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Advantageous effects of bentonite on the growth attributes and metabolic compounds of two mesophytic plants growing in desert sandy soils

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Abstract

Background The best use of sandy soil in hot arid and semi-arid lands for cultivation is the ability to improve its physical and chemical properties. Therefore, the application of eco-friendly and natural substances added to sandy soils has been proven to improve the water retention and nutrient deficiency, consequently the agricultural outputs. The aim of the present investigation is to study the advantageous effects of natural substances application such as bentonite (a Type of clay) to improve the quality of desert sandy soils and plant productivity. The effect of bentonite on the growth and metabolites attributes of two mesophytes (cultivate *Zea mays* and wild *Senna occidentalis*) growing in three sandy soils were studied.

Results The data obtained indicated that the morphological parameters such as length and fresh weight of shoot and root in *S. occidentalis* and *Z. mays* plants were positively affected by the soil texture, bentonite and or their interaction. In calcareous sandy soil, the water content of soil, shoot and root were tended to a maximum value with added certain concentration of bentonite. With fine sands, the total chlorophyll content in both plants was markedly increased with the application of bentonite, which had a dominant role. The same role of bentonite was an effect on the different metabolic compounds such as total soluble proteins, free amino acids and soluble

sugars in organs of investigated plants. Fine sand exerted a high content of soluble proteins and soluble sugars, whereas the calcareous sandy soil accelerates the free amino acids in various plant organs. In general, bentonite had a major role in the osmo-metabolic compounds of both plant organs as well as on the soluble proteins of *Senna occidentalis* root. Significant correlations existed between the water content of soil and plant organs with morphological and metabolic compounds.

Conclusion This investigation studies the advantageous effects of bentonite to improve the quality of desert sandy soil and plant productivity. Bentonite had a positive effect on the growth and metabolites of *Zea mays* and *Senna occidentalis* growing in three sandy soils. Also, bentonite affects the chlorophyll and different metabolic compounds (total soluble proteins, free amino acids and soluble sugars) in two plants.

Keywords: Bentonite, desert sands, *Senna*, *Zea*, growth, metabolites.

Introduction

Plant growth and development is mainly based on the soil quality, water availability and nutrients acquired by plant roots. In arid and semi- arid climate sandy soils have severe consequences for plantation. Therefore, the improvement of sandy soil can be released by using natural amendments such as bentonite. Hence, the addition of bentonite may be an effective approach for solving many problems affecting biochemical activity and plant growth under harsh environmental conditions [1].

The reclamation of sandy soil by application of betonies has beneficial effects on the retain water and nutrients in sandy soil. Also, bentonite addition as a colloidal substance has a capacity to mitigate the nutrient ion leaching by binding on its surface [2-3] and has been proven to improve soil water retention and nutrients necessary for plant productivity [4-5]. Furthermore, the bentonite exhibited a synergistic effect for the growth of plants in sandy soils [6]. The addition of these amendments has a

potential for improving plant photosynthesis ultimately photosynthetic capacity and plant carbon metabolism [7]. Thus, photosynthetic rate exhibited a high value, attributed to increase chlorophyll content in plant leaf. Bandian *et.al.* [8] revealed that the high chlorophyll content was found in beds possessing high bentonite levels. Additionally, the essential element contents in bentonite could increase plant biomass and make more exchange sites available to hold plant nutrients for plant growth [9]. Moreover, increasing nutrients in bentonite increased the root ability to uptake more elements such as P and N consequently, increasing in different plant metabolites. [10]. Furthermore, the accumulation of K in roots with bentonite application can increase the ions related to osmolality. Consequently, the accumulation of metabolites and ions in plants serve as compatible solutes which are related to osmotic adjustments.

In general, sandy soil is poor in retained water and weakness in its chemical properties leads to free percolation because of deficiency of fine particles. Therefore, the goal of this investigation was an attempt to understand the role of bentonite as a natural source for improving the sandy soil inhabits warm desert which participates in retained water and sufficient nutrients, leading to increase plant cropping and productivity. Accordingly, the effect of bentonite, soil texture and their interaction on some growth and physiological parameters in two mesophytic plants (*Zea mays* L., cultivated plant and *Senna occidentalis* (L) Link, wild plant) were studied.

Materials and methods of bentonite

Two plants namely: *Zea mays* L., var. *everta* Sturt. (cultivated plant) and *Senna occidentalis* (L.) Link (wild plant) were used for experimentation. Experimental seeds of *Z. mays* were supplied by the Crop Science Department, Faculty of Agriculture, Assiut University. *Senna occidentalis* is wild mesophyte growing in the Botany farm of Assiut University and the specimens of plant were deposited in Assiut University herbarium (ASTU), Egypt after being identified by K.A. Farghali professor of Plant Ecology according to Tackhlom (1974) and Boulus (1999). The seeds of *senna* were collected from the plant during spring season. Plants were grown in plastic pots

containing 400 gm air dry soil of three types of soil textures contributed to different ecological affiliation of the Egyptian desert. These soils were collected from 1- Mediterranean coastal dunes have oolitic calcareous sandy soil (Cal. soil), 2- Wadi El-Assuiti in the eastern desert have coarse sandy soil (C. soil) and Kharga Oosis region in the western desert have fine sandy soil (F. soil). Each type of soil incubated seed containing certain amounts of bentonite levels as follows: 0 % as control, 1.5 %, 3 % and 5 % of the soil weight. Three pots (replicates) were assigned at random to each treatment level. Soil was irrigated with distilled water reaching field capacity.

The experiment was carried out under natural laboratory conditions, where the air temperature was 36-26 and at day and night, respectively, relative humidity of air was 40-43% with daily artificial and natural illumination. At the end of the experiment (two weeks for *Zea mays* and four weeks for *Senna occidentalis*), the growth parameters of healthy seedlings of the two investigated plants were done. These parameters included: shoot and root length, fresh weight of shoot and root, shoot/root ratio of length, shoot/root ratio of fresh weight, water content of the two plant organs and soil water content.

Determination of total chlorophyll (Chl.) content:

In fresh leaves, the total chlorophyll ($a + b$) content was extracted using 85% acetone and determined according to Lichtenthaler [11].

Preparation of plant extracts for analysis:

For determination of water-soluble metabolites, the seedlings of both species were washed with distilled water and dried thoroughly with filter paper. The excised organs (shoots and roots) were then freshly weighed (0.5gm) and immediately blended with 10 ml of ice-cold distilled water, then centrifugation at 7000 r.p.m. was carried out for 15 min. The supernatant was transferred to a glass bottle; the extracts were subjected to deep freezing until analysis.

Determination of soluble nitrogen metabolites:

Soluble proteins and free amino acids were determined according to procedures described by Lowry *et al.* [12], Lee and Takahashi [13], respectively. The content of each metabolite in the different experimental plants has been expressed in mg/gm. fresh wt. by using spectrophotometer UNICAM model UV-Vi's spectrometry (Made in England).

Determination of soluble sugars (S.S.):

In two investigated plants, both organ (shoot or root) extracts, soluble sugars were determined according to Dubois *et al* [14].

Statistical analysis:

The effects of single factors (soil type and percentage of bentonite) and their interaction (Soil texture x bentonite) were evaluated via analysis of variance (F values), the sharing coefficient percentage (role of each factor on the tested parameters), and the simple linear correlation coefficient, r. [15]. This statistical analysis was carried out via the SPSS program [16].

Results

The effect of bentonite, soil texture and their interaction on growth and metabolic attributes in both *Zea mays* and *Senna occidentalis* plants were illustrated in figures (1-7).

Growth parameters:

a- Length of organs:

In *Z. mays* plants, the addition of bentonite (3-5% of soil weight) exhibited an increase in both shoot and root lengths (SL and RL). A maximum shoot length (42.3 cm) was observed in the calcareous (Cal.) soil. While the coarse sandy soil (C. soil) encourages the root length and produces 24.0 cm (Figure 1). The SL, RL and SL/RL ratio was greatly affected by 1.5 % bentonite and produced a highest value (2.3) in fine sand soil (F soil). Similarly, in *S. occidentalis* the applied of 3-5 % bentonite stimulates the SL and RL; particularly in plants grown in Cal. soil (Maximum length of shoot and root was 42.33 cm and 27.5 cm, respectively). The SL/RL ratio showed

a similar pattern at different bentonite levels and soil textures (Figure 2). Statistically, bentonite had a dominant role on the shoot length of *Z. mays* and root length of *S. occidentalis* as well as SL/RL ratio of *Z. mays* (Table 1). The same role was played by the soil factor in the case of root length of *Z. mays* as well as SL and SL/RL ratio in *S. occidentalis*.

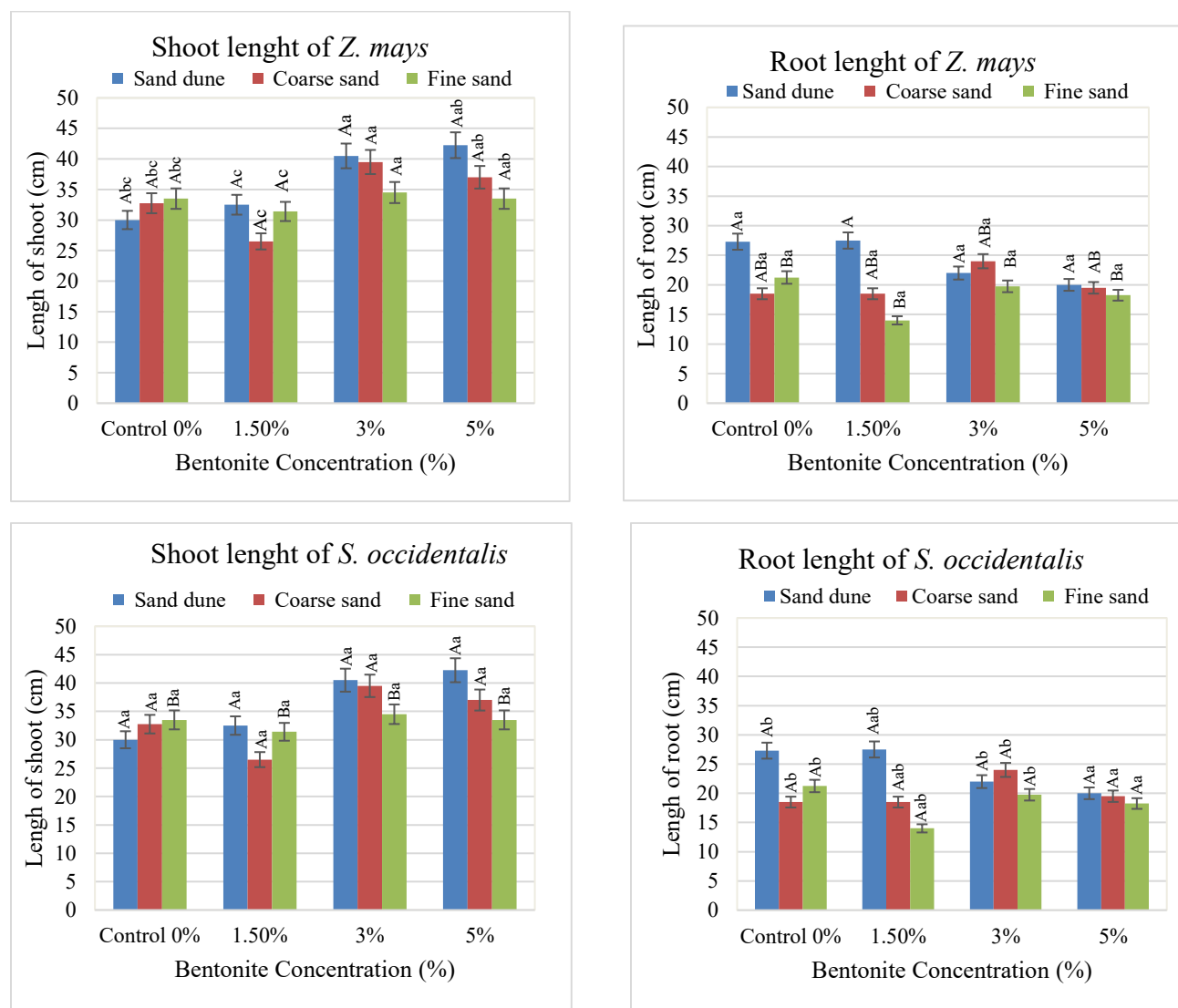


Figure 1. Average values of shoot and root length (cm) of plants investigated at different bentonite concentrations (%) and soil textures, [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicate no significant difference according to Tukey test].

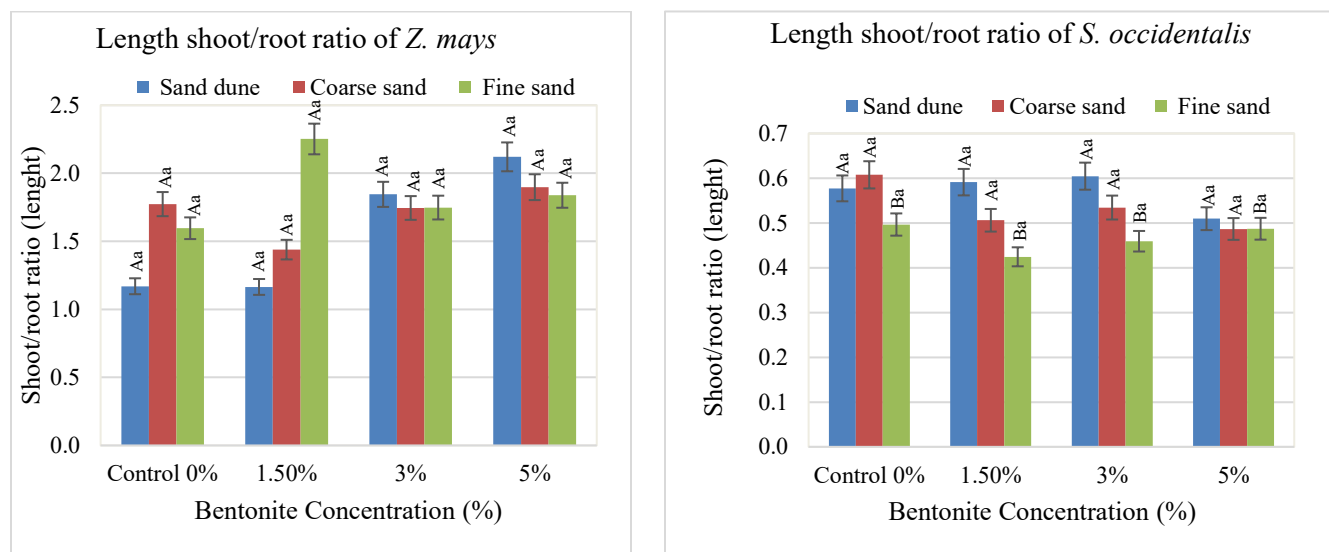


Figure 2. Average values of shoot / root ratio of length of plants investigated at different bentonite concentrations (%) and soil textures [values having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicates no significant difference according to Tukey test].

Table 1. F and share% values of the effect of soil texture, bentonite and their interaction on the length (L) of the plant organs investigated.

	Organ parameter Source of variance	Shoot length			Root length		SL/RL Ratio	
		df	F	Share (%)	F	Share (%)	F	Share (%)
<i>Z. mays</i>	Soil texture	2	2.05	9.08	7.90**	43.90	4.04*	13.24
	Bentonite	3	9.40**	62.36	1.45	12.07	5.56**	27.31
	Soil texture x Bentonite	6	2.15	28.56	2.64*	44.03	6.05**	59.45
<i>S. occidentalis</i>	Soil texture	2	10.46**	69.02	0.96	5.96	12.04**	56.58
	Bentonite	3	1.48	14.68	7.98**	74.01	2.78	19.63
	Soil texture x Bentonite	6	0.82	16.30	1.08	20.03	1.69	23.80

*Significant at 0.05 confidence level **significant at 0.01 confidence level

b-Fresh weight:

The fresh shoot weight (S Wt.) of *Z. mays* gained the highest value at 5% bentonite added to Cal. soil (Figure 3). The same was true in the case of fresh root weight (R

Wt.) without bentonite. It was found that, a maximum of S Wt. of 3.9 gm. and R Wt. of 1.8 gm. at 3-5% bentonite with substrate Cal. soil. The S Wt./ R Wt. ratio of 3.6 existed at applied 5% bentonite in fine sandy soil. In *S. occidentalis*, the S Wt. and R Wt. obtained a high biomass at applied 1.5% bentonite in plants grown in Cal. soil (1.6 gm. and 1.2 gm., respectively). The calcareous soil exerted a high S Wt. / R Wt. ratio (3.6), while the lowest ratio was obtained in fine soil (Figure 4). The F values and sharing % indicated that the bentonite effect was highly significant and had a dominant role on the R Wt. The same role of (Soil x bentonite) interaction was realized in the case of S Wt. (Table 2).

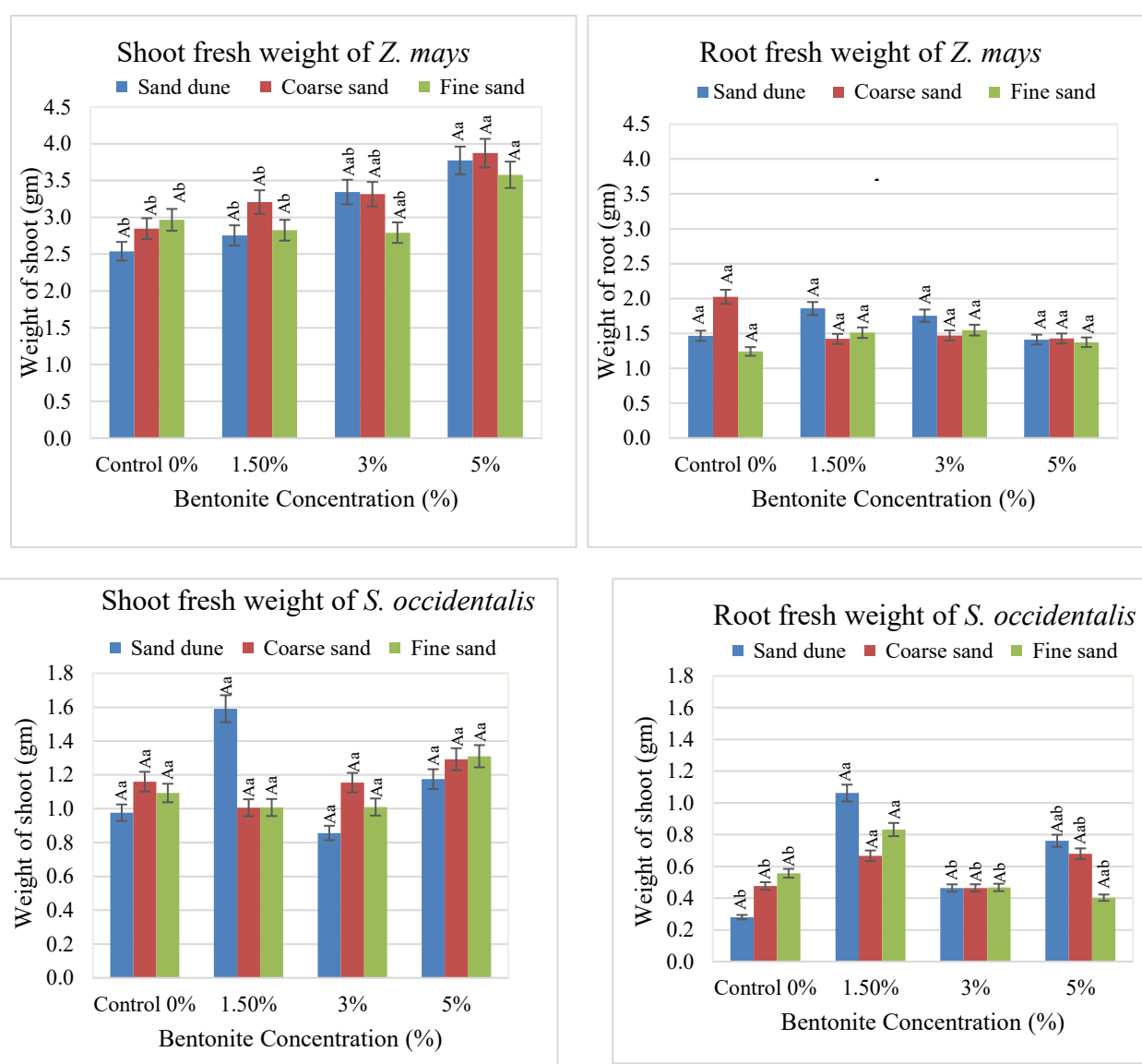


Figure 3. Average values of shoot and root weight of plants investigated at different bentonite concentrations (%) and soil textures [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicates no significant difference according to Tukey test].

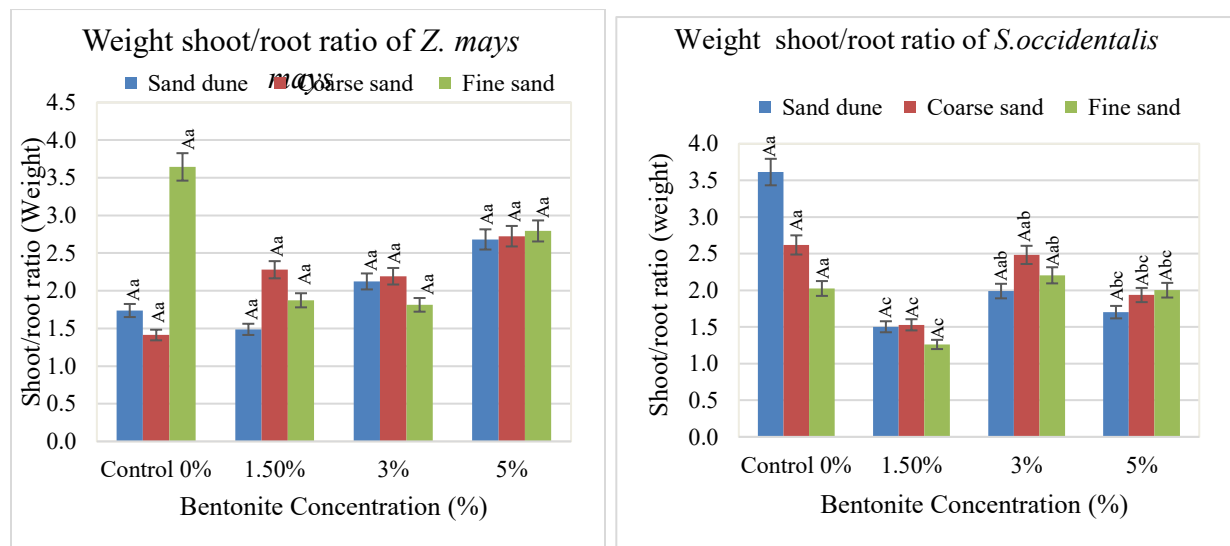


Figure 4. Average values of weight shoot / root ratio of plants investigated at different bentonite concentrations (%) and soil textures [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicates no significant difference according to Tukey test].

Table 2. F and share% values of the effect of soil texture, bentonite and their interaction on the fresh weight (F Wt.) of the investigated plant organs.

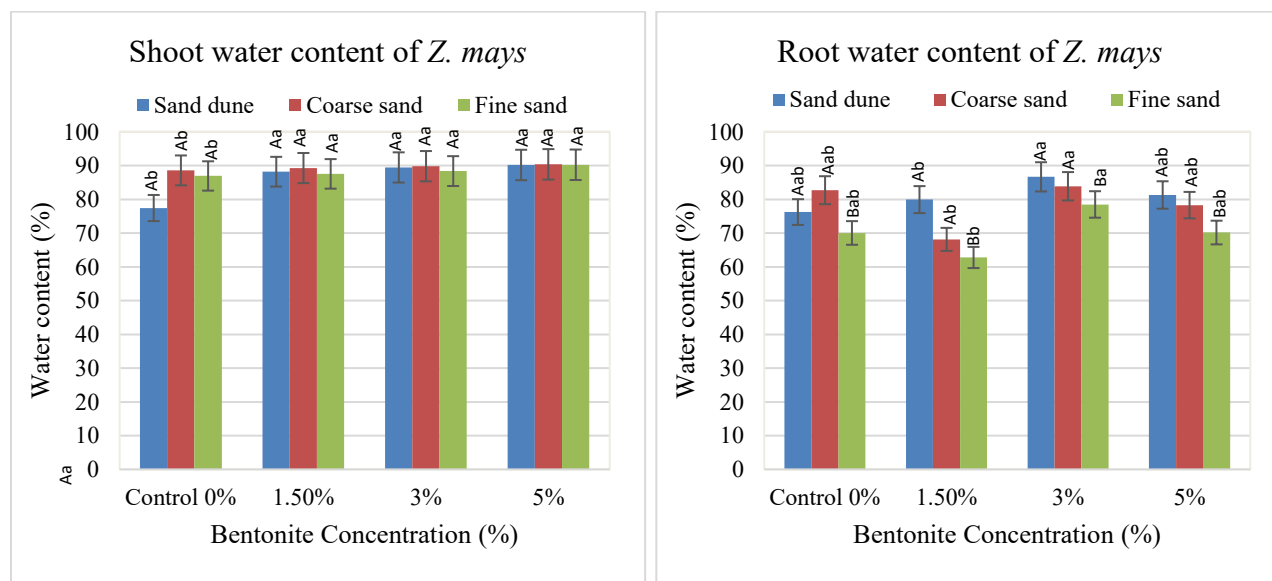
	Organ parameter Source of variance	df	Shoot weight		Root weight		S Wt./RWt. Ratio	
			F	Share (%)	F	Share (%)	F	Share (%)
<i>Z. mays</i>	Soil texture	2	0.57	7.80	0.81	17.19	0.99	12.87
	Bentonite	3	3.81*	77.87	0.43	13.86	1.39	27.19
	Soil texture x Bentonite	6	0.35	14.33	1.08	68.94	1.53	59.94
<i>S. occidentalis</i>	Soil texture	2	0.21	1.37	0.61	2.81	0.61	10.17
	Bentonite	3	2.84	28.39	9.16**	63.26	1.04	26.24
	Soil texture x Bentonite	6	3.51*	70.24	2.46	33.93	1.26	63.59

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Water content in shoot, root and soil:

The presence of bentonite (3-5%) exhibited an increase in the water content of shoot of *Z. mays* plants grown in various investigated soils and in root at 3% bentonite (Figure 5). In *S. occidentalis* the maximum content of shoot was shown at 5% bentonite in coarse sand and at 1.5% in cal. soil, while high water content in root existed at 1.5% bentonite. The single factors and their interaction effect were significant (with some exceptions) on the water content organs of both species. Bentonite played a dominant role on the water content of shoot, whereas the soil texture had the same role in the case of the root (Table 3).

Applying bentonite exhibited an increase in the soil water, particularly in the calcareous dandy soil (Figure 6). Bentonite, soil texture and/or their interaction had a significant effect on the soil content, where their interaction played the main role (Table 3).



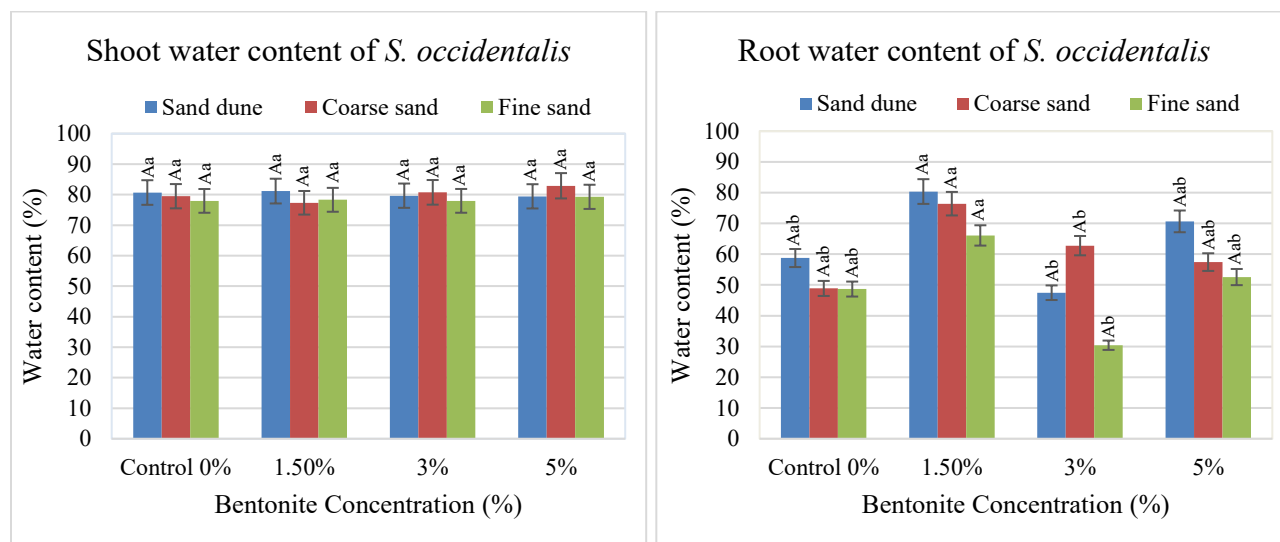


Figure 5. The average values of shoot & root water content of both plants investigated at different bentonite concentrations (%) soil texture, [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicate no significant difference according to Tukey test].

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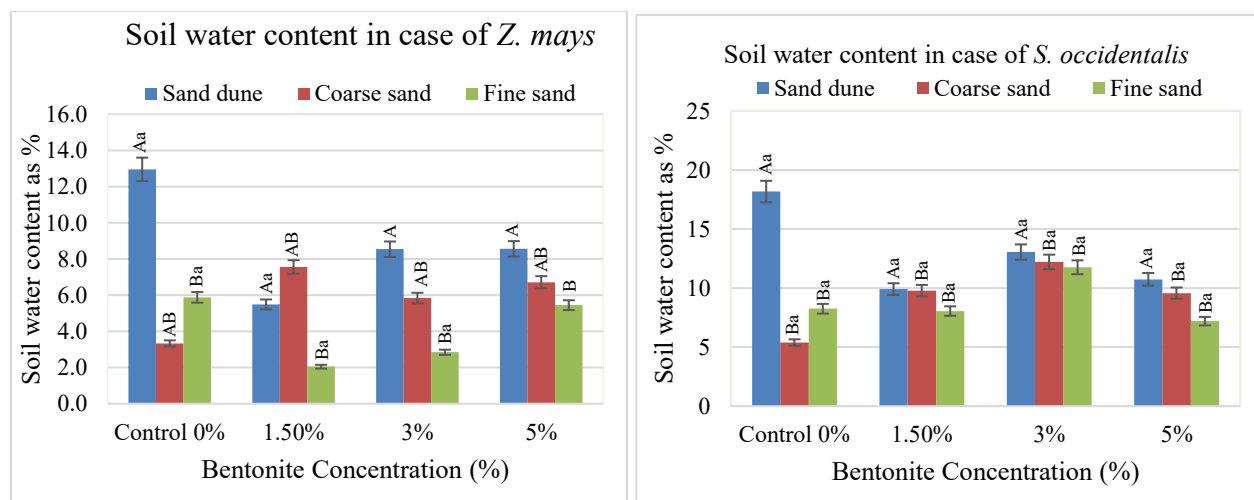


Figure 6. Average values of water content in the soil cultivated by plants investigated at different bentonite concentrations (%) and soil textures [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicates no significant difference according to Tukey test].

Table 3. F and share% values of the effect of soil texture, bentonite and their interaction on the water contents of the soil and investigated plant organs.

	Water content		% Soil water content		% Plant water content of Shoot		% Plant water content of Root	
	Source of Variance	df	F	Share (%)	F	Share (%)	F	Share (%)
<i>Z. mays</i>	Soil texture	2	8.37**	49.28	12.85**	15.04	8.78**	48.42
	Bentonite	3	1.22	10.78	26.14**	45.92	4.97**	41.13
	Soil texture x Bentonite	6	2.26	39.93	11.11**	39.04	0.63	10.45
<i>S. Occidentalis</i>	Soil texture	2	12.40**	34.96	1.738	30.87	2.204	23.01
	Bentonite	3	3.95*	16.68	0.560	14.91	3.80*	59.49
	Soil texture x Bentonite	6	5.72**	48.35	1.018	54.22	0.559	17.50

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Chlorophyll content:

Noticeably, the applied 1.5 – 3% bentonite stimulated the total chlorophyll content in *Z. mays* leaves which tended to a maximum (1.63 mg. g⁻¹ fresh leaf weight) in calcareous and coarse sandy soils. Adversely, in *S. occidentalis*, the chlorophyll content was variable. Regardless of soil texture, the 5% bentonite concentration stimulates the total chlorophyll content in *S. occidentalis* (Figure 7). Statistical analysis indicated that the effect of investigated factors was highly significant on the total chlorophyll of both species. Bentonite and interaction (soil texture x bentonite) had a dominant and subdominant role, respectively on the total chlorophyll of both investigated plants (Table 4).

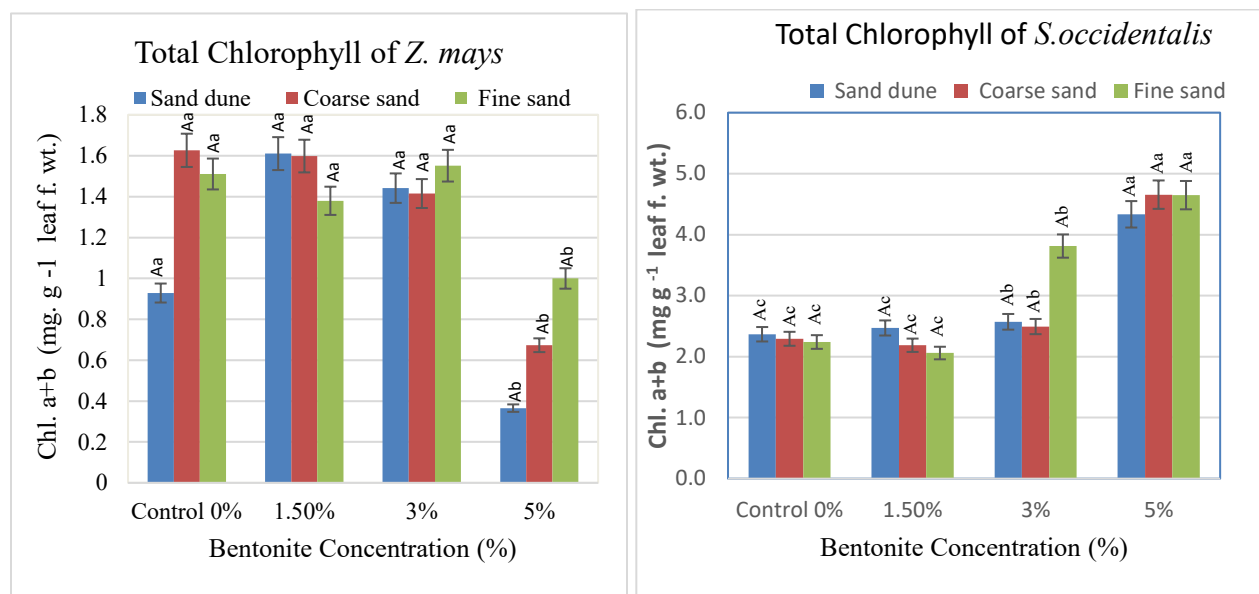


Figure 7. Total chlorophyll ($a + b$) contents of fresh leaves (mg. g^{-1} fresh weight) of plants investigated at different bentonite concentrations (%) and soil textures [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicate no significant difference according to Tukey test].

Table 4. F and share% values of the effect of soil texture, bentonite and their interaction on the total chlorophyll of the investigated plant.

Source of variance \ Total chlorophyll	df	Total Chl. of <i>Zea</i>		Total Chl. of <i>Senna</i>	
		F	Share (%)	F	Share (%)
Soil texture	2	5.16*	9.38	3.49*	1.67
Bentonite	3	26.59**	72.54	124.45**	89.17
Soil texture x Bentonite	6	3.31*	18.08	6.40**	9.17

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Metabolic compounds:

Soil texture, bentonite and their interaction effect on the metabolic compounds. (Soluble proteins, free amino acids and soluble sugars) in the plants investigated were shown in figures (8-10).

a- Total soluble proteins (S.P.):

In general, the soluble protein in shoot showed a higher content than that in root. The low concentration of bentonite (1.5%) had a boosting effect on the total soluble proteins in shoots and roots of *Z. mays*, particularly in fine soil (Figure 8). Maximum soluble protein content was 8.4 and 4.4 mg g⁻¹ fresh weight, respectively. The S.P. content in *S. occidentalis* was higher than that in the case of *Z. mays* plants. A maximum S.P. content was of 9.6 and 12.9 mg g⁻¹ fresh weight in *Senna* shoot and root, respectively. While high S.P. content in shoot was observed in calcareous soil, the same pattern in root existed in the fine soil at different bentonite levels. Bentonite and soil texture singly had a highly significant effect on the soluble proteins of *S. occidentalis* root, where bentonite played the main role and soil texture role was subsidiary (Table 5).

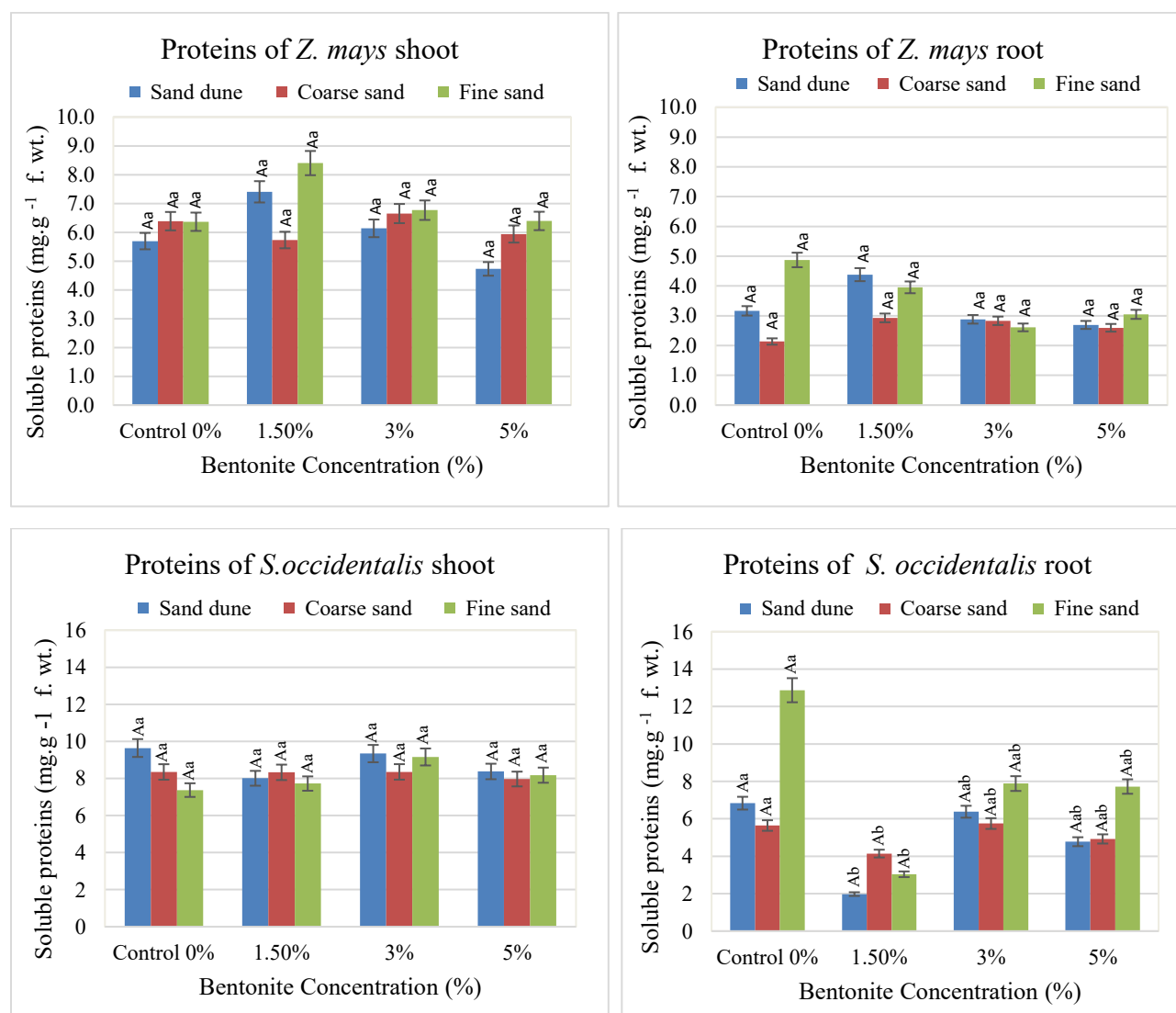


Figure 8. Total soluble protein contents (mg. g⁻¹ fresh weight) in shoots and roots of plants investigated at different bentonite concentrations (%) and soil texture [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicate no significant difference according to Tukey test].

Table 5. F and share% values of the effect of soil texture, bentonite and their interaction on the total soluble proteins (SP) of the investigated plant organs.

Content Source of variance	df	<i>Z. mays</i>				<i>S. occidentalis</i>			
		Shoot SP		Root SP		Shoot SP		Root SP	
		F	Share (%)	F	Share (%)	F	Share (%)	F	Share (%)
Soil texture	2	1.62	24.03	3.18	28.62	0.358	24.664	4.09*	24.845
Bentonite	3	1.74	38.74	2.17	29.21	0.296	30.621	5.83**	53.032
Soil texture x Bentonite	6	0.84	37.23	1.56	42.17	0.216	44.715	1.215	22.123

*Significant at 0.05 confidence level **significant at 0.01 confidence level

b-Total free amino acids (A.A.):

Similarly, the low free amino acids were observed in root than those of shoot. In both shoot and root the applied bentonite (3-5%) stimulates the free amino acids content in *Z. mays* plants grown in calcareous soil. Also, calcareous and fine sandy soils exhibited an increase in the amino acids content in both organs of *S. occidentalis* with increases of bentonite concentration (Figure 9).

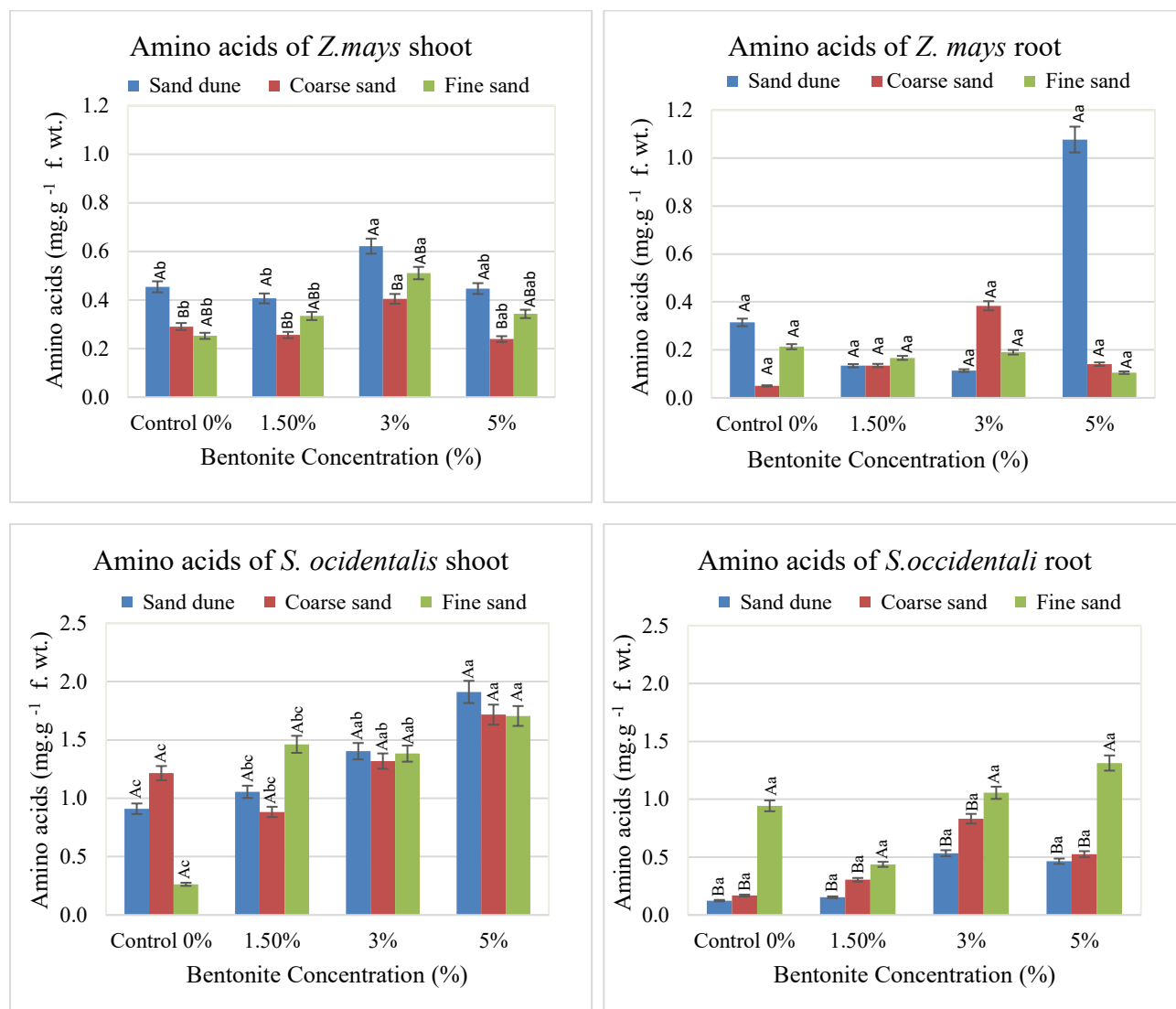


Figure 9. Free Amino acids contents (mg.g⁻¹ fresh weight) in shoots and roots of plants investigated at different bentonite concentrations (%) and soil textures [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicates no significant difference according to Tukey test].

The F values indicated that bentonite had a significant effect and played the major role on the free amino acids in different *Z. mays* and *S. occidentalis* organs. Exceptionally, in the case of *Senna* roots, the soil texture had the main role, and the bentonite role was subsidiary. Also, the interaction (soil texture x bentonite) had a dominant role on the A.A. of *Z. mays* roots (Table 6)

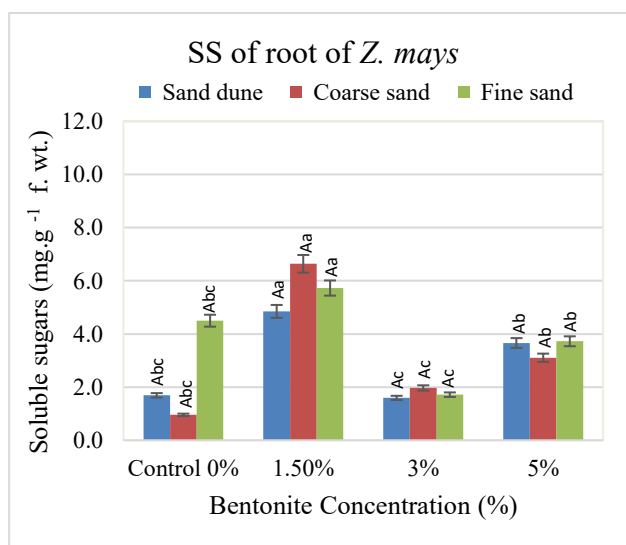
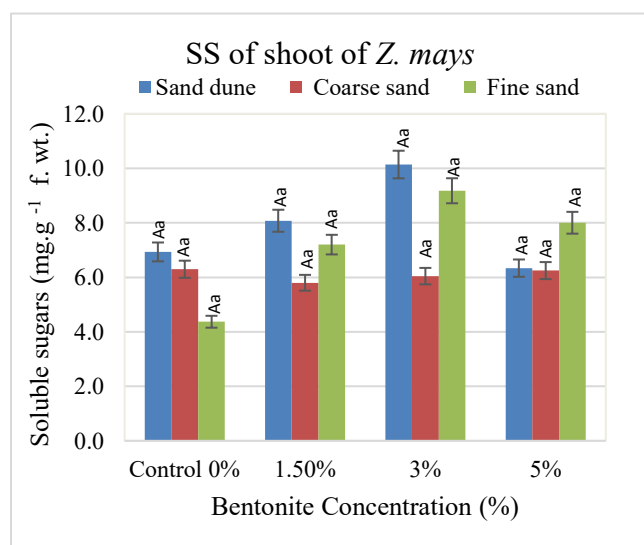
Table 6. F and share% values of the effect of soil texture, bentonite and their interaction on the total free amino acids (AA) of the plant organs investigated.

Content Source of variance	df	<i>Z. mays</i>				<i>S. occidentalis</i>			
		Shoot AA		Root AA		Shoot AA		Root AA	
		F	Share (%)	F	Share (%)	F	Share (%)	F	Share (%)
Soil texture	2	6.94**	47.22	12.00**	17.90	0.449	1.287	10.35**	51.633
Bentonite	3	4.59*	46.90	8.20**	18.36	16.12**	69.216	4.77*	35.645
Soil texture x Bentonite	6	0.29	5.88	14.24**	63.75	3.43*	29.497	0.850	12.721

*Significant at 0.05 confidence level **significant at 0.01 confidence level

c-Soluble sugars (S.S.):

The addition of 3% bentonite had a boosting effect on the soluble sugars of *Z. mays* shoots in calcareous soil. Likewise, in roots, the soluble sugar content (Maximum 6.6 mg, g leaf fresh wt.) was stimulatory applying 1.5% bentonite in coarse sand. In fine sand, bentonite at 3% had a boosting effect on the soluble sugar content in both shoot and root of *S. occidentalis*. In general, the soluble sugar content in roots of both species investigated was higher than that of shoots (Figure 10). The F value revealed that the bentonite or /and its interaction with soil texture had a significant effect and played the dominant and subdominant roles on the soluble sugars in different tested plants organs except in the case of *Zea* shoots (Table 7).



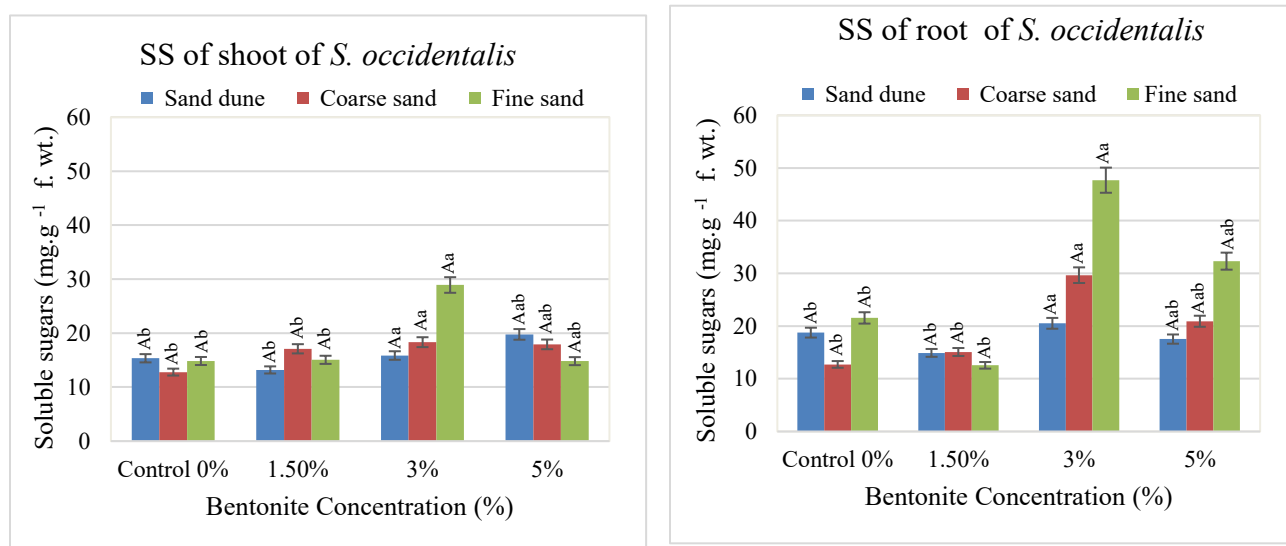


Figure 10. Total soluble sugar content (mg. g⁻¹ fresh weight) in shoots and roots of plants investigated at different bentonite concentrations (%) and soil textures [vales having similar symbols (A, B. soil texture and a, b. bentonite conc.) indicates no significant difference according to Tukey test].

Table 7. F and share% values of the effect of soil texture, bentonite and their interaction on the total soluble sugars (SS) of investigated plant organs.

Content Source of variance	df	<i>Z. mays</i>				<i>S. occidentalis</i>			
		Shoot SS		Root SS		Shoot SS		Root SS	
		F	Share (%)	F	Share (%)	F	Share (%)	F	Share (%)
Soil texture	2	2.74	23.27	5.53*	5.65	1.94	6.19	4.31*	22.94
Bentonite	3	2.91	37.11	49.38**	75.60	8.44**	40.46	6.48**	51.71
Soil texture x Bentonite	6	1.55	39.63	6.12**	18.75	5.56**	53.35	1.59	25.35

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Correlations between growth attributes, water content and metabolites

A significant positive correlation was found between water content of soil, shoot and root with different growth parameters of *Z. mays* under the effect of soil texture x bentonite interaction (Table 8). Under bentonite factor, the shoot length (SL) was positively correlated with free amino acids (A.A) and negatively with soluble proteins (S.P.).

Table 8. Significant correlations between water content of soil, shoot and root with different growth parameters (length and weight) of *Z. mays* organs

Parameters Factors	Soil WC. x RL	Shoot WC. x S Wt.	Root WC. .x SL	Root WC. x SL/RL
Soil texture	0.997*	0.641	0.841	-1.00*
Bentonite	0.239	0.795	0.830	0.173
Soil texture x Bentonite	0.594*	0.665*	0.672*	-0.289

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Root weight (R Wt.) was negatively correlated with A.A. and soluble sugars (S.S.) under the effect of soil texture and bentonite, respectively. While, S.S. had a positive correlation with shoot Wt. /root Wt. ratio under soil texture factor (Table 9).

In *S. occidentalis*, the soil water content was positively correlated with root length and weight under the effect of interaction (soil texture x bentonite) and soil texture, respectively (Table 10). The effect of bentonite and its interaction with soil texture had a positive correlation between shoot S.P. and soil water. Root water content was negatively correlated with different metabolites under soil texture and its interaction with bentonite. Also, root weight was positively correlated with water content under bentonite factor and its interaction with soil texture. The correlation of shoot length was significant positive with shoot S.P. and root A.A. under soil texture and bentonite, respectively (Table 11).

Table 9. Significant correlation coefficient between metabolites (SP, AA and SS) and growth parameters (length and weight) of *Z. mays* organs.

Content	Root SS		Root AA		Root SP
Parameter	R. Wt.	S Wt. / R. Wt.	SL	R. Wt.	SL
Factors					
Soil texture	-0.999*	0.999*	-0.268	0.661	-0.042
Bentonite	-0.004	-0.256	0.952*	-0.969*	-0.992**
Soil texture x Bentonite	-0.460	-0.310	0.371	-0.324	-0.277

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Table 10. Significant correlation coefficient between soil water content with growth parameters (length and weight) and soluble proteins (SP) of *S. occidentalis* organs.

% soil water content				
Parameters	Root L.	Shoot Wt.	Root Wt.	Shoot SP
Factors				
Soil texture	0.978	0.524	1.000**	0.996
Bentonite	0.802	-0.954*	-0.714	0.984*
Soil texture x Bentonite	0.653*	-0.376	-0.351	0.761**

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Table 11. Significant correlation coefficient between root water content with root weight and metabolites (SP, AA and SS) of *S. occidentalis* organs.

%Root water content					
Parameters	Root SP	Root AA	Shoot SS	Root SS	Root Wt.
Factors					
Soil texture	-0.989	-1.000*	-1.000**	-0.999*	0.713
Bentonite	-0.873	-0.624	-0.543	-0.749	0.972*
Soil texture x Bentonite	-0.673*	-0.548	-0.463	-0.668*	0.667*

*Significant at 0.05 confidence level **significant at 0.01 confidence level

Discussion

Application of bentonite in different sandy soils of hot deserts has a potential role on the physical and chemical soil properties, ultimately on the plant health and productivity. The increase in root biomass and length enhances plant ability to absorb water from soil depth [17]. Obtained data indicated that the addition of moderate amounts of bentonite (3%) to oolitic calcareous sandy soil produced a high length of both shoot and root systems of *Z. mays* and *S. occidentalis*. Likewise, the increased

bentonite concentration to the same soil exhibited an increase in weight of both species' organs. While the shoot/root ratio of length and weight parameters exerted a maximum value at relatively high bentonite content (5% of dry soil Wt.) in fine sandy soil. This implied that the bentonite application in sandy soil promotes most morphological traits and water use efficiency in plants cultivated under water deficit condition [18]. Therefore, the presence of bentonite in drought- affected soils has a negative impact of drought on the plant growth due to improved soil moisture retention [19-20]. Consequently, bentonite amendment facilitates the availability of water and nutrients for plant development [21]. Statistically, the bentonite had a dominant role on the length and weight of *Z. mays* shoot. This was true in case of root length and weight of *S. occidentalis*. Whereas the soil texture played the same role on the shoot and root length of *Z. mays* and, *S. occidentalis*, respectively. Also, the (soil texture X bentonite) interaction had a major in the case of length shoot/root ratio of *Z. mays*. This means that the bentonite addition to growth substrates enhanced the agronomic attributes of experiment plants [22].

The water content in aerial and sub-soil, a part of the plants investigated, was slightly affected by soil texture. The addition of moderate bentonite (3%) amounts to the used sands, exhibiting an increase in the water content of shoot and root in both *Z. mays* and *S. occidentalis*. Apparently, bentonite accelerates the soil water retention which helps the water uptake by plants roots and indicates a significant effect of bentonite or its interaction with soil texture on the soil water content, particularly in calcareous sands. Also, the addition of colloidal soil particles influences soil-plant relationships, quality of nutrients and water availability [23]. Therefore, adding soil supplements to sandy soil will improve soil accessible water consequently plant yield [24]. The F test and sharing % indicated that the bentonite played the main role and had a significant effect on the water content of *Z. mays* shoot and *S. occidentalis* root. Likewise, the same effect of soil texture and bentonite was recorded on the water content of *Z. mays* roots.

The effects of a soil amendment enhanced the sandy soil properties and plant photosynthesis activity resulting in more sustainable plant production. Hence, bentonite application enhanced photosynthetic activity [25]. Under low bentonite levels (1.5-3.0%), exhibited an increase in the total chlorophyll of *Z. mays* plants, whereas the same was true in *S. occidentalis* at relatively high bentonite level, particularly in fine sandy soil. Moreover, the highest chlorophyll content existed in the beds possessing the highest bentonite content [8]. The statistical analysis indicated that the bentonite had a highly significant role and the major role on the total chlorophyll of both investigated plants and the (soil texture x bentonite) had a secondary role. Accordingly, the presence of restricted amounts of bentonite in the growth substrates had a boosting effect on the chlorophyll contents in plants [22].

The accumulation of soluble osmolytes and proteins in plant tissues under water stress can provide a situation for continuance of water uptake for root zone. Therefore, amending soil with bentonite enhances the plant's ability to absorb retained soil water. Within plants, the water bound partially depends on a colloidal property of soluble proteins. The water-soluble proteins of plants investigated were responded to the bentonite application, particularly fine sand. Accordingly, the soluble proteins in the roots of *Z. mays* and *S. occidentalis* exhibited an increase at moderate bentonite levels. The same existed in the shoot of *Z. mays* in fine sand and *S. occidentalis* in calcareous sand. Noticeably, the effect of bentonite played the main role on soluble proteins of *Z. mays* plants and the soil texture had the secondary role.

The accumulating osmotically active metabolites such as soluble sugars and free amino acids in plants contribute to osmotic adjustment by lowering the internal osmotic potential, ultimately facilitating drought tolerance [26]. The data obtained elucidated that the free amino acids in both shoot and root of *Z. mays* and *S. occidentalis* had a highest value in presence of 3-5% bentonite added to calcareous sandy soil. Moreover, the bentonite or its interaction with soil texture had a significant effect and dominant role on the free amino acids of various plant organs investigated.

Generally, the bentonite played a crucial role (singly or its interaction with sand) on the free amino acids of *Z. mays* and *S. occidentalis* cultivated in sandy soils, particularly calcareous sands. The positive effect of bentonite on the chemical composition and metabolites in plant tissues may be due to improving essential properties of sandy soil [10].

The soil supplied with moderate bentonite levels produced a maximum amount of soluble sugars in shoot and root of both *Z. mays* and *S. occidentalis* plants grown in fine sands. Therefore, the increased soluble sugars of root are accompanied by an increase in its capacity for water uptake and retention under drought conditions [27]. According to F values and sharing % the soluble sugars of investigated plants were greatly affected by bentonite factor, whereas the interaction (soil texture x bentonite) had a similar role on S.S. of *S. occidentalis* shoot. This was an agreement with Bandian *et al.* [8] who reported that the soluble carbohydrates contents were enhanced by bentonite used. The amending of soil with bentonite could significantly reduce the soluble carbohydrate levels accumulated under drought stress [25].

Several significant positive correlations were announced between the water content of the soil and plant organs with growth parameters of *Z. mays* under (bentonite x soil texture) interaction. Conversely, under the bentonite factor effect, the different metabolic compounds were negatively correlated with the growth parameters due to translocation of metabolites to shoot and root construction. In agreement with Farghali and El-Aidrous [28], the total chlorophyll was positively correlated with soluble proteins and negatively correlated with free amino acids in root and participate in the construction of protein molecules in shoot under the effect of bentonite, soil texture and/ or their interaction. In the case of *S. occidentalis* plant, the same correlations were found between different investigated parameters.

Conclusion

Apparently, the obtained data revealed that the application of bentonite as a low cost and abundance deposits in the Arabian deserts increases the nutrients availability and

soil water retention. Results indicated that, the added 3% bentonite concentration to sandy soil, particularly calcareous sands improved the growth parameters of mesophytic plants such as length and biomass of shoots and roots. The total chlorophyll was markedly increased in plants due to high nutrient availability. The water-soluble metabolites get the best amounts in plants due to bentonite in addition to the sand substrate. Comparatively, the cultivated *Z. mays* show superiority over in the growth parameters than that in the wild *S. occidentalis*. Otherwise, the wild mesophyte outperforms the cultivated plant in the metabolic compound contents. This reflected an advantageous strategy of wild plants for increase in osmo-metabolic adjustment which helpful in the drought tolerance of plants exposed to arid and semi-arid conditions.

Abbreviations

Z. mays: *Zea mays*

S. occidentalis: *Senna occidentalis*

Cal. soil: Oolitic calcareous sandy soil in Mediterranean coastal dunes

C. soil: coarse sandy soil in Wadi El- Assuiti and the eastern desert.

F. soil: fine sandy soil in Kharga Oasis region in the western desert.

S Wt.: shoot weight

R Wt.: root weight

S Wt./ R Wt. ratio: shoot weight/ root weight ratio

S.L.: shoot length

R.L.: root length

S.L./ R.L.: shoot length/ root length ratio.

Soil x bentonite: interaction between soil and bentonite

S.P.: soluble proteins

A.A.: amino acids

S.S: soluble sugars

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Authors' contributions

Farghali, K. A. and Suzan A. Tammam: speculation, data curation, formal analysis, writing review, validation, writing-original draft and editing the manuscript. All authors read and approved of the final manuscript.

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Availability of data and materials

All the data is in the published article

Declarations

Ethics approval and consent to participate

This study uses plant materials and does not utilize transgenic technology, neither involves endangered or protected species. We complied with all relevant institutional, national and international guidelines and the appropriate permissions were obtained from Faculty of Science, Assiut University, Egypt, for obtaining Zea, Senna seeds. This study was supported by the Department of Botany & Microbiology, Faculty of Science, Assiut University, including handling these two plants and processing the experiment.

Consent for publication

Not applicable. The authors confirm that the manuscript has been read and approved by all authors. The authors declare that this manuscript has not been published and is not under consideration for publication elsewhere. All methods were carried out in accordance with relevant guidelines and regulations.

Competing interests

There was no conflict of interest from the authors.

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