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EFFECTS OF LOCALLY-PRODUCED COMPOST ON PHYSICAL PROPERTIES OF SOILS WITH DIFFERENT TEXTURES

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ABSTRACT

The effects of adding different rates of locally-produced compost to three different soils (sand, S; sand loam, SL; and sand clay loam, SCL) on some important physical properties were evaluated. Determined parameters included, soil bulk density, moisture limits: namely saturation percentage (SP), field capacity (FC) and Wilting percent (WP), soil moisture-tension characteristics, cumulative evaporation, and germination capability. Nine compost-soil mixing rates were utilized for moisture characteristics and evaporation experiments and six rates for germination tests. Increased compost application rates resulted in marked lowering of the bulk densities in all soils. Densities at 50% mixtures were reduced to about 60% of their original values. Available water (AW) was found to increase with increased compost content, with more pronounced effect on sand. Effects of both soil type and compost rate were highly significant $(\alpha=0.001)$. *Maximum increase for all soils occurred at 50% rate, with relative increases of 391.4, 228.9 and 196.2% for S, SL and SCL, respectively. At 8% compost application rate, the relative increase was approximately 200, 134, and 128%, respectively. The effect of compost on AW% was found to fit very strongly a polynomial function of the form:* $y=ax^3+bx^2+cx+d$, *where y is AW% and x is compost %, with* $R^2>0.997$. *Cumulative water evaporation from soils with different compost contents showed different behavior over two stages of the process: an early stage, where higher compost rates resulted in less evaporation, and a late stage where increase in compost content led to increased evaporation. The two stages were distinguished based on differences in the ability of different soil-compost mixtures to cope with external evaporativity at different moisture contents. Soils high in compost content were able to sustain significant evaporation rates for longer duration due to improved water retention. The early stage was characterized as being shortest in S and longest in SCL textures, and as being shorter for a given soil in summer than in winter season. Effects of soil type, compost content and season were highly significant* $(\alpha=0.001)$ *at all times. Adding compost was seen to boost the soil as a plant-growing media. For all soils, higher germination rates were associated with compost application. An "economic" rate was identified as related to higher "relative" rates. These rates matched germination rates of approximately 83% for seeds of both tomato and cucumber and 70% for lettuce. Both germination percent and relative increase in germination followed logarithmic functions of the form:* $y= a \ln x + b$, *where y is germination % or relative increase %, and x is compost %, with* R^2 *values varying but mostly ranging between 0.90 and 0.99. Effect of compost was highly significant* $(\alpha=0.001)$. *Soil effect was not coherent and no significant season effect was seen.*

Key words: Compost, Moisture retention, Evaporation.

INTRODUCTION

The soils of the Nile valley and Delta are composed primarily of recent alluvial deposits of the Nile River floods (Ball, 1939). Egypt is located in an arid zone, and agriculture depends mainly on the Nile River water for irrigation. Efficient optimization of water utilization by improved implementation and good management of both water and soil in old and newly reclaimed agricultural lands is greatly required.

Co-compost refers to a technology for compost production from farm waste disposal materials. Primarily, the disposal materials contain straw bale, cotton dust and wheat straw. Fresh farm waste disposal materials are fermented by co-compost method (Sherief *et. al.*, 1998). In Egypt the compost is produced locally at Abu-Quir plant project at Montaza Municipality.

The rates of biological and chemical reactions affecting crop growth are influenced by the amount of organic materials. They are added as manure or compost to the soil in presence of moisture, causing soil temperature to rise, and warming the soil profile. The importance of organic materials in good agronomic practice has long been recognized. Numerous research works (Jackson and kirkham, 1958; Kohnke, 1968; Flaig, 1976; Sehatta *et.al.*, 1993) have recognized a group of basic and specific requirements that must be fulfilled for successful farming, namely: providing the soil with humus-carrying substances, regular supply of soil with water, nitrogen, phosphorus, potassium and trace elements, correct crop rotation, and effective tillage. These factors were found to have big influences on the physical properties of soils and hence on their productivities. The importance of compost comes from its ability to supply the soil with humus, which is an important element in successful farming due to its main role in plant nutrition and plant water uptake. Naturally, the organic substances taken out of the soil by crops should be replaced. If this is not done, the soil will be starved out and eventually turns into steppe or desert (Buhler, 1978; Shehatta et.al. 1993). The use of compost is beneficial not only to farming, forestry, parks, nursery and vegetable gardening, but also as an effective means of disposal of municipal and farming wastes. It is a way of

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recycling valuable organic material which would otherwise have to be either burnt or dumped and thus withdrawn from its natural circulation. With organic substances, compost creates suitable living conditions for micro-organisms. It plays an essential role in giving the top soil the desired structure (Hauck, 1982; Sumner, 2000), and contributes substantially to the topsoil's capability to absorb optimally the administered mineral fertilizers and water. The capability of compost to hold the applied water and nutrients for the plants is of particular significance in coarse-textured soils (e.g., sands) where the organic substance is missing and water and nutrient requirements are high. In coarse-textured soils, large portions of nutrients and water seep away and are lost. Compost ensures more effective use of both water and nutrients. Considerable savings in water and fertilizers were reported with the application of organic substance to the soil (Im, 1980). As the compost becomes more mature, it imparts to the soil some of its own nutrients, representing a valuable contribution to the plants' nutrition. Large part of the latter must be supplied by fertilizers of high concentration. Compost is thus not intended as a replacement for chemical fertilizers, but as a carrier of the indispensable humus which ensures the optimum use of the nutrients (Im, 1980). The guidelines for compost application are derived from the following factors: a) degree of compost maturation, b) climatic conditions of the area in question, c) soil characteristics, nature and method of cultivation, d) types of planted crops; and, e) time of application.

It is known that the beneficial effects of compost and organic material additions on physical conditions of sandy soils comprise improving aggregate formation, aggregate water-stability, and water holding characteristics (Marshall, and Holmes, 1988; Sumner, 2000). In loam and clay soils, organic substances improve soil conditions by providing good aeration, better water infiltration and drainage through the soil. The main physical properties of the soils; including water holding capacity, evaporation and bulk density are drastically affected by the organic material content (Henderson and Perry, 1955; Ibrahiem *et al.*, 1976; Alan, *et. al.*, 1980; Bakri, 2000). Evaporation from soil is a drying process in which moisture is removed from soil to the atmosphere until equilibrium between moisture in the soil and atmospheric air is attained. Evaporation is thus significantly influenced by the physical condition and properties of the soil (Sumner, 2000). Soil texture and soil water holding characteristics are two of the most important factors in this regard.

Hauck (1982) realized that when mixing compost or organic matter with the soil, the mixture absorbs water rapidly to provide increased moisture storage. Not all the amount of stored water in the soil can be used to meet plant water requirements. Only the amounts of available water are considered. This crucial range of moisture is that held between the limits of field capacity and wilting point.

The work reported in this manuscript is a study of the effects of locally-produced compost on some physical properties of sandy, sandy loam and sandy clay loam soils. Studied parameters include moisture limits (saturation, field capacity and wilting percentages), density, water retention, evaporation, and seed germination; the latter being an indicator of the possible enhancement in the soil's agronomic productivity.

MATERIALS AND METHODS

Experimental work took place at the Soil Salinity and Alkalinity laboratory, Soil, Water and Environment Research Institute and at Montaza Municipality in Alexandria, during 2000-2001. Winter measurements were taken in December and summer measurements in July.

1. Soil Samples

Soil samples were collected from three sites representing three different soil textures. The sites are: 1) El-Nubaria region, about 80 km south of Alexandria with a sandy texture; 2) El-Nahda region, about 30 km south of Alexandria; with sandy loam texture; and 3) Khorshed area, located about 15 km south of Alexandria, with sand clay loam texture. Samples at all three sites were collected at depths of 0-30 cm.

2. Soil Mechanical Analysis

Mechanical analysis of the soil samples was carried out by the hydrometer method (Bouyoucos, 1962).

3. Moisture Limits and Soil Moisture Characteristic Curves

Saturation percentage (SP) was determined according to the American Society for Testing and Materials (ASTM) standards (1992), (ASTM, D 2325- 68, and ASTM, D 3152 - 72). Field capacity (FC) and wilting point (WP) were determined from the soil moisture-tension characteristic curve. Soil moisture characteristic curve was determined by means of an extraction unit, following the method outlined by ASTM (1992) and Soil Moisture Equipment Corp. (SMEC, 1993), and was also applied to the compost treatments. The apparatus models used were Model No. 1000, pressure membrane extractor, Model No. 1500 G1, 15-bar pressure plate extractor with cells, and Model No. 1600 G1, 5- bar extractor with cells.

4. Soil Bulk Density

The bulk density was determined in situ using a sharp-edged cylindrical soil sampler, 10-cm long with an inside diameter of 4.7 cm, (Black, 1965). For the compost and soil-compost mixtures, the bulk density was determined by a duplicate core sampler, 10 cm long and 10 cm inside diameter, with a perforated bottom disk. The sampler was filled with compost or soil-compost mixture. It was knocked 4 times with a

1-kg weight on its top. The core samples were allowed to dry for 24 hours before determining their dry weight and thus their densities (Sherief et. al. 1998; ASTM, D 2937-83, 1992).

5. Soil Chemical Analysis and Organic Matter

The soil chemical analysis was determined for an extract of soil saturated paste. Analysis included electric conductivity (EC), soluble cations (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}), anions (CO_3^{-}, HCO_3^{-}, Cl^{-} and SO_4^{-}), calcium carbonates ($CaCO_3$), pH (Black, 1965; Page 1982), organic matter (OM), and total nitrogen percentage (Allison, 1965).

6. Treatments (Soil-Compost Mixtures)

Nine treatments of soil-compost mixtures were examined in the study of the effect of physical and hydro-physical properties, while only six treatments were applied in the germination experiment. The treatments in the first category included the following successive percentages of compost in relation to total dry soil weight: 0 (control), 2, 4, 6, 8, 10, 25, 33 and 50%. In the germination experiment, rates of 0, 2, 4, 6, 8 and 10% were applied, covering rates usually applied in common practices. In both cases all treatment were in 3 replicates and were performed for each of the three soil types.

7. Compost Physical and Chemical Analyses, and Organic Matter

Determined physical properties of the compost included bulk density, saturation percentage, field capacity, wilting point, and percentage of available water (Klute, 1986). Gravimetric moisture contents (g g^{-1}) were determined according to Black (1965). Chemical analysis included pH, OM%, organic carbon %, total N%, C/N ratio, P_2O_5%, K_2O%, Ca, Mg, Fe, Mn, and Zn. Chemical and OM determinations were made according to Page (1982) and Allison (1965), respectively.

8. Moisture Retention of Soil-Compost Mixtures

Effect of compost mixing rate on moisture retention was determined through the construction of moisture-tension characteristic curves. These were performed using same techniques (American Society for Testing and Materials, ASTM, 1992 and Soil Moisture Equipment Corp., SMEC, 1993) as in (3) above.

9. Evaporation Rate

Soil-compost mixtures of the nine treatments, each in three replicates, were packed in polyvinyl chloride (PVC) cylindrical pots (30 cm inside diameter and 35 cm high). The pots were perforated at the bottom with 10 holes, 1 cm. diameter each, to drain excess water. The pots were packed to the determined soil-compost bulk density, then inserted in an open field of bare dry soil at Montaza Municipality. The open field containing the pots was wetted to saturation and covered by plastic sheets for 24 hours to prevent evaporation until moisture equilibrium was attained. During this time most of the free (gravitational) water is drained out. Evaporation water losses from compost-soil mixtures were determined via sampling the moisture contents remaining in the soil at given times. Sampling was done using a tube sampler, 2 cm in diameter and 30 cm long. The soil samples were taken after 1, 2, 3, 5, 7, 10, 15 and 30 days during the months of December and July (representing winter and summer seasons, respectively). Moisture contents, (weight basis) were determined gravimetrically.

10. Seed Germination

Soil-compost mixtures of the three soil types were used in the six different treatment levels described above to determine the effect of soil type and soil-compost mixing rates on seed germination. The mixtures were packed into PVC pots, 30 cm inside diameter and 25 cm long. The Pots were inserted in the open field of bare dry soil. The pots were wetted to saturation and covered by plastic sheets to prevent evaporation for 24 hours until moisture equilibrium was reached. Tomato, cucumber and lettuce seeds were planted for this experiment during winter season (December). The vegetables were irrigated when water depletion reached 50% of the available water, according to Premachandra *et al.* (1992). The vegetable germination percentages were recorded 21 days after planting.

11. Data analysis

Data was analyzed statistically (Steel and Torrie, 1980) and by mathematical regression where appropriate. Statistical software package used is STATGRAPHICS® v. 2.6 and 5.1, STATPOINT, Inc. Virginia, USA.

RESULTS AND DISCUSSION

Analysis results of the physical and chemicals properties of the three soils are presented in Tables 1 and 2. Table 1 displays the particle size distribution, texture class, bulk density and saturation percentage. The texture classes of soils I, II, and III are sand (S), sand loam (SL) and sand clay loam (SCL), respectively. Coarse, medium, fine and total sands are highest in soil I and have a decreasing trend from soils I to III. Expectedly, clay content is highest in soil III and lowest in I. The bulk densities of the three soils are within typical values for the given texture classes. These densities correspond to total porosity values of about 41.1, 50.9, and 54.0% for the three soils in respective order. Total porosity, together with dominant pore sizes, are important factors in determining the ability of soil to retain its moisture. Naturally, the finest-textured soil (soil III) has the smallest dominant pore sizes. Some discrepancy was noticed between the above porosity values (which are calculated based on bulk and particle densities) and porosity values determined as the product of saturation percentage (determined for saturated soil paste on weight basis) and bulk density. The latter produced values that were somewhat smaller in the sandy soil, comparable in the sandy loam soil, and greater in sandy clay loam soil as compared with values calculated by the densities. Table 2 displays the results of the chemical analysis of the three soils, including, EC, soluble cations and anions, organic matter, total N content, $CaCo_3$ and pH. The investigated soils have low salinity (EC < 2dS/m for all soils) and are poor in nutrients and organic matter content. The soils are neutral (soils II and III) to slightly alkaline (soil I).

Results of physical and chemical analyses of compost are shown in Tables 3 and 4. The determined saturation percentage (SP), field capacity (FC), and wilting percentage (WP) of the pure compost are 187%, 103.5% and 18.1%, respectively. The high SP and FC values reflect the high ability of compost material to retain water. The value of the saturation percentage for the pure compost is thus nearly 10, 5 and 4 times as that of soils I, II and III, respectively. The large difference between FC and WP is reflected in the markedly high available moisture (85.4% by weight, Table 3), which represents good soil water storage capacity. The bulk density of compost was found to be 0.52 g cm^{-3}. Results of chemical analysis of the compost indicate a C/N ration of 21.76. The fermented compost is rich in nutrients N, P, K, trace elements and organic matter content (Table 4).

The bulk densities of the soil-compost mixtures are presented in Table 5. A consistent pattern of decrease in density was observed with successive additions of compost in the soil-compost mixtures for all three soils. The bulk density reached values as low as 0.93, 0.80, and 0.76 g cm^{-3} at the 50% mixing rate for soils I, II and III, respectively. These resulting densities represent approximately 60-62% of the original densities (0-compost) of all three soils.

Moisture retention data (soil moisture-tension characteristics) of the three experimental soils are given in Table 6. Statistical testing indicated that the moisture characteristic differences are significant among the three soils, being more so between soil I (the sandy soil) and each of the other two soils (significant @ α = 0.01). Soils II and III were, however, different in their moisture retention properties only at α = 0.10. Table 7 displays the moisture percentages (weight basis) at saturation (SP), field capacity (FC), and wilting point (WP) of soil-compost mixtures for the nine different compost applications rates. Table 7 shows also the calculated available water (AW) under each treatment, as well as the relative increase (%) in the available water corresponding to various treatments. Results reflect a trend of increasing available water (AW) of the soil-compost mixtures with increased percentage of added compost in the mixture. This trend appeared to hold for all treatments and all three soils. Results are depicted in Fig. 1. The maximum values of relative increase in available water were 391.35, 228.93 and 196.18% for soils I, II and III, respectively, occurring at the 50% compost treatment. The effect of adding compost to soil is boosting the ability of the soil to retain water, and hence increasing its content of available water. However, the effect appeared more pronounced for the sandy soil (soil I) in comparison with the other two soils (SL and SCL textures). The relative increase for soil I was nearly twice as much as that of each of the other two soils (Table 7). Notably, the available water percent in the sandy soil (soil I) increased nearly 4 times from treatment 1 (0% compost) to treatment 9 (50% compost), rising from 6.9% to 27.1%, while the corresponding increases in soils II and III were much less (from 16.5% to 37.8%, and from 21.2% to 41.6%, for soils II and III, respectively). Even at the much lower compost mixing rate of 8%, a relative increase of nearly 200% in available water was achieved in the sandy soil, compared with approximately 134 and 128% in the case of the sandy loam and sandy clay loam soils, respectively. This strongly suggests that the impact of compost application, even at relatively small amounts, to sandy-textured soils is expected to result in significant improvement in the soil's water holding capacity. Fig. 2 shows results of regression of the available water (%) against percent compost added. It is noticeable that, for all three soils, the AW curves strongly fit a 3rd order polynomial equation of the form:

$$y=ax^3+bx^2+cx+d \quad [1]$$

where y is AW% and x is compost %, with markedly high determination coefficients approaching nearly 1.0 (ranging between 0.998 and 0.999 and being significant @ 0.001). Organic substances, when added to sandy soils, help improve the formation of more water-stable aggregates and thus enhance the chances of forming more small pores. Additionally, the organic material itself has significantly high capacity of holding water for prolonged times and under higher magnitudes of suction. This secures higher available water for the growing plants and provides more favorable conditions for plant uptake of water from the root zone.

Analysis of variance (ANOVA, Table 8) showed highly significant effects for both soil type and added compost rates on available moisture (α = 0.001 for both factors). However, based on calculated F-ratios, soil effect appeared stronger.

The effect of compost application rates on water evaporation from soil-compost mixtures was monitored over a period of 30 days. Evaporation measurements were performed over two seasons. One set of data was collected during the month of December (representing winter) and the other in July (representing summer). Results are illustrated in Fig. 3.

Table 1. Soil physical analysis of experiment soils.

Soil	Particle size distribution					Texture class	Bulk density	Saturation percentage
	Coarse sand 2 - 0.5 mm.	Medium sand 0.5 -.25 mm.	Fine sand .25 - .05 mm	Silt .05-.002 mm.	clay .002 < n.m.			
I	15.3	20.7	59.3	0	4.7	S	1.56	19.5
II	10.2	15.1	57.0	2.6	15.1	SL	1.30	38.88
III	3.40	13.1	46.7	7.9	28.9	SCL	1.22	52.16

Table 2. Chemical characteristics of experiment soils.

Soil	EC, m.mohs	Soluble cations, m.e/l				Soluble anions, m.e/l				O.M. %	Total N %	CaCO %	pH
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO3^{=}$	$HCO3^{-}$	Cl^{-}	$SO4^{=}$				
I	1.68	2.16	3.46	11.62	0.37	0.0	3.83	11.79	1.99	0.23	0.06	6.94	8.3
II	1.76	5.76	3.38	9.09	0.41	0.0	0.79	12.80	5.42	0.28	0.10	21.90	7.5
III	1.50	8.21	5.71	1.68	0.12	0.0	6.25	6.33	2.68	0.93	0.14	4.11	7.4

Table 3. Physical and moisture properties of the compost.

Moisture characteristics				Bulk density gm/cm3
Saturation percentage	Field capacity %	Wilting point %	Available water %	
187.0	103.5	18.1	85.4	0.52

Table 4. Chemical analysis of compost.

pH	OM %	Organic carbon %	Total N %	C/N ratio	P_2O_5 %	K_2O PPM	Ca %	Mg PPM	Fe PPM	Mn PPM	Zn PPM
7.6	72	42	1.93	21.76	1.3	630	1.33	944	1788	340	160

Table 5. Bulk density of soil-compost mixtures

Treatments	Bulk density, g cm^{-3}		
% compost	Soil I (sandy)	Soil II (sandy loam)	Soil III (sandy clay loam)
0	1.56	1.3	1.22
2	1.53	1.28	1.20
4	1.51	1.26	1.18
6	1.48	1.24	1.16
8	1.46	1.22	1.15
10	1.43	1.20	1.13
25	1.25	1.05	0.99
33	1.14	0.97	0.92
50	0.93	0.80	0.76

Table 6. Soil moisture- tension data for the three experiment soils.

	SOIL I (sandy)			SOIL II (sandy loam)			SOIL III (sandy clay loam)		
Tension cm water	θ_w %	Degree of saturation, s %	AW %	θ_w %	Degree of saturation, s %	AW %	θ_w %	Degree of saturation, s %	AW %
0.00	19.5	100.00		38.88	100.00		52.16	100.00	
103.0	8.12	63.55		30.33	78.01		44.48	85.28	
310.0	7.63	59.64		25.02	64.35		34.76	66.64	
517.0	6.96	54.39		21.63	55.63		30.72	58.90	
826.0	6.05	47.28		19.16	49.28		28.16	53.99	
1033.0	4.43	34.59	6.93	16.43	42.26	16.49	25.77	49.41	21.21
3099.0	3.01	23.55		14.31	36.81		23.24	44.56	
5165.0	2.22	17.38		13.01	33.46		19.88	38.11	
8264.0	1.23	9.62		12.09	31.10		17.04	32.67	
10330.0	0.08	0.64		10.24	26.34		15.09	28.93	
15495.0	0.71	5.52		8.53	21.94		13.55	25.98	

Cumulative evaporation water loss was found to increase with increasing compost content for all three soil textures and over the two seasons. The 30-day cumulative evaporation losses for the 50% compost treatment in winter season were 39.30, 51.25 and 63.06 mm for soils I, II and III, respectively. Corresponding summer values were 41.23, 54.49 and 68.07 for the three soils in the same order. Cumulative evaporation associated with the control soils (0%-compost) were 12.1, 34.9 and 47.8 mm in December and 12.3, 36.0, and 48.5 mm in July, for soils I, II and III, respectively. The trends of increasing cumulative evaporation losses with compost application rate were seen to display a coherent pattern only after a certain period of time (an early "initial" stage), which varied among the three soils. During this initial period of time, the pattern of cumulative water loss was mostly reversed as compared with the ultimate pattern. Nevertheless, the 30-day cumulative evaporation was a distinct function of compost content. The duration of the initial stage was shorter in sand (~7-8 days) than in sand loam (12-15 days) and sand clay loam (13-17 days) in December data (Fig. 3). July data showed similar trends for the sand loam and sand clay loam, but the initial periods were shorter than in winter (these being approximately 5-7 days for sand loam and 8-10 days for sand clay loam). This "reversed" early pattern was not distinguishable in the sandy soil. During these early stages and before the final order was approached, soils with higher compost treatments showed lower cumulative evaporation losses than did the ones with lower compost rate treatments, then the curves switched order. This change in the relative positions of the curves appears to reflect the relationship between soil type (mainly texture), external evaporative demand (evaporativity) and soil moisture content. Shortly after saturation, and for a few days depending on soil, the moisture content in the soil does not represent a limiting factor in the evaporation process, and the amount of evaporated water is determined primarily by the external evaporative demand, coupled with the ability of the soil to conduct water vapor to the atmosphere (ease of water vapor release- or escape- from soil pores, which is influenced by the adhesive forces that act between soil matrix and water molecules). Hence, the soil with lower water-holding capacity would release its water more readily during that stage. Therefore, soil mixtures that showed higher evaporation rates during that stage are those with the least amounts of added compost; and vice-versa; soil mixtures with high compost content showed much lower evaporation during those early days. Later in the process, when soil-compost mixtures have lost significant amounts of their original water contents, evaporation becomes more controlled by the availability of soil water. At this later stage, soils with less organic materials would have lost most of their available water, and consequently evaporate less. Meanwhile, soils with higher contents of compost materials will still be having considerable amounts of water and can thus fulfill external evaporative demand. The shorter early periods observed for the sand loam and sand clay loam in summer data and the disappearance of that period in the case of sand are apparently due to the fact that drying takes place at a faster pace during summer time due to increased external evaporative demand.

The observed pattern of association between compost content and cumulative evaporation losses draws the attention to an important consequence. In spite of the fact that higher evaporation from compost-rich soils during the later stage of evaporation is caused by higher water content and improved water retention properties, the outcome is not favorable, as it simply means losing water. This leads to low water use efficiency, which defeats the purpose of using compost or other amendments in the first place. An important conclusion to make in this regard, therefore, is that special care must be given to cropping compost-mixed soils to minimize evaporation. Insulation of soil surface is an obvious option. This may be done through the use of tunnel cropping, controlled greenhouses, or by using surface mulching, particularly in hot climates and under warm summer conditions.

Detailed ANOVA analysis reflected the effects of soil, compost application rate, and season on cumulative evaporation. Measurements taken at all time intervals consistently showed that soil texture, compost content, and season, all have highly significant effects on evaporation (all @ $\alpha = 0.001$). At all times, the effect of soil type (texture) remained, consistently, the most dominant of all factors. The significance of the other two factors, namely compost and season, changed over the monitoring time. At early times, the effect of compost content showed relatively lower F-ratios (while still highly significant) than the season effect (Table 9). As time advanced, however, the effect of compost application rate displayed progressive increase, having, after 30 days, an F-ratio more than 6 times greater than that of the season, and about 64 times greater than that determined for compost effect after 7 days. The increasing importance of the effect of compost content at later times is apparently related to the fact that later in the evaporation process the moisture content becomes the decisive factor when soils high in compost content have more moisture to cope with evaporation demand, as explained earlier. Significant interaction effects were seen between all pairs of factors. The greatest- and most persistent- significant interaction effect ($\alpha = 0.001$) occurred between soil type and compost content. This interaction is perhaps the easiest to comprehend. Soil type is the major influential factor determining evaporation, yet it is a factor that is most susceptible to changes with compost content.

Soil × season interactions showed significant effect ($\alpha = 0.01$) starting day 10 and high significance ($\alpha = 0.001$) afterwards. Compost × season interaction showed significant effects, where significance levels ranged between 0.001 (days 7, 10 and 15) and 0.01 (day 30). Some of the ANOVA results are shown in Table 9 for evaporation data taken after 7, 10, 15, and 30 days.

The effect of compost application rate on improving the soil as a plant-growing media was examined through studying the rate of germination of different vegetable seeds. Seed germination of 3 vegetable crops, namely tomato, cucumber and lettuce was monitored after 21 days during the month of December over two consecutive seasons. Results, presented in Fig. 4, showed that the germination percentage increased with increasing compost application rate for all three soils. Under no compost application (control treatment), germination ratios (%) for tomato seeds were 71.9, 67.9 and 66.89% in soils I, II and III, respectively. Corresponding ratios for the 10% compost treatment were 93, 86.5 and 83.1% for the three soils, in the same order.

For cucumber seeds, germination percentages for the control (0% compost) were 49.1, 67.1 and 68.4% in soils I, II and III, respectively. Corresponding values for the 10 % compost treatment were 98.0, 93.1 and 94.5 for the three soils in the same order. Germination percentages for lettuce seeds were 48.5, 42.4 and 40.9 for site I, II and III respectively for the control. The rates improved for the 10 % compost treatment and rose to 77.5, 73.4 and 71.6 for the three soils in the same order.

For all seed types and soils, a general trend of increasing germination percentage was seen to be associated with increase in added compost. The response of germination rates to the varying compost application percentages varied, however, among soils, and took some "diminishing return" patterns in most cases, particularly for the sandy soil (Fig. 4). Regressions patterns followed a logarithmic function of the form:

$$y = a \ln x + b \qquad [2]$$

where y is germination % and x is compost %. Determination coefficients indicated statistical significance in all cases; mostly at 0.01 ($R^2 \geq 0.9197$), and in fewer cases at 0.05 ($0.9197 \geq R^2 \geq 0.7709$). Equations and determination coefficients are shown in Fig. 4. Although highest germination rates were attained at the highest compost application rates, some "economic" rates could be identified. These are the rates associated with higher *relative* (and not necessarily the *absolute* highest) germination rates.

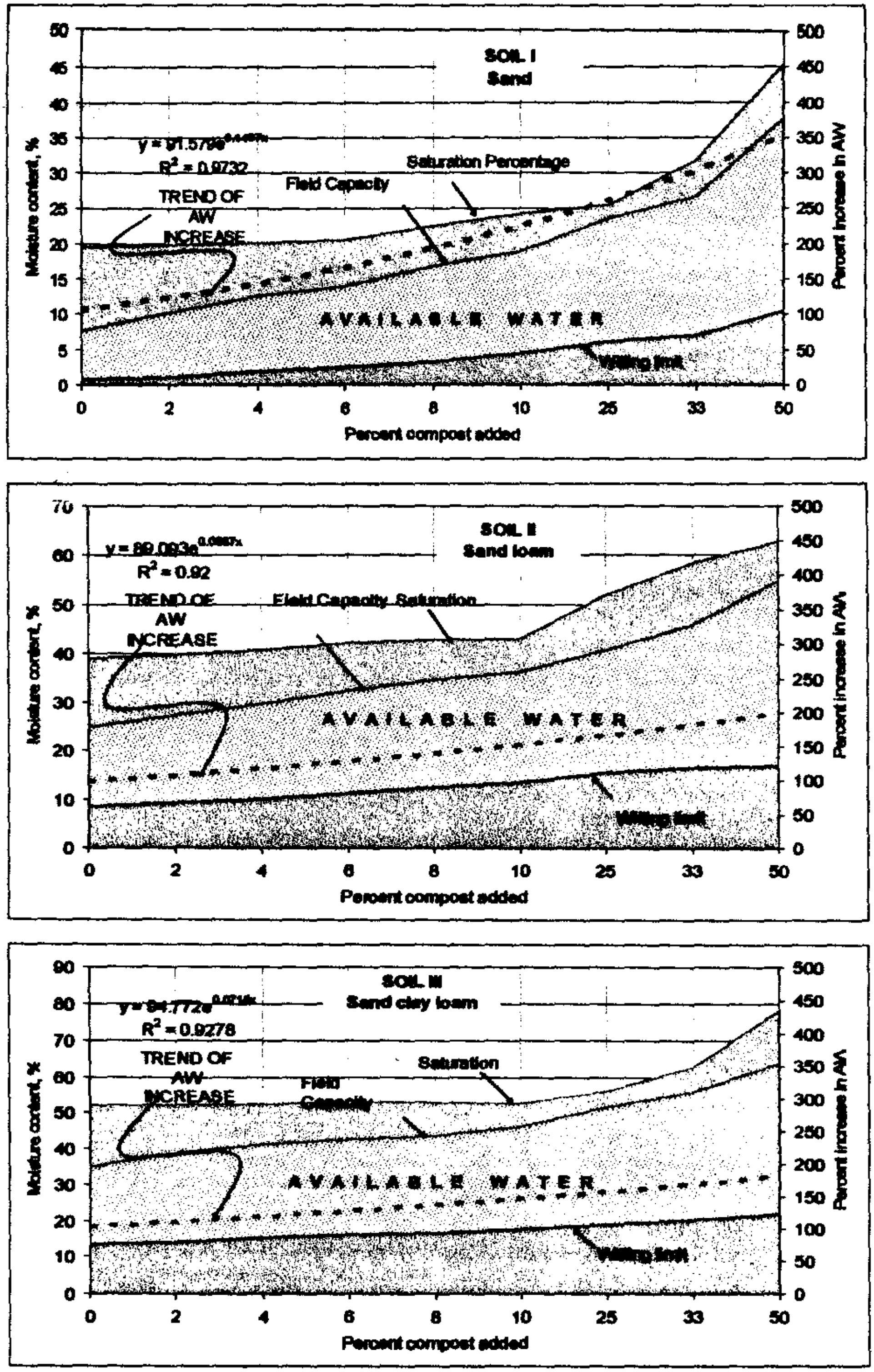


Fig. 1. Saturation percentage (SP), field capacity (FC), wilting point (WP) and available water (AW) in sand, sand loam, and sand clay loam soils, as affected by increasing rates of added compost.

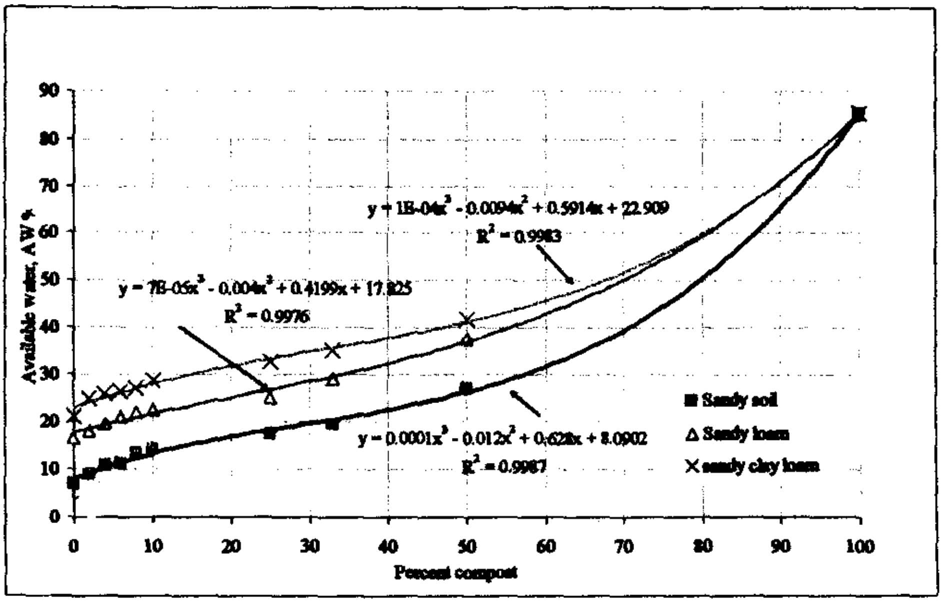


Fig. 2. Effect of compost application rate on available water in sand, sand loam, and sand clay loam soils.

Table 7. Moisture parameters (Saturation percent, SP; field capacity, FC; wilting point, WP; and available water AW) for different compost-soil mixtures.

Compost %	SOIL I (sand)					SOIL II (sand loam)					SOIL III (sand clay loam)				
	SP %	FC %	WP %	AW %	% of AW	SP %	FC %	WP %	AW %	% of AW	SP %	FC %	WP %	AW %	% of AW
00	19.5	7.6	0.7	6.9	100	38.9	25	8.5	16.5	100	52.2	34.8	13.6	21.2	100
2.0	19.8	10.2	1.1	9.1	131.4	39.8	27.5	9.4	18	109.3	52.2	38.9	14.1	24.8	116.9
4.0	20.1	12.7	1.9	10.7	154.9	40.8	29.9	10.2	19.7	119.3	52.4	41.3	15.3	26	122.6
6.0	20.6	13.9	2.6	11.3	163.7	42.1	32.6	11.4	21.2	128.6	53.1	42.6	16.2	26.3	124.1
8.0	22.6	16.9	3.2	13.6	196.9	42.7	34.8	12.7	22.1	134.1	53	43.8	16.7	27.1	127.7
10.0	24.3	18.9	4.6	14.4	207.6	43.1	36.2	13.5	22.7	137.8	52.7	46.5	17.9	28.6	134.7
25.0	25.6	23.6	6.1	17.6	253.3	52	40.8	15.6	25.2	152.6	56.1	51.8	19.1	32.7	145
33.0	31.9	26.7	7.1	19.6	283.2	58.4	45.9	16.7	29.2	177.2	62.9	55.8	20.5	35.3	166.2
50.0	45.4	37.7	10.6	27.1	391.4	62.7	54.8	17.1	37.8	228.9	78.4	63.8	22.2	41.6	196.2
100.0	187	103.5	18.1	85.4	1232.8	187	103.5	18.1	85.4	517.9	187	103.5	18.1	85.4	402.6

Table 8. Analysis of variance (ANOVA) for available moisture data– Sums of squares, F-ratios, and significance levels.

Source of variation	Sum of squares	d.f.	Mean square	F-ratio(1)
MAIN EFFECTS				
A: SOIL	1004.8422	2	502.4211	1103.549***
B: COMPOST CONTENT	950.8000	8	118.8500	261.049***
RESIDUAL	7.28444	16	0.455277	
TOTAL (CORRECTED)	1962.9267	26		

(1) All F-ratios are based on the residual mean square error.

*, **, *** denote significance at 0.05, 0.01, and 0.001, respectively.

Compost rates associated with most beneficial return were taken as points corresponding to higher change in germination percentage (greater slopes on germination curves and marked increase in values, Fig. 4 and Table 10). For tomato seeds, these rates were 4, 6, and 8% for soils I, II, and III, respectively, matching germination rates of about 83%. For cucumber, corresponding rates of compost applications were 4, 6, and 6% for soils I, II, and III, respectively, where over 83% germination occurred. Compost rates associated with most beneficial increase in lettuce germination rates were 6%, 6% and 8% for soils I, II and III, respectively. Attained germination percentage was approximately 70% in this case.

ANOVA tests reflected highly significant effects (α = 0.001) for compost application rates on germination percentages in all three soils. F-ratios calculated for compost effect varied markedly and were of the order: cucumber > tomato > lettuce (Table 11). Fig. 5 shows the pooled least squares means. Based on overall pooled averages, compost-treated sandy soil had higher germination percentages for tomato and lettuce seeds than did the sand loam or sand clay loam, but had lower germination rates for cucumber than the other two soils. Soil effect was highly significant ($\alpha = 0.001$) only in the case of tomato seeds. No significant interaction effects were seen except for the one case of soil × compost for cucumber seeds (Table 11).

Regression of the relative increase in germination percentage reflected a more marked response of all soils to compost content (Fig. 4). The relative increase (%) followed the same logarithmic function as the germination percentage curves:

$$y = a \ln x + b \qquad [3]$$

where y is the relative increase in germination percentage and x the percent compost added. Greater relative increase in germination was seen in sandy soil in the cases of tomato and cucumber seeds. Relative rates of increase in sand loam were second and sand clay loam had the lowest relative increase in germination. For lettuce, sandy clay loam soil had the highest relative increase in germination, followed by sand loam and sand. Apparently, sandy soils benefited markedly from added compost material. High response of germination to compost additions in sand is explained by the naturally-poor nutrient content and low water holding capacity of sand. Any addition of organic material to such a poor soil enhances its water retention capability as well as its nutrient supply, and is thus markedly reflected in improved properties and increased productivity. The higher response of the sandy clay loam soil in the case of lettuce seeds is also consistent with the known favorable effects of organic materials on clay-rich soils (Marshall, 1988; Sumner, 2000). Organic materials enhance better aggregation which results in better aeration and drainage and leads to improved productivity.

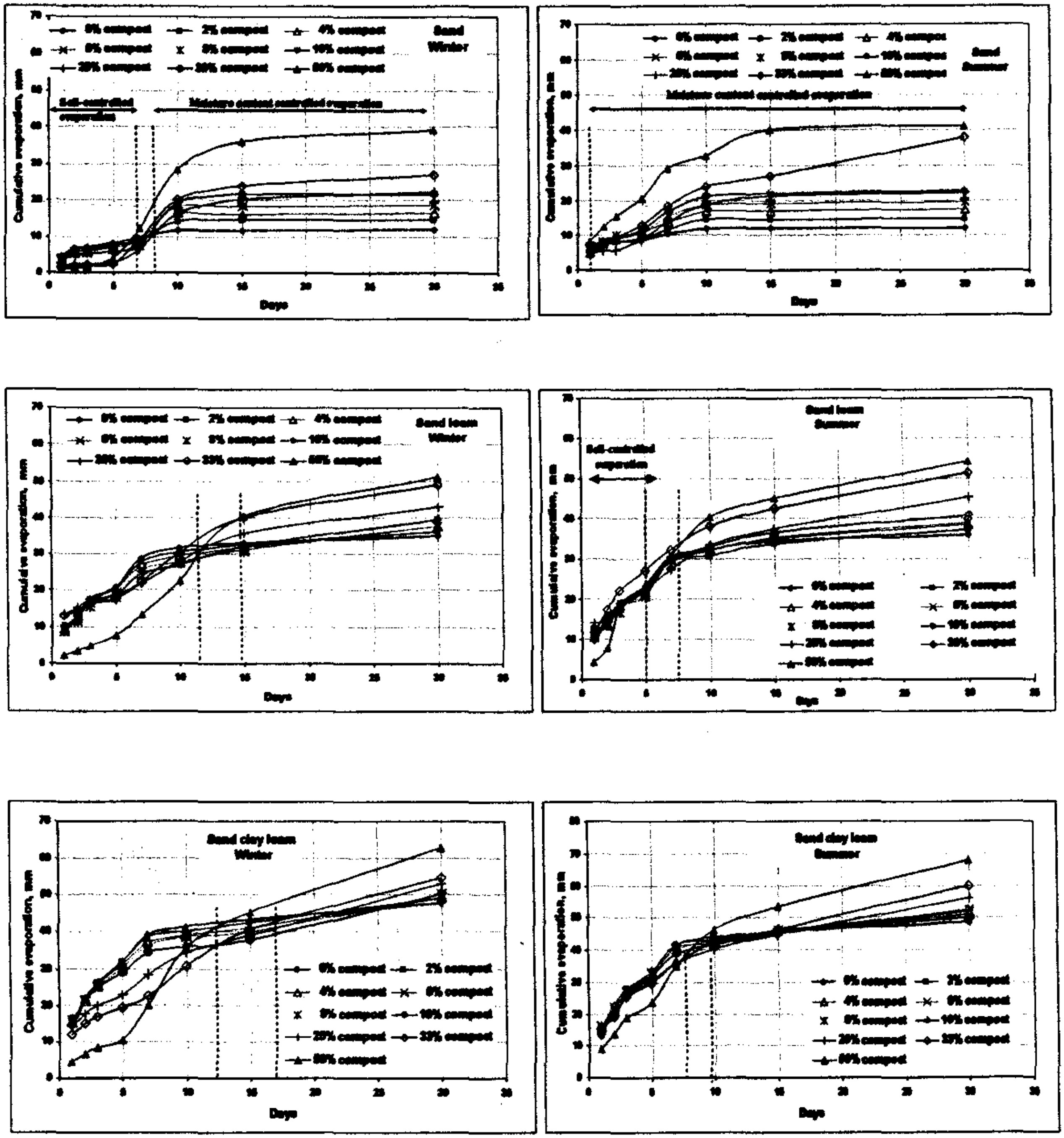


Fig. 3. Cumulative evaporation over a 30-day period from sandy, sandy loam, and sandy clay loam soils in winter (left) and summer (right) under different application rates of compost.

Table 9. Analysis of variance (ANOVA) for evaporation data– Sums of squares, F-ratios, and significance levels. Excerpted results of days 7, 10, 15 and 30.

No. of days	Source of variation	Sum of squares	d.f.	Mean square	F-ratio[1]
7	MAIN EFFECTS				
	A: SOIL	4949.8190	2	2474.9095	2185.279***
	B: COMPOST CONTENT	120.9074	8	15.1134	13.345***
	C: SEASON	585.8181	1	585.8181	517.262***
	INTERACTIONS				
	AB:	515.58704	16	32.224190	28.453***
	AC:	5.58080	2	2.790402	2.464
	BC:	245.61676	8	30.702095	27.109***
	RESIDUAL	18.120596	16	1.1325373	
	TOTAL (CORRECTED)	6441.4498	53		
10	MAIN EFFECTS				
	A: SOIL	3927.8442	2	1963.9221	787.883***
	B: COMPOST CONTENT	154.1763	8	19.2720	7.732***
	C: SEASON	256.6296	1	256.6296	102.954***
	INTERACTIONS				
	AB:	397.55212	16	24.847007	9.968***
	AC:	47.67854	2	23.839272	9.564**
	BC:	124.13687	8	15.517108	6.225***
	RESIDUAL	39.882489	16	2.4926556	
	TOTAL (CORRECTED)	4947.9002	53		
15	MAIN EFFECTS				
	A: SOIL	4857.5178	2	2428.7589	5970.135***
	B: COMPOST CONTENT	853.1939	8	106.6492	262.155***
	C: SEASON	146.2241	1	146.2241	359.434***
	INTERACTIONS				
	AB	396.24976	16	24.765610	60.876***
	AC	39.51248	2	19.756239	48.563***
	BC	20.33187	8	2.541483	6.247***
	RESIDUAL	6.5090889	16	0.4068181	
	TOTAL (CORRECTED)	6319.5389	53		
30	MAIN EFFECTS				
	A: SOIL	9060.2687	2	4530.1344	15030.861***
	B: COMPOST CONTENT	2044.12623	8	255.5158	847.794***
	C: SEASON	8.4560	1	38.4560	127.596***
	INTERACTIONS				
	AB	136.06274	16	8.5039213	28.216***
	AC	6.71924	2	3.3596222	11.147***
	BC	10.19157	8	1.2739458	4.227**
	RESIDUAL	4.8222222	16	0.3013889	
	TOTAL (CORRECTED)	11300.647	53		

[1] All F-ratios are based on the residual mean square error.

*, **, *** denote significance at 0.05, 0.01, and 0.001, respectively.

Table 10. Germination percentages of tomato, cucumber, and lettuce, 21 day after seeding in sand, sand loam, and sand clay loam soils, mixed with compost at different rates

Compost %	Tomato			Cucumber			Lettuce		
	S	SL	SCL	S	SL	SCL	S	SL	SCL
0	71.9*	67.9	66.9	49.1	67.1	68.4	48.5	42.4	40.9
2	74.8	68.4	69.9	63.8	72.2	73.6	58.6	52.9	49.8
4	83.3	72.4	71.3	83.6	79.9	76.4	59.4	54.4	54.9
6	86.9	82.6	80.2	89.8	84.5	85.6	76.7	73.6	67.8
8	91.7	82.5	83.2	93.9	88.3	87.2	73.6	70.4	72.6
10	93	86.5	83.1	98	93.1	94.5	77.5	73.4	71.6

* Values shown are averages of two seasons.

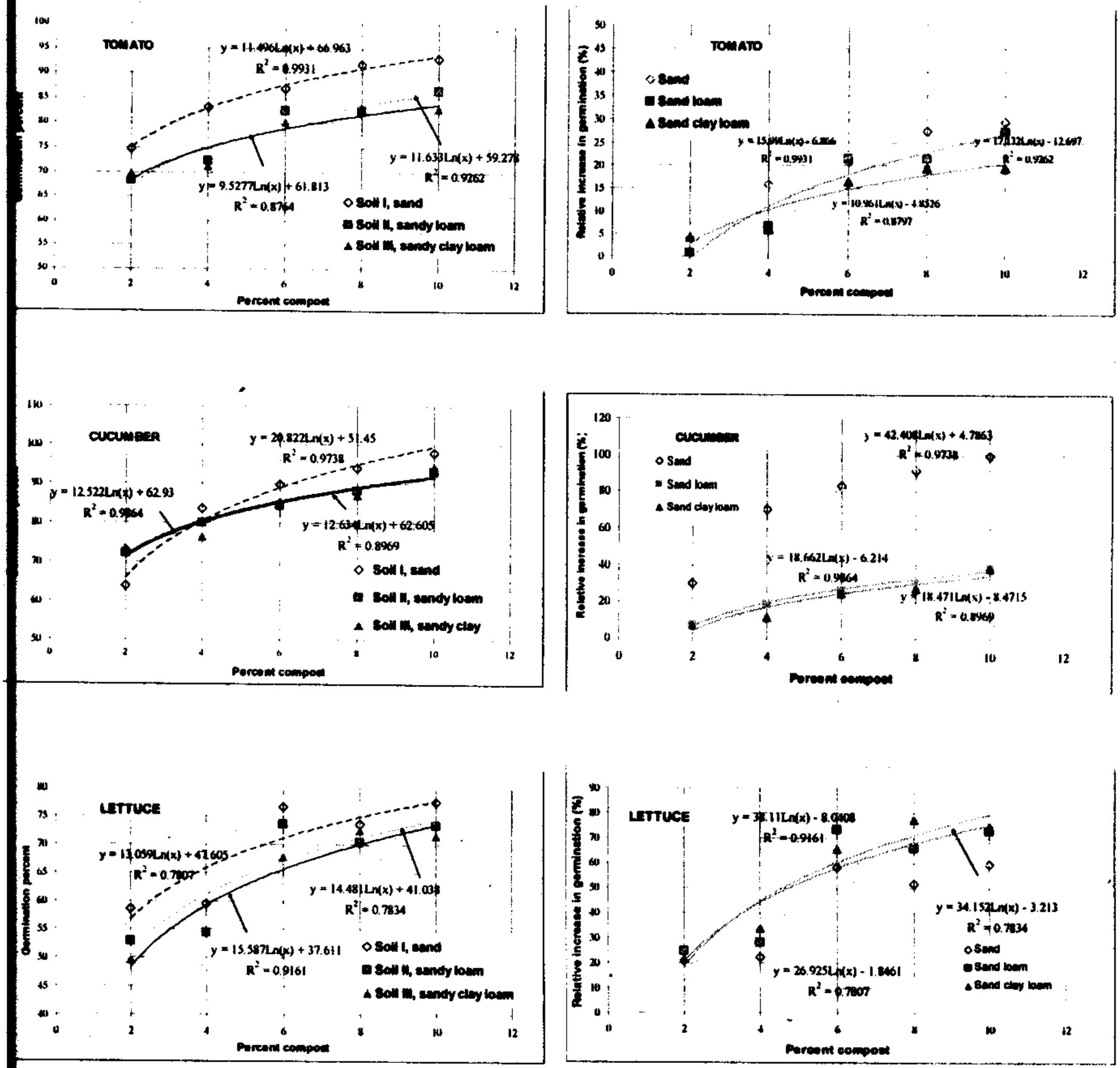


Fig. 4. Seed germination percentages (left) and relative increase in germination (right) for tomato, cucumber, and lettuce seeds in sandy, sandy loam and sandy clay loam soils, as affected by compost content.

Values of $R^2 \geq 0.9197$ indicate determination coefficients significant at 0.01
Values of R^2 such that: $0.9197 \geq R^2 \geq 0.7709$ indicate determination coefficients significant at 0.05

Table 11. Analysis of variance (ANOVA) for seed germination data– Sums of squares, F-ratios, and significance levels.

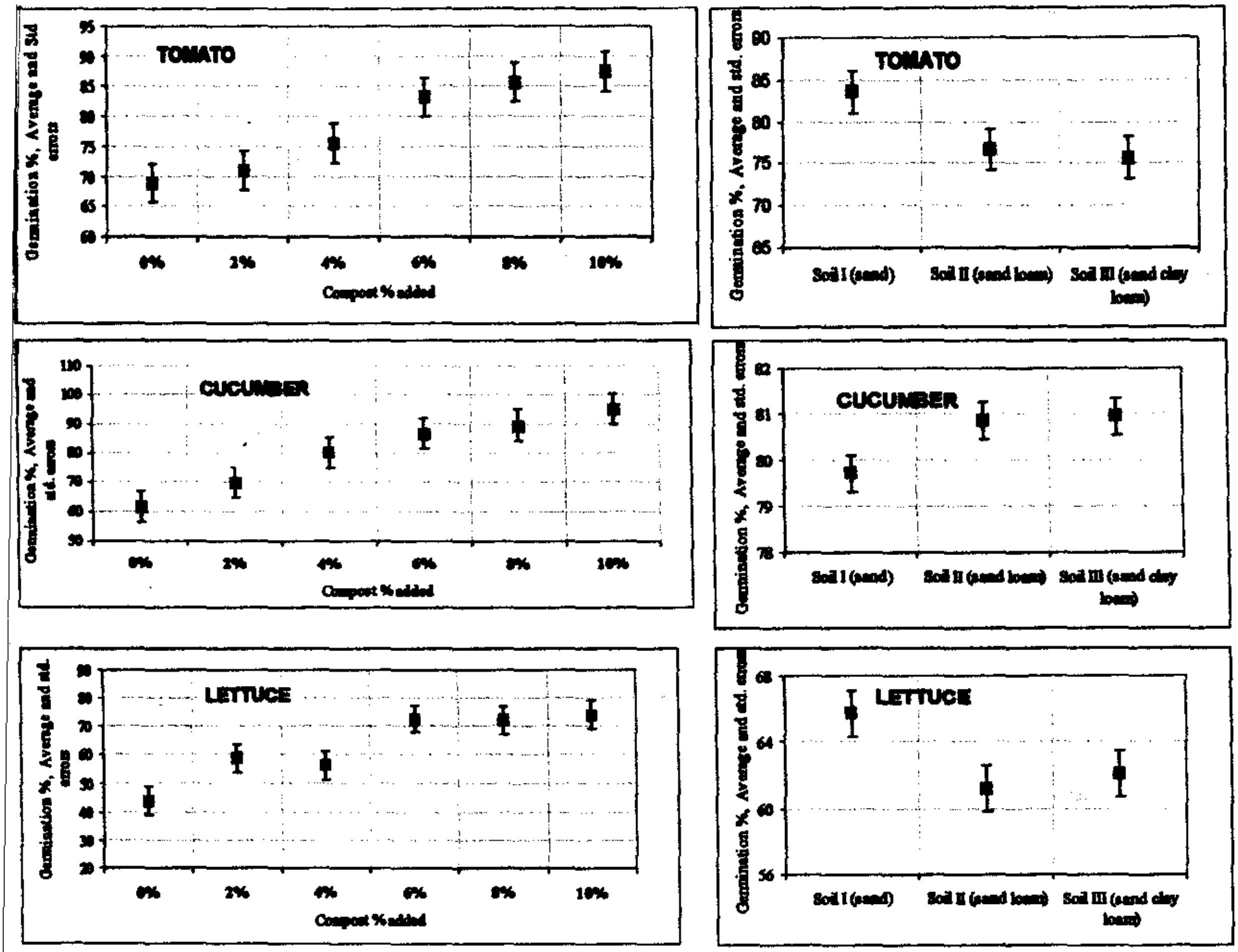
	Source of variation	Sum of squares	d.f.	Mean square	F-ratio(1)
Tomato	MAIN EFFECTS				
	A: SOIL	438.5756	2	219.28778	43.579***
	B: COMPOST CONTENT	1878.0456	5	375.60911	74.644***
	C: SEASON	2.5600	1	2.56000	0.509
	INTERACTIONS				
	AB:	62.477778	10	6.247778	1.242
	AC:	0.3466667	2	0.1733333	0.034
	BC:	26.853333	5	5.3706667	1.067
	RESIDUAL	50.320000	10	5.0320000	
	TOTAL (CORRECTED)	2459.1789	35		
Cucumber	MAIN EFFECTS				
	A: SOIL	11.5800	2	5.79000	1.506
	B: COMPOST CONTENT	4879.7067	5	975.94133	253.843***
	C: SEASON	0.0100	1	0.01000	0.003
	INTERACTIONS				
	AB:	726.51333	10	72.651333	18.897***
	AC:	0.98000	2	0.490000	0.127
	BC:	38.38333	5	7.676667	1.997
	RESIDUAL	38.446667	10	3.8446667	
	TOTAL (CORRECTED)	5695.6200	35		
Lettuce	MAIN EFFECTS				
	A: SOIL	137.8867	2	68.94333	1.803
	B: COMPOST CONTENT	4384.0267	5	876.80533	22.926***
	C:SEASON	7.8400	1	7.84000	0.205
	INTERACTIONS				
	AB:	227.88667	10	22.788667	0.596
	AC:	66.84667	2	33.423333	0.874
	BC:	336.58667	5	67.317333	1.760
	RESIDUAL	382.44667	10	38.244667	
	TOTAL (CORRECTED)	5543.5200	35		

(1) All F-ratios are based on the residual mean square error.

*,**,*** denote significance at 0.05, 0.01, and 0.001, respectively.

CONCLUSIONS

The results of the work presented in this manuscript reiterate the highly important role of organic substances in soil. Adding compost material to soils improved water holding capacity and increased their available water content. It also increased cumulative evaporation over prolonged periods (~10-30 days). Seed germination rates were consistently improved with increased applications, showing high benefits at relatively low addition rates. Organic material improve soil physical properties via improving aggregation and increasing the amount of water-stable aggregates in coarse soil, while it boosts the condition of finer-textured soil through better aeration and improved drainability. While increased water retention, AW %, and germination are all favorable, increased evaporation, even though it reflects better water retention, must be dealt with carefully for improved water use efficiency. Use of compost-soil mixtures under conditions of high evaporative demands must be avoided. Good management would require that compost-soil mixtures be used in covered agronomic settings (greenhouse, tunnels, etc.) or with surface mulch, particularly under warm summer conditions.



5. Pooled Least squared means and standard errors of germination percentages for tomato, cucumber, and lettuce seeds planted in sandy, sandy loam, and sandy clay loam soils as affected by added different rates of compost. Left: Pooled averages over soils and season showing the overall effect of compost content. Right: Pooled averages over compost content and season, showing overall effect of soil.

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الملخص العربي

تأثير السماد العضوي المكمور (الكومبوست compost) المحلي على الخصائص الفيزيائية لأراض مختلفة القوام

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أجريت دراسة لبحث تأثير إضافة معدلات مختلفة من السماد العضوي المكمور (الكومبوست Compost) والملتج محليًا إلى ثلاث أراض مختلفة (رملية sandy، لومية رملية sandy loam، ولومية طينية رملية sandy clay loam) على بعض الخصائص الفيزيائية للتربة. أدت زيادة معدلات الإضافة إلى خفض واضح في الكثافة الظاهرية لكل الأراضي. عند الخلط بنسبة ٥٠% انخفضت الكثافات إلى نحو ٦٠% من القيمة الأصلية. أوضحت التجارب أن نسبة الماء المتاح (AW) قد ازدادت مع زيادة إضافة السماد، حيث كان التأثير أكثر وضوحًا في حالة التربة الرملية. وكانت تأثيرات كل من التربة والسماد معنوية جدًا من الناحية الإحصائية $(\alpha = 0.001)$. حدثت أعلى معدلات للزيادة في الماء المتاح عند الخلط بمعدل ٥٠% لكل الأراضي حيث كانت الزيادة النسبية نحو ٣٩١,٤، ٢٢٨,٩ و١٩٦,٢% للتربة الرملية واللومية الرملية واللومية الطينية الرملية، على الترتيب. كما أن الإضافة بنسبة ٨% أدت إلى زيادة نسبية مقدارها حوالي ٢٠٠، ١٣٤، ١٢٨% للأراضي الثلاث على التوالي. وقد وجد أن العلاقة بين النسبة المضافة من الكومبوست والماء المتاح تتبع بقوة معادلة متعددة الحدود polynomial function على الصورة $y = ax^3 + bx^2 + cx + d$ ، حيث y هي الماء المتاح % وx هي النسبة المئوية للكومبوست المضاف، وكان معامل التقدير (R^2) determination coefficient > 0.997 بحيث يعكس ارتباطًا معنويًا مرتفعًا $(\alpha = 0.001)$. أظهرت النتائج أن البخر التجميعي للماء من الأراضي المختلفة تحت معدلات السماد العضوي المختلفة يعكس سلوكًا متغيرًا عبر مرحلتين تشملهما عملية البخر: مرحلة مبكرة وفيها تؤدي معدلات الكومبوست الأعلى إلى مقادير أقل من البخر التجميعي، ومرحلة متأخرة وفيها تؤدي زيادة معدلات السماد إلى زيادة البخر التجميعي. تم التمييز بين المرحلتين عل أساس اختلاف قدرة التربة المختلطة بالكومبوست على مقابلة القوة التبخيرية الخارجية external evaporativity عند مستويات الرطوبة المختلفة بالتربة، بحيث كانت التربة ذات المحتوى الأعلى من الكومبوست أكثر قدرة على مواصلة البخر بمعدلات مؤثرة لمدد أطول نتيجة لتحسن قدرتها على الاحتفاظ بالرطوبة. تميزت المرحلة المبكرة بأنها الأقصر زمنًا في التربة الرملية والأطول في التربة اللومية الطينية الرملية، كما كانت أقصر لتربة معينة في فصل الصيف عنها في الشتاء. وقد وجد أن التأثيرات جميعها (نوع التربة، محتوى التربة من السماد المضاف وكذلك الموسم) عالية المعنوية $(\alpha = 0.001)$ في كل الأوقات على مدى عملية البخر (٣٠ يومًا). أدت إضافة الكومبوست إلى تحسين قدرة التربة كبيئة لنمو النبات. فبالنسبة لكل الأراضي، ارتبطت معدلات الإنبات الأعلى بمعدلات الإضافة الأعلى للكومبوست. تم تمييز معدلات إضافة "اقتصادية" كمعدلات ترتبط بالزيادات "النسبية" الأعلى من الإنبات. هذه المعدلات قابلتها معدلات إنبات مقدارها نحو ٨٣% لكل من بذور الطماطم والخيار ونحو ٧٠% للخس. وقد تبعت كل من معدلات الإنبات (%) وكذلك الزيادة النسبية للإنبات دالة لوغارتمية على الصورة $y = a \ln x + b$ ،حيث y هي نسبة الإنبات (%) أو الزيادة النسبية للإنبات (%) وx وهي نسبة السماد العضوي المضاف، بمعاملات تقدير (R^2) تتراوح بين ٠,٩٠، و٠,٩٩ في معظم الأحوال. كان تأثير إضافة الكومبوست معنويًا $(\alpha = 0.001)$، بينما لم يكن تأثير نوع التربة ثابتًا، أما تأثير الموسم فلم يكن معنويًا من الناحية الاحصائية.