mediterranean soil initial physio-chemical properties were pH value 7.72, average lime content 20%, organic matter 2%, sand 27.8%, clay 31.2% and silt was 41%. The average temperature for the June-September period in Adana was 27 ºC, the average sunshine duration was 10 hours, the highest average temperature was 33.3 ºC and the average relative humidity was 66% (General Directorate of Meteorology Station, 2014).

The experiment under the conditions of Şanlıurfa was conducted in the Harran soil Series, which was a wide, spread area in the region and was located entirely in the research station. These series soils were alluvial parent material, flat and nearly flat inclined deep-profiled soils (Sakin et. al., 2010). Typical red profiles were clayey textured and the entire profile was very calcareous (Table 1). The A, B, C horizon soils, pH was between 7.3-7.8 and organic matter content was low, cation exchange capacity (CEC) was high. The average temperature for the June-September period was 29.5 ºC, the mean sunshine duration was 11.48 hours, the highest temperature was 44.4 ºC and the average relative humidity was around 36.5% (General Directorate of Meteorology Station, 2014).

Experimental management

The experiments were conducted in summer seasons (June to September) of Turkey in the year of 2016 and 2017. The plot sizes of each experiment were 5 × 5 m^2. Each plot contained 4 lines. The line to line distance was 70 cm. The plant to plant distance was 15 cm. Initial seeding rates of both two year experiments were 70,000 seeds ha^{-1}. Each plot was thinned to 10 plants at 10 days after sowing (DAS). Triple super phosphate (TSP) was used as a phosphorus fertilizer source. A 50 P_2O_5 kg ha^{-1} was applied as a basal dose. Urea was applied as a nitrogen (N) fertilizer source. A 100 kg N ha^{-1} was applied as split dose. A first and second split dose of N was applied at 15 and 45 DAS. The plant was harvested at 89 DAS in both years.

Root sample collection procedure

Root samples were collected according to monolith root sampling techniques (Riedell & Osborne, 2017). Monolith sampling was used to remove a soil block (30 cm long by 10 cm wide by 30 cm deep) in which root length was measured after grid sampling. Soil–root monoliths were taken on the same dates as roots were dug using standard techniques. Roots were separated from soil manually and washed by tap water initially.

Soil analysis

Soil pH was determined by saturation using a ratio of 1:2.5 soil to water by pH meter. Electrical conductivity (EC) were obtained in triplicate using a ratio 1:2.5 soil to water with an Orion model 115A plus conductivity meter bridge (Schlichting & Blume, 1966). The lime content of the soil was measured by Scheibler calcimetres and the results were calculated as %

$CaCO_3$(Carter, 1993). Organic Carbon was determined according to Walkley-Black method and results were calculated as % (Nelson & Sommers, 1982). Soil structure, the texture of the soil was determined according to (Bouyoucos, 1962).

Plant and root analysis

Sweet Sorghum was harvested at dough stage (89 days after planting). Root samples was taken (30 cm long, 15 cm wide, and 30 cm deep) from soil monolith. The monolith soil sampler (Buman, Schumacher, & Riedell, 1994), modified from the design of (Walker & Coventry, 1976). Roots were separated from the soil manually and were washed with distilled water and oven-dried at 65°C for 48h, ground top truss through 0.5 mm sieve and stored prior to total nitrogen and carbon analysis. Plant and root samples collected for estimation of dry matter accumulation at 89 days after planting, total carbon (TC) and nitrogen (N) content of the plant and root samples determined by combustion using a Thermo Fisher Scientific FLASH 2000 Series CN Elemental Analyzer (Thermo Fisher Scientific, Waltham, USA).

Root biomass and trait measurements

Root samples were taken within (0-30 cm) soil depth and washed from soil with water, collecting all root material retained on a 250 µm sieve. Samples were first passed through a 2 mm sieve with water to loosen the soil particles ensuring all water was collected. Root material was dried in a fan forced oven at 65°C for at least 48 h until constant weight. Root dry weights were converted to an equivalent mass per hectare of soil surface (kg ha^{-1}) using the cross sectional surface area of the soil core. Carbon accumulation (kg ha^{-1}) in aboveground biomass and roots was determined by multiplying dry matter weight by total C concentration. Annual C inputs from the rooting systems of sweet sorghum were estimated to determine how it may compensate for the removal of aboveground biomass. For convert of aboveground and belowground carbon to carbon dioxide calculator: One ton of carbon equals 44/12 = 11/3 = 3.67 tons of CO_2.

Root morphological characteristics measurement

The roots were separated from the shoots. The separated roots were washed 3-4 times with deionized water. Then, the whole root system was scanned by a root-system scanner. Root morphological characteristics was measured using the software WinRHIZO image analysis system (WIN MAC, Regent Instruments Inc., Quebec, Canada, http://www.regentinstruments.com/) (Arsenault et. al., 1995).

Statistical analysis

Results were analyzed by two-way analysis of variance (ANOVA) using Genstat 12th edition for Windows (Lawes Agricultural Trust, UK). In order to investigate the effect of mycorrhizae on shoot dry weight, root dry weight, root colonization, mycorrhizal dependency, C and N dynamics data were analyzed using the Statistical Analysis System (SAS 9.1.3). All the statistical testing was performed based on $P \leq 0.05$ as the critical level for the significance of Turkey.

Conclusion

This study showed wide varying greater sweet sorghum genotype root biomass and greater root morphological characteristics in different ecological zones of Turkey. Root turnover and carbon input rate was dependent upon sweet sorghum genotype and location (4109 kg/ ha C in Adana location by Wray genotype). Several sweet sorghum genotypes offer to increase soil C under different climatic conditions of Turkey through increased root mass inputs and rooting depth. Findings also indicated that several sweet sorghum cultivation enhances C stock in shoot, root and soils. These results indicate for enhancing soil carbon sequestration by Sweet Sorghum. Thus sweet sorghum has the capacity to sequester C in soil. This study supports the establishment of annual sweet sorghum genotypes cultivation to enhance C and N stock in soil. However, there is a need for long term studies to establish soil C balance under different climatic condition.

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