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FULL LENGTH ARTICLE

Reclamation of calcareous soil and improvement of squash growth using brewers' spent grain and compost

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Abstract Brewer's spent grain represents approximately 85% of the by-products generated by the beer industry. It is acidic and rich in organic matter and nutrients. In Egypt, spent grain has no value and is available at no cost all year. Incubation and germination experiments were conducted to assess the potential of using spent grain and compost to increase soil fertility and squash (*Cucurbita pepo* L.) growth in a calcareous soil. Amendments were two rates of spent grain (13.5, 26.7 g kg^{-1}), two rates of compost (24.7, 49.4 g kg^{-1}), a blend of lowest rates of compost and spent grain and a control. Treatments were mixed with calcareous soil, placed in pots and incubated anaerobically under field conditions for one month. After incubation 15 squash seeds were planted in the soil pots. Highest rate of spent grain most effectively increased soil water holding capacity, organic matter, macronutrients, micronutrients, germination parameters, and reduced soil pH. Mixing compost with spent grain was more effective than high rate of compost in increasing water holding capacity, soil nutrients, and decreasing soil pH. While both treatments were equally effective in enhancing squash germination and increasing soil organic matter. Spent grain is more effective than compost in improving properties of calcareous soils, and is much less expensive.

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1. Introduction

Calcareous soils contain high levels of calcium carbonate ($CaCO_3$) that affects soil properties related to plant growth, such as soil water relations and the availability of plant nutrients (Elgabaly, 1973). They are common in the arid areas of the earth (FAO, 2016) occupying >30% of the earth's surface, and their $CaCO_3$ content varies from just detectable up to 95%

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(Marschner, 1995). Cultivation of calcareous soils presents many challenges, such as low water holding capacity, high infiltration rate, poor structure, low organic matter (OM) and clay content, low CEC, loss of nutrients via leaching or deep percolation, surface crusting and cracking, high pH and loss of nitrogen (N) fertilizers, low availability of nutrients particularly phosphorous (P) and micronutrients, and a nutritional imbalance between elements such as potassium (K), magnesium (Mg) and calcium (Ca) (Elgabaly, 1973; El-Hady and Abo-Sedera, 2006; FAO, 2016). Under such severe conditions, desired yield levels are difficult to attain.

Calcareous soil lacks the OM necessary for optimum soil function as cropland. The addition of organic amendments improves soil chemical and physical properties, initiates nutrient cycling, and provides a functioning environment for vegetation.

Due to the shortage of organic farm waste in Egypt, industrial organic by-products may be utilized as alternatives to traditional organic fertilizers. Brewer's spent grain (SG) is a by-product of the beer industry, representing approximately 85% of the total by-products generated (Mussatto et al., 2006). It is acidic, rich in protein, cellulose, lignin, hemicelluloses, arabinoxylan, lipid and ash (Mussatto and Roberto, 2006; Tang et al., 2009), C, N, P, K, Ca, Mg, Copper (Cu), Cobalt (Co), Iron (Fe), Manganese (Mn), Selenium (Se), Sulfate (SO_4), as well as vitamins and amino acids (Mussatto and Roberto, 2006; Essien and Udotong, 2008). Thus, it holds promise for use in agriculture. For every 100 liters of beer produced, 20 kg of spent grain is generated (Mussatto, 2014). SG disposal is often an environmental problem; therefore, reuse of this by-product is an important issue to address. The characteristics of SG make it good candidate for use in agriculture.

In Egypt, spent grain is a waste product and available in large quantities at no cost throughout the year. Given the recent escalation in fertilizer costs, alternative uses for such products need to be explored. Few researchers have investigated the use of spent grain as a soil amendment and there is little information for using spent grain as an amendment for calcareous soil. Therefore, the objective of this study was to assess the potential for using spent grain as an organic source to increase soil fertility and crop growth in calcareous soil. Adapting this system may alleviate the environmental and economic problems of excess waste and degraded soil. The specific objectives are to determine the effectiveness of using spent grain and compost as amendments for calcareous soils to increase water holding capacity, enhance soil sequestration of macro and micronutrients, and increase the growth of squash grown on amended soils.

2. Materials and methods

2.1. Soil sampling and location

Calcareous soil samples (*Typic Calciorthids*) were collected from the experimental farm of the City of Scientific Research and Technological Applications (SRTA-City), New Borg El-Arab, Egypt (Approximately latitude is 30°51′58.1″N and 2 9°34′31.8″E). The climate is typically Mediterranean with dry and hot summers and cool and wet winters. The mean annual temperature is 20.3 °C, average high temperature is 26.5 °C and mean low temperature is 13.3 °C. Annual precipitation is 149 mm, mainly falling in the months of November through February (Climate-Data.org, 2016). Soil samples were collected at a depth of 0–30 cm, air-dried and sieved through a 2-mm sieve prior to analysis. Sub-samples of the air-dried soil were used for the chemical and physical parameters. The main properties of the soil are shown in Table 1.

2.2. Amendments

Two types of organic amendments were used (compost and spent grain) in this study. The compost consisted of animal waste and plant residues, from the composting facility of College of Agriculture, Moshtohor, Al Qalyubia Governorate, Egypt. The spent grain, a by-product from the beer industry, was obtained from Al Ahram Beverages Company, Abu Hammad, Al Sharkia Governorate, Egypt. The properties of the compost and spent grain were determined according to the standard procedures described by Kehres (2003). The main properties of the compost and spent grain are shown in Table 2.

2.3. Experimental setup

Two pot experiments were carried out during the summer of 2014 at the experimental farm of the SRTA-City.

2.3.1. Incubation experiment

Amendment materials were applied to calcareous soils at 2 different rates of compost and spent grain (Table 3). The base rate of compost (C1) and spent grain (T1) was the amount of compost or spent grain necessary to increase soil organic matter by 1%. Compost and spent grain were also added at 2 times the base rate (C2 and T2). Additional treatments included a blend of compost and spent grain (C1T1) and a control (no amendment). All treatments were mixed with 8 kg soil and placed in polyethylene pots. In order to allow

Table 1 Calcareous soil characterization before treatment applications.

Analyte	Calcareous soil
pH (1:2.5 w:w)	8.34
EC (dS m^{-1}, 1:1 w:w)	1.74
Total N (%)	0.03
Available P (mg kg^{-1})	4.20
Available K (mg kg^{-1})	320.2
Total $CaCO_3$ (%)	30.6
CEC ($Cmol^{+}$ kg^{-1})	11.81
Organic matter (%)	0.96
Organic C (%)	0.56
Total DOC (%)	0.012
Sand (%)	64.1
Silt (%)	15.2
Clay (%)	20.7
Texture	Sandy clay loam
Fe (mg kg^{-1})	4.10
Zn (mg kg^{-1})	1.43
Mn (mg kg^{-1})	3.49
Cu (mg kg^{-1})	0.61
B (mg kg^{-1})	0.30

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Table 2 Amendment characterizations (oven dry weight basis).

Analyte	Compost	Spent grain
pH (1:5 w:w)	7.20	4.16
EC (dS m^{-1}, 1:5 w:w)	5.81	1.45
Organic matter (%)	40.5	75
Total N (%)	2.10	6.12
Total P (%)	1.03	1.86
Total K (%)	0.57	2.74
Organic carbon (%)	23.5	43.5
C:N ratio	11.2	7.1
Moisture (%)	22	75
Fe (mg kg^{-1})	960	1130
Zn (mg kg^{-1})	220	368
Mn (mg kg^{-1})	100	210
Cu (mg kg^{-1})	61	98
B (mg kg^{-1})	26	39

Table 3 Amendment application rates (oven dry weight basis).

Treatment		Incubation Exp.	Germination Exp.
		g kg^{-1}	
Ctrl (−)	Negative control	No amendment	No amendment
Ctrl (+)	Positive control	–	NPK[a]
T1	Spent grain	13.3	13.3
T2	Spent grain	26.7	26.7
C1	Compost	24.7	24.7
C2	Compost	49.4	49.4
C1T1	Compost + Spent grain	C1 + T1	C1 + T1

[a] 50% of NPK recommendation rate (Ammonium nitrate 0.18 g kg^{-1} + Triple super phosphate 0.67 g kg^{-1} + Potassium sulfate 0.05 g kg^{-1}).

applied amendments to have an effect on soil properties, all pots, along with controls, were incubated for one month without plants. Each pot was sealed in a clear polyethylene bag and incubated anaerobically under field conditions for one month starting on 1st of June, 2014. The soil pots were buried in a bare field with the upper portions exposed to the atmospheric conditions. Pots were placed in a randomized complete block design with four replications for each treatment. Pots were equilibrated at 65% of saturation capacity according to the Romanenko equation (Romanenko, 1961). After incubation, the soils were analyzed for some physical and chemical properties.

2.3.2. Germination experiment

After the incubation period, the plastic covers were removed and the pots were planted with 15 squash seeds (*Cucurbita pepo L.*). To ensure that nutrients were not limited at germination, 50% of the NPK rates recommended for squash were added to all pots except for negative control (Table 3). All pots were watered with tap water at rates calculated using Romanenko's equation. The germination trial lasted for 15 days. The number of germinated seeds was recorded daily. The germination of the seeds was evaluated using the following parameters; coefficient of velocity of germination (CVG), final germination percentage (FGP), germination index (GI), and dry weight. The Coefficient of velocity of germination (CVG) was evaluated according to Maguire (1962) as follows:

$$\mathrm{CVG} = \frac{(G1 + G2 + \cdots + Gn)}{(1 \times G1 + 2 \times G2 + \cdots + n \times Gn)}$$

where G is the number of germinated seeds and n is the last day of germination.

The final germination percentage (FGP) was obtained by dividing the final number of germinated seeds in each pot by the total number of sown seeds, multiplied by 100. Germination Index (GI) was calculated as described by the Association of Official Seed Analysts (AOSA, 1983) as follows:

$$\mathrm{GI} = \frac{\text{number of germinated seeds in the first count}}{\text{days of first count}} + \cdots + \cdots + \frac{\text{number of germinated seeds in the final count}}{\text{days of final count}}$$

At the end of the experiment, the plants were harvested and washed using distilled water, air dried, and oven dried at 65 °C for 48 h and biomass yield was recorded.

2.4. Soil analysis

Soil samples were air dried, ground to < 2 mm, and analyzed for pH in 1:2.5 soil water suspension (Jackson, 1958). Electrical conductivity (EC) was determined in 1:1 soil water extract (Jackson, 1958). Cation exchange capacity (CEC) was determined by IM NaOAc method (Rhoades, 1982). Total carbonate content was determined using calcimeter (Nelson 1982). Total nitrogen was determined by Micro-Kjeldehl method (Bremner and Mulvaney, 1982). Soil organic matter was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). Available K was estimated by 1 N ammonium acetate solution and measured by the flame photometer (Jackson, 1958). Total dissolved organic carbon was determined using the TOC analyzer (multi-N/C UV3100, Analytik Jena product, Germany) at 1100 °C. Available zinc, copper, iron, boron and manganese were extracted by DTPA solution as explained by Lindsay and Norvell (1978) then measured with inductively coupled plasma (ICP) atomic emission spectroscopy. Available phosphorus was extracted with 0.5 N $NaHCO_3$ according to Olsen and Sommers (1982). Particle-size distribution was determined by hydrometer as described by Gee and Bauder (1986). The soil water-characteristic curve was measured for the site soil using pressure plate extractors (Dane and Hopmans 2002) in a matric potential range of 0.0–20 m. Water holding capacity (WHC) was determined according to Skene et al. (1995).

2.5. Statistical analysis

To test for statistical differences, an analysis of variance was calculated using PROC GLM followed by Fisher's protected least significant difference for mean comparisons using SAS

13.1 statistical software (SAS Institute, 2013). A significance level of $\alpha = 0.05$ was chosen to reduce the likelihood of a Type II error in analysis of incubated soil and germination data.

3. Results

3.1. Incubation experiment

3.1.1. Water holding capacity and soil-water characteristic curves

Table 4 contains the ratios of air-dry water content of treated calcareous soils to the air-dry water content of the control soil. In addition, WHC ratios of treated soil to the WHC of control soil are shown. Spent grain (T2) was superior to all other treatments. The ratio of air-dry water content of T2 was nearly twice the water content of the control. The ratios of WHC behaved similarly in all treatments for air-dry conditions. T2 significantly increased WHC compared to all other organic treatments. The compost treatments (C1 and C2) have lower ratios of the soil water content at both air dry and WHC compared to the same rate of the spent grain treatments (T1 and T2). The organic amendments enhanced the water ratio at air-dry condition more than at WHC.

The soil-water characteristic curves of the studied soil are shown in Fig. 1. These curves are expressed as water content ratios (organic treated: control). The soil-water characteristic curves are greatly affected by the addition of organic matter. The ratios increase as the soil matric suction increases until matric suction of 700 cm and stays nearly constant between matric suction of 1000 and 2000 cm. These ratios behaved similar to the trend of air-dry and WHC ratios and followed the order of T2 > C1T1 > C2 > T1 > C1 > Ctrl. The spent grain (T2) positively affected the soil-retained water more than compost (C2). The soil retained water depends on the amount and type of organic amendments. At matric suction of 700 cm, the corresponding water content ratios were 5.74, 3.95, 3.10, 1.98, 1.58 and 1 for T2, C1T1, C2, T1, C1 and Ctrl, respectively. Accordingly, the high rate of spent grain (T2) possessed the greatest water content at a wide range of soil water suction.

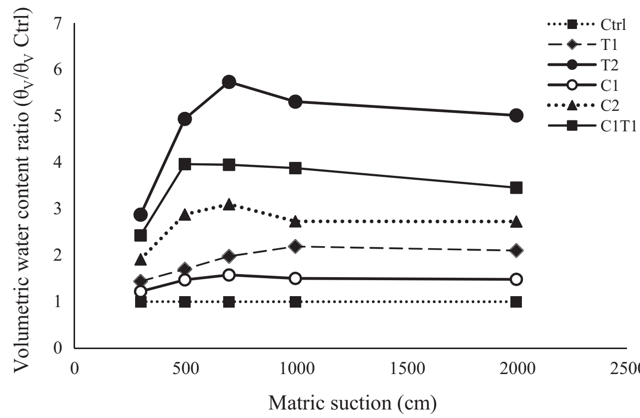

Figure 1 Ratio of water contents for the organic treated to control of calcareous soil. All values represent the mean of four replicates.

3.1.2. Calcareous soil chemistry

Soil pH responded rapidly to all amendment applications; during incubation, pH had decreased to within the ideal range for plants (Table 5). The differences in the pH values among the treatments and the control were significant. C1T1 and T2 possessed the lowest pH values compared to the other treatments. The reduction of pH was affected by the application rate and type of amendment. All organic amendments lead to significant increases in soil OM and dissolved organic carbon (DOC) (Table 5). The largest increases were observed with the T2, C2 and C1T1 treatments. One month after amendment incorporation, OM and DOC were increased in all treatments compared to control (ranged from 63% increase in the C1 pots to 194% increase in the T2 pots for OM, and from 66% increase in the C1 pots to 308% increase in the T2 pots for DOC).

Soil N, P, and K were significantly increased by all organic treatments compared to the control (ranged from 2 to 13-fold increase for N; 100 to 265% for P; and 23 to 117% for K) suggesting that all of organic treatments were effective at adding N, P and K to calcareous soil (Table 5). The spent grain application rates (T1 and T2) were superior compared to the same rate of compost for soil N, P, and K. The high rate of SG (T2) significantly produced larger increases in soil N and P than in the other organic amendment, while C1T1 was statistically similar to T2 and both significantly increased soil K compared to other organic amendments. Soil N, P and K increased as the application rate of spent grain or compost increased.

Table 6 shows that Fe, Mn and Zn had similar trend. Fe, Mn and Zn concentrations followed the order T2 > C1T1 > C2 > T1 > C1 > Ctrl > initial condition. For all studied micronutrients, the largest increases were observed with the 2× spent grain treatment while the lowest increases were observed with 1× compost treatment. Available micronutrients were significantly increased by T2 treatment compared to control (6.7, 5.4, 4.5, 7.7 and 6.4 folds increase in Fe, Mn, Zn, Cu and B, respectively).

Table 4 Ratio of water contents in air-dry and water holding capacity (WHC) of calcareous soil.

Treatment	Air-dry water ratio[a]	WHC[b]
Ctrl	1.00 d[c]	1.00 e
T1	1.58 b	1.30 c
T2	1.86 a	1.57 a
C1	1.49 c	1.18 d
C2	1.64 b	1.35 c
C1T1	1.82 a	1.50 b

[a] Air dry water content of treated soil: air-dry water content of control soil.
[b] WHC of treated soil: WHC of control soil.
[c] Within columns, values followed by different lowercase letters are significantly different at $\alpha = 0.05$.

3.2. Germination experiment

In the germination experiment, the compost, spent grain and a mixture of both were evaluated as seed germination accelerators/inhibitors of Squash seeds (*Cucurbita pepo* L.). Germination of the seeds was evaluated using three parameters; coefficient of velocity of germination (CVG), final germination

Table 5 Chemical properties of calcareous soil after one month of incubation with different organic sources.

Treatment	Soil pH	OM (%)	DOC (%)	Total N (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})
Initial	8.34	0.98	0.013	0.030	4.20	320
Ctrl	8.29 a[a]	0.84 c	0.045 e	0.023 e	3.70 d	338 c
T1	7.85 b	1.84 b	0.083 c	0.106 cd	8.85 c	459 b
T2	7.61 cd	2.89 a	0.183 a	0.227 a	13.54 a	642 a
C1	7.88 b	1.60 b	0.075 cd	0.072 d	7.39 c	416 bc
C2	7.76 bc	2.75 a	0.124 b	0.133 bc	8.36 c	496 b
C1T1	7.51 d	2.80 a	0.135 b	0.150 b	10.66 b	734 a

[a] Within columns, values followed by different lowercase letters are significantly different at $\alpha = 0.05$.

Table 6 Micronutrient concentrations in calcareous soil one month after incubation with different organic amendments.

Treatment	Fe	Mn	Zn	Cu	B
	mg kg^{-1}				
Initial	4.10	3.49	1.43	0.61	0.30
Ctrl	3.64 e[a]	2.96 d	1.68 c	0.41 f	0.38 d
T1	10.48 d	5.37 c	2.25 c	2.67 b	1.76 b
T2	24.40 a	12.75 a	7.53 a	3.17 a	2.41 a
C1	8.91 d	4.34 cd	1.89 c	1.11 e	1.32 c
C2	13.81 c	9.14 b	4.19 b	1.42 d	1.64 b
C1T1	20.01 b	12.09 a	6.99 a	2.35 c	1.55 cb

[a] Within columns, values followed by different lowercase letters are significantly different at $\alpha = 0.05$.

percentage (FGP) and germination index (GI). Table 7 showed the values of germination parameters (CVG, FGP and GI) in the calcareous soil. The spent grain (T2) possessed the greatest CVG values while the Ctrl- gave the lowest. The CVG values followed the order T2 > C1T1 > T1 > C2 > C1 > Ctrl+ > Ctrl−. The values of final germination percentage (FGP) for the Ctrl+ and Ctrl− were 57 and 62%, respectively. While, the corresponding values for T2 and T1 were 98 and 92%, respectively. The differences in the FGP among the treated soils were significant in comparison to either control treatments. Furthermore, the FGP of T2 treatment was superior compared to all treatments. The germination index (GI) is one parameter, which explains seed vigor. The values of GI of squash followed the order T2 ⩾ T1 > C1 > C1T1 > C2 > Ctrl− > Ctrl+. The GI values are a function of the amendments incubated with soil.

Table 7 Germination parameters of squash (15 days after sowing) in calcareous soil amendment with compost and spent grain.

Treatment	CVG (day^{-1})	FGP (%)	GI
Ctrl−	0.120 c[a]	61.7 c	2.40 b
Ctrl+	0.121 c	56.7 c	2.18 b
T1	0.156 b	91.7 ab	5.17 a
T2	0.185 a	98.3 a	5.17 a
C1	0.148 b	80.0 b	4.54 a
C2	0.150 b	85.0 b	4.41 a
C1T1	0.178 a	83.3 b	4.45 a

[a] Within columns, values followed by different lowercase letters are significantly different at $\alpha = 0.05$.

The spent grain treatments increased the GI values compared to the compost treatments. The differences among the organic treatments were significant compared to both controls.

Both controls and the 1× compost treatment produced relatively poor growth; the C1T1, T1 and C2 treatments, however, significantly increased squash growth. The 2× spent grain amendment produced greater growth than any compost treatment (almost 1.65 times more than the 2× compost treatment), demonstrating a greater capacity to support vegetation in calcareous soils (Fig. 2). Increasing the amounts of spent grain produced increasing squash growth showing that spent grain can effectively improve biomass yields, especially when applied at high rates to degraded soils. In general, the organic treated soils differed significantly compared to both controls.

4. Discussion

Soil texture and organic matter content are key components that determine soil water holding capacity (WHC). Generally, the addition of an organic source to calcareous soil increases the retained soil water compared to the control. This increase may be due to microbial activity that decomposes the organic compounds and hence increases OM, which improves WHC of the soil (Burgin and Groffman, 2012). Our results are similar to those of other researchers who reported that addition of compost fertilizer and cow manure increased the mean WHC of soils (Vengadaramana and Jashothan, 2012), while Hudson (1994) reported significant positive correlations between organic matter content, and available water capacity (AWC), for sand, silt loam and silty clay loam texture groups. In all texture groups, as OM content increased from 0.5% to 3%, AWC of the soil more than doubled.

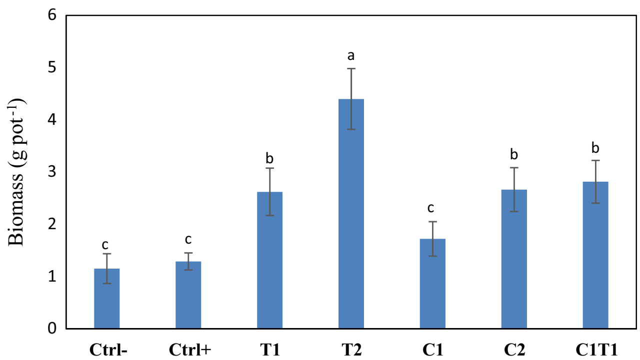

Figure 2 Total squash yield by treatment. All values represent the mean of four replicates ± S.D. Columns labeled with the same letter are not significantly different at $\alpha = 0.05$.

Decreasing soil pH of alkaline soils leads to increases in nutrient availability. The reduction of pH was affected by the application rate and type of amendment. As the application rate of amendments increased the pH decreased compared to the initial or control treatments. This reduction in the pH values might be due to increase of the groups of carboxyl and phenol as a result of the decomposition of organic residue and the reduction of bicarbonate in the soil. SG is acidic in nature. Therefore, this could be better utilized than compost as an amendment for reclamation of calcareous soils. Šimek and Cooper (2002) reported that decrease of pH might be due to the presence of phenolic and fatty acids created by decomposition of the amendments, which reduces soil pH. The pH results in this study were comparable to those presented by Franco-Otero et al. (2012).

The magnitude of the increase in OM and DOC tends to correspond with the quantities of OM added by each treatment; thus, the largest increases were observed with the T2, C2 and C1T1 treatments. Similarly, Eghball (2002) reported significantly greater soil organic matter levels in plots treated with organic manure than those untreated ones. This provides essential nutrient cations that are available for plant uptake. The high percentage of DOC for organic amended soil could be due to the high microbial activity during the mineralization of organic components. The presence of the organic source enhances microbial activity and the production of dissolved carbon (carbon dioxide). The amount of DOC in the study is similar to the results reported by Ouedraogo et al. (2001).

All of organic treatments were effective at adding N, P and K to calcareous soil. Mineralization of organic materials as well as the nutrients present in the SG and compost is responsible for increasing the availability of plant nutrients in soil. Furthermore, SG or compost should be applied before planting to give sufficient time for natural oxidation of organic materials, which in turn enhances the soil available nutrients. Similar to the results of the present study, incubation of some organic sources resulted high total N (Eghball, 2002, Melero-Sanchez et al., 2008). Our results also concur with those of Yu et al. (2013) who found that the application of composted poultry manure or organic fertilizer led to the increase of available P and organic matter content in soil. This increase in available P is due to the reduction in pH as a result of organic matter decomposition. Herencia et al. (2007) reported that the use of organic fertilizer resulted in higher soil organic matter, soil N content, available P and K, than in untreated soils. Our results differ from those of Hartl et al. (2003), who found no difference in soil nutrient concentrations between soils receiving composted biowaste or no organic inputs in a field study, while Gutser et al. (2005) found that addition of organic manure increased the organic matter content, which in turn increased the levels of Ca, K and Mg.

Decreased availability of soil Fe, Mn, Zn, Cu, and B is associated with calcareous soils (Marschner, 1995). Limited availability of these elements results from pH effects and interactions with soil carbonates (Loeppert et al., 1984). Amendments provide micronutrients to enrich the calcareous soil. Although, the quantities of added micronutrients (Fe, B, Cu, and Zn) by spent grain are less than that added by the same rate of compost (63%, 80%, 86%, and 90% for Fe, B, Zn, and Cu, respectively) (Tables 2 and 3). The spent grain application rates (T1 and T2) were superior compared to the same rate of compost for all studied micronutrients (Table 6). The superiority of the spent grain was due to its effect on lowering soil pH as well as solubility and chelation effect of organic matter. Accordingly, the application of spent grain to enrich a soil with micronutrients is highly recommended. The mineralization of organic compounds leads to decrease in soil pH, which increases micronutrient availability in the soil. Low molecular weight organic acids from decomposition of soil organic matter form soluble complexes with metal ions (Ramachandran and D'Souza, 1998). The presented results are in agreement with the results presented by Bhanooduth (2006) who reported that the available micronutrients (Fe, Cu, Zn and Mn) are increased by using compost and organic wastes.

Seedling emergence is the most important factor in the establishment of optimum plant density for a maximum yield. For all studied germination parameters, there were no significant differences between Ctrl− and Ctrl+, indicating that adding mineral fertilizers to the calcareous soil had no effect on seed germination. The difference in germination parameters was due to the application of organic amendments as compared to the mineral fertilizer. A study involving sewage sludge applied to a corn crop measured a 1.3-fold increase in corn yield after 12 weeks compared to plots amended with NH_4NO_3, demonstrating the ability of fresh organic wastes to improve yields (Sims and Boswell, 1980). The enhancement of seed germination with organic amendments might be due to organic matter application rates, which increases soil water holding capacity, soil aeration, OM of the soil and provides plant macro and micronutrients. It is worth noting that spent grain as an amendment is more effective than compost to promote seed germination in calcareous soil. Our results are similar to Önemli (2004) who reported an increase in the sunflower seed emergence as the soil organic matter increased. Similarly, Abul-Soud et al. (2010) showed that increasing cattle manure rate from 12 to 36 tons ha^{-1} led to a significant increase in the squash growth and yield parameters. In addition, Selim et al. (2012) reported a positive correlation between the germination index (GI) of cress and NO_3-N, P and K content.

5. Conclusion

All amendments examined in this research, including spent grain, compost, and spent grain mixed with compost, were effective at ameliorating soil physical and chemical limitations of calcareous soil and enhancing seed germination. The application of spent grain to calcareous soil proved to be an extremely effective method of reducing pH and increasing soil water holding capacity, organic matter, macronutrients, micronutrients, germination parameters and squash yield. Hence, use of this organic waste in agricultural production provides an economic and environmentally friendly method of disposal, while improving soil fertility and crop yield. Mixing spent grain with compost was more effective than compost alone in increasing water holding capacity, soil nutrients, and reducing soil pH. Either compost alone or compost + spent grain was equally effective at enhancing squash germination and increasing soil organic matter.

The economics of calcareous soil reclamation necessitate an inexpensive method for widespread adaptation and successful implementation. Spent grain avoids the cost of composting. Therefore, it is a more economical amendment than compost. The examined treatments must be further conducted as long-term field experiments to determine whether the results obtained in this controlled and short-term experiment also occur under variable field conditions.

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