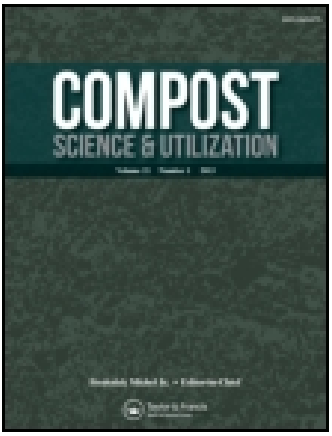

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The Effect Of Municipal Solid Waste Compost Application On Soil Water and Water Stress in Irrigated Corn

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Land application of municipal solid waste (MSW) compost increases soil organic matter content and influences soil physical properties. This study was conducted to measure the effect of compost on the water holding capacity of soil and water status in corn (*Zea mays* L.) from 1993 to 1995. The soil was a Hubbard loamy sand (sandy, mixed, Udorthentic Haploboroll) cropped to irrigated corn at the Sand Plain Research Farm at Becker, MN. Compost treatments on dry weight basis were 0 and 90 Mg ha^{-1} yr^{-1} from 1993 to 1995, and a one time application at 270 Mg ha^{-1} in 1993. The soil moisture retention curves were generated in 1994 and corn leaf water potential and soil bulk density were measured each growing season. Based on water retention curves, the addition of compost increased the water holding capacity of soil without significant increase in the estimated available water. This was contradicted by field measurements which showed that compared to a fertilized control one compost source at the 270 Mg ha^{-1} rate in the year of application increased plant water stress by 0.22 MPa, likely due to salt loading. In the year after the application of the 270 Mg ha^{-1}, two compost sources increased soil water content and corn yield 0.14 cm^3 cm^{-3} and 0.9 Mg ha^{-1} respectively. The yield increase was also associated with a reduction in plant water stress of 0.14 MPa due to one of the compost sources.

Introduction

Soil physical properties such as aggregate stability, soil structure, pore size distribution, soil density, and water holding capacity can change when soil is amended with organic matter. The addition of organic soil conditioners has been shown to reduce aggregate breakdown and slow seal formation by rain drop impact due to the increased strength in the bonds between the constituents forming aggregates (Shainberg *et al.* 1992). The reduction of organic matter upon cultivation and crop production can also result in increased soil erosion and decreased soil productivity (De Haan 1981; Elliott 1986).

Sewage sludge and refuse compost amendments have been shown to increase total porosity and pore size distribution of soil (Pagliai *et al.* 1981). Bugbee and Frink (1989) found that composted waste in potting mixes was similar in aeration, water holding capacity, and other media properties compared to potting mixes alone. Organic amendments can reduce soil penetration resistance and bulk density (Tester 1990; Kreft 1987) and increase water holding capacity of soils, particularly in coarse-textured soils (Kreft 1987). A reduction in available water capacity is considered a major factor contributing to loss of soil productivity (Bauer and Black 1992). In a field study, municipal solid waste (MSW) compost applied in well-drained sandy soil has been shown to increase moisture availability to young slash pine (Bengtson and Cornette 1973) without an adverse effect of compost on soil or trees. The objectives of this study were to evaluate the effect of MSW compost amendment on corn grain yield, soil bulk density, soil water content, and moisture availability in well-drained sandy soils amended with MSW compost.

Materials and Methods

The field experiment was conducted from 1993 to 1995 on a Hubbard loamy sand soil (pH of 5.8 and organic matter content of 1.4 percent) at the University of Minnesota Sand Plain Research Farm at Becker, MN. The two composts, Truman and Wright, were obtained from Truman, Minnesota and Buffalo, Minnesota respectively. The Truman compost was made using the Siloda process (OTVD French technology) and the Wright compost was made using the windrow process (Buhler Swiss technology). The feedstocks for composting were highly variable and included various proportions of cardboard, paper, food waste, and yard waste. Plastic, glass, stone, and metal contaminants were removed before composting. The compost had less than 2.8% inert fraction (< 6 mm) by weight.

Selected chemical properties of the composts from 1993 to 1995 are presented in Table 1. Total N and C in compost were measured by Kjeldahl and dry combustion methods, respectively (Bremner and Mulvaney 1982; Nelson and Sommers 1982). Compost NO_3—N and NH4+-N were extracted in 2 M KCl (Keeney and Nelson 1982) and measured by conductrimetic method (Carlson 1990). Total P and K in the composts were measured by ICP following dry ashing procedures (Munter 1984). Total P ranged from 1.7 to 2.6 g kg^{-1} for Truman compost and from 1.3 to 2.9 g kg^{-1} for Wright compost. Total K ranged from 2.4 to 3.8 g kg^{-1} for Truman compost and from 1.8 to 3.8 g kg^{-1} for Wright compost. The composts met heavy metal standards of the United States Environmental Protection Agency 503 regulations for sewage sludge (USEPA 1993).

TABLE 1.
Selected chemical characteristics of composts

Year	Compost Source	Compost Rate† Mg ha^{-1}	Organic C (g kg^{-1})	N (g kg^{-1})	C:N	Inorganic N§ (kg ha^{-1})	Organic N§ (kg ha^{-1})	EC S m^{-1}
1993	Truman	90	200	9	22	27	783	1.7
		270	200	9	22	81	2349	1.7
	Wright	90	170	11	15	46	944	1.6
		270	170	11	15	138	2830	1.6
1994	Truman	90	240	9	27	66	744	1.5
	Wright	90	180	10	18	31	869	0.9
1995	Truman	90	230	10	23	27	873	1.3
	Wright	90	200	9	22	27	783	1.6

†Compost applied one time at 270 Mg ha^{-1} in 1993 or annually at 90 Mg ha^{-1} from 1993 to 1995.
§N applied at compost application rate of 270 Mg ha^{-1} or 90 Mg ha^{-1} y^{-1}.

The soil was amended with either Truman or Wright compost each at 90 and 270 Mg ha^{-1} (dry weight basis) in 1993. In 1994 and 1995, plots that had received 90 Mg ha^{-1} compost received an additional 90 Mg ha^{-1} each year (total 270 dry Mg ha^{-1} from 1993 to 1995). Municipal solid waste compost was weighed in a tractor mounted front-end loader on load cells to within ±10 kg, transferred into a manure spreader, applied to each designated 7.6 m by 4.6 m plot, and then incorporated by moldboard plowing to a depth of 20 cm. The compost and nonamended control treatments which were replicated four times also received sidedress applications of 250 kg N ha^{-1} as urea each year. In addition to the N treatment, starter fertilizer at rates of 13 kg N ha^{-1}, 7 kg P ha^{-1}, and 50 kg K ha^{-1} was banded each year at planting to all plots. All sidedress N was immediately incorporated by irrigation or cultivation. Details of the experimental design can be found in Mamo *et al.* (1999).

Corn was irrigated using the soil water deficit (checkbook method) for irrigation scheduling (Wright and Bergsrud 1991). The soil water deficit is the amount of water needed to restore the soil water in the rooting zone to field capacity. Usually, the allowable soil water deficit is set for a given crop and soil specifying the maximum amount of water to be depleted before initiating irrigation. The water balance method was used to estimate the daily change in soil water storage (ÎS) for the entire growing season.

$$\Delta S = P + I - ET \qquad [1]$$

where P is measured rainfall precipitation (mm), I is amount of irrigation water applied (mm), and ET is evapotranspiration (mm) or crop water use for different growth stages of corn estimated by Wright and Bergsrud (1991) using the Penman equation.

Bulk Density

In 1993, a bulk density sampler was used to obtain field cores with 5 cm diameter by 5 cm height at depths of 0 to 10 cm and 10 to 20 cm. In 1994, soil samples were only taken from 0 to 10 cm depth. All measurements were done on four replications.

Moisture Retention Curves

Moisture retention curves were generated on soil (0 to 25 cm depth) collected in 1994 after the second year compost application. The field moist soil was artificially packed in cores with 5 cm diameter by 5 cm height. For the lower tensions (5×10^{-4}, 1×10^{-3}, 2×10^{-3}, 3×10^{-3}, 5×10^{-3}, 7.5×10^{-3}, and 0.01 MPa), the hanging water column method was used (Klute 1986). Approximately 24 to 48 hours were allowed for the system to equilibrate after which the weight of the core was recorded. For the higher tensions (0.03, 0.05, and 0.1 MPa), a pressure plate chamber was used. The pressure of the plate was set for each pressure and allowed to equilibrate for two days after which soil cores were taken out. The van Genuchten equation (van Genuchten 1980) was used to predict the water content (θ) at tension, h as:

$$\theta = \theta_r + \frac{(\theta_s + \theta_r)}{[1 + (ah)^n]^m}; \quad m = 1 - \frac{1}{n} \qquad [2]$$

where, θ_r and θ_s are the residual and saturated water contents, respectively; and a, n, and m are empirical parameters. The available water holding capacity (AWHC) was taken as the difference between water content at h = 0.01 MPa ($\theta_{0.01}$) and h = 1.5 MPa ($\theta_{1.5}$) using Equation [2].

Plant Moisture Status Measurement

From 1993 to 1996, plant water status was measured using the pressure chamber method (Hsiao 1990). In 1993, plant water status measurements were made on treatments with 270 Mg ha^{-1} compost receiving 250 kg N ha^{-1}. In 1994 and 1995, plant water status measurements were made on the residual 270 Mg ha^{-1} compost treatments and the 90 Mg ha^{-1} yr^{-1} compost treatments all receiving 250 kg N ha^{-1}. Although an irrigation schedule to minimize water stress was used, stress measurements were made two to three days following rainfall or irrigation to characterize any stress just prior to the next irrigation or rainfall. Rainfall and irrigation data are presented in Figure 1.

The first measurement of the day was made before 1000 hrs. when evaporative demand was low, and the second measurement of the day was made in the afternoon between 1200 and 1600 hrs. when demand was high. Measurements were made on two leaves per plant and four replications after silk emergence between the end of July and early August. A pressure chamber equipped with compressed N gas, a pressure gauge, a leaf holder, and pressure vessel was used for the measurements. The procedure involved sealing the freshly cut leaf into the chamber with the cut surface protruding and applying pressure to force water out of the leaf cells. The pressure needed to force the first drop of water out of the leaf is the leaf water potential (Kramer 1983).

Data Analysis

Data were compared by analysis of variance procedures. Statistical analyses were performed using Statistical Analysis System version 6.04 (SAS 1986). The level of significance was set at statistical $P \leq 0.100$.

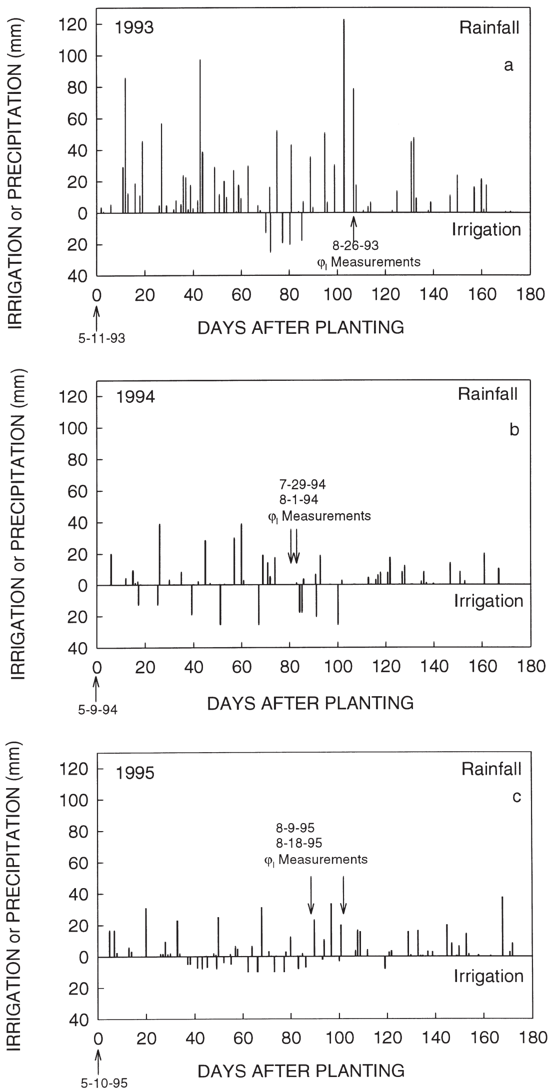

Figure 1. Rainfall and irrigation for the a) 1993, b) 1994, and c) 1995 growing seasons.

Results and Discussion

Moisture Retention Curve

The Wright compost generally had lower C:N ratio than the Truman composts in all three years (Table 1). Higher C:N ratios are often associated with immaturity and can affect plant response when applied to soils (He *et al.* 1992). While specific maturity tests were not conducted on any of the composts used in this study, visually, the Wright compost was darker and appeared more decomposed than the Truman compost. In addition the salt content of both composts was high (Table 1) considering that most compost for agricultural land application have much lower salt content.

Compost treatments did not significantly affect moisture retention over the range of pressures studied (Figure 2). Since, the retention curve was generated one year after compost application, the effect on the AWHC was expected to be high. However, the moisture retention curve was shifted upward without any significant increase in the available water (Table 2). Khaleel *et al.* (1981) also reported that organic amendment increased the moisture content at both field capacity and wilting point resulting in no net change in AWHC. In a field study, Turner *et al.* (1994) observed that water content was lower and approaching the control soil one year after compost application on a sandy soil.

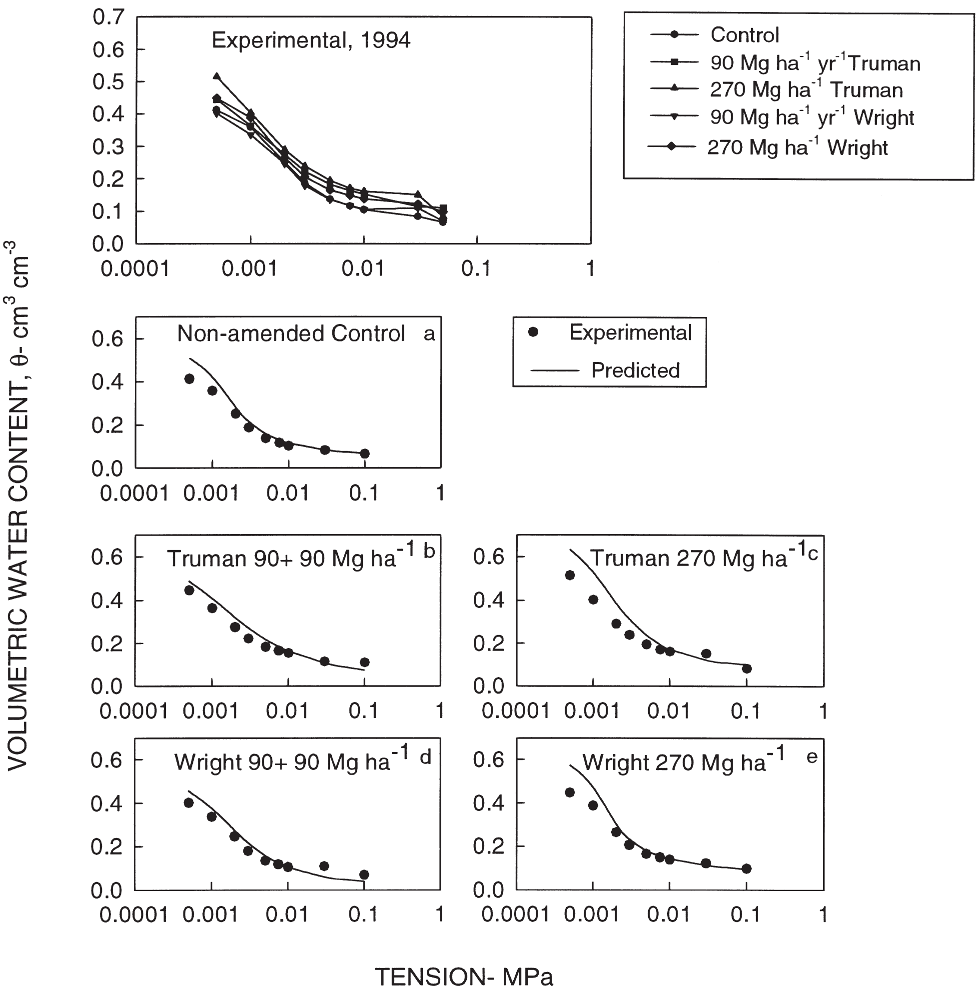

Figure 2. Experimental and modeled moisture retention curve of soil amended with MSW compost.

The corresponding values of the van Genuchten's equation (van Genuchten *et al.* 1991) parameters are presented in Table 2. The water content at 0.01 ($\theta_{0.01}$) and 1.5 ($\theta_{1.5}$) MPa were not different among treatments. Orthogonal contrasts showed no significant difference in van Genutchen's parameters between control and compost treatments. The AWHC by volume ranged from 6.2 percent to 12.1 percent.

TABLE 2.
Parametric constants used in van Genuchten's equations describing water content relationship to pressure head for Hubbard loamy sand soil soil amended with MSW compost.§

Source	Compost (Mg ha^{-1})	a (cm^{-1})	n	θ_s	θ_r	$\theta_{0.01}$ cm^{3}cm^{-3}	$\theta_{1.5}$	AWHC
Control	0	0.153	2.0	0.480	0.05	0.1160	0.0544	0.0616
Truman	90+ 90†	0.141	1.5	0.506	0.03	0.1624	0.0420	0.1204
Truman	270‡	0.102	1.9	0.524	0.09	0.1706	0.0887	0.0819
Wright	90+ 90†	0.112	1.8	0.465	0.03	0.1040	0.0280	0.0760
Wright	270‡	0.167	2.2	0.510	0.06	0.1428	0.0759	0.0669
Compost (*P-value*)		0.89	0.78	0.03	0.82	0.45	0.80	0.41
LSD		0.209	1.4	0.033	0.16	0.1053	0.1519	0.0808

§ θ_s and θ_r saturated and residual water contents, respectively, and a and n, empirical constants.
† 90 Mg ha^{-1} applied annually from 1993 to 1994.
‡ 270 Mg ha^{-1} applied in 1993.

Field Bulk Density and Water Content

Compost application at the 270 Mg ha^{-1} rate decreased soil bulk density and increased water content in 1993 and 1994 (Tables 3 and 4). Since, the compost was incorporated by moldboard plowing to a 20 cm depth, soil bulk density at 10 to 20 cm depth was much lower than that of the control the first year. The decrease in bulk density as a result of organic amendment with compost has also been reported by Kreft (1987), Gupta *et al.* (1977) and Khaleel *et al.* (1981). At 10 to 20 cm depth, the addition of 270 Mg ha^{-1} Truman or Wright composts decreased the bulk density of the soil by 31 percent and 25 percent, respectively. Others have shown similar findings, where the addition of organic waste decreased the bulk density of soil by 28 percent to 30 percent (Gupta *et al.* 1977; Weil and Kroonjte 1979). The water content was significantly higher with depth in soil with 270 Mg ha^{-1} compost (significant compost by depth interaction, $P < 0.05$).

In 1994, bulk density was much lower in soil amended with 270 Mg ha^{-1} compost compared to that in 1993 at the 0 to 10 cm depth (Tables 3 and 4). The decrease in bulk density in soil amended with 270 Mg ha^{-1} compost was 44 percent for Truman and 38 percent for Wright. The bulk density at the surface was lower in 1994 than 1993 (average decrease of

TABLE 3.
Bulk density and water content measured in 1993

Compost	Rate (Mg ha^{-1})	Bulk Density (Mg m^{-3})	Volume Water-θ (cm^3 cm^{-3})
		0-10 cm	
Control	0	1.55	0.16
Truman	270‡	1.50	0.16
Wright	270‡	1.48	0.16
		10-20 cm	
Control	0	1.61	0.18
Truman	270‡	1.09	0.32
Wright	270‡	1.24	0.24
		P-Value	
Compost		0.10	0.15
Depth		0.19	0.03
Compost*depth		0.08	0.07

‡ 270 Mg ha^{-1} applied in 1993.

TABLE 4.
Bulk density and water content measured in 1994

Compost	Rate (Mg ha^{-1})	Bulk Density (Mg m^{-3})	Volume Water-θ (cm^3 cm^{-3})
		0-10 cm	
Control	0	1.61a	0.09c
Truman	90+ 90†	1.54a	0.08c
Truman	270‡	0.95b	0.23ab
Wright	90+ 90†	1.45a	0.10abc
Wright	270‡	0.98b	0.25a
Compost (*P-value*)		< 0.01	< 0.01

† 90 Mg ha^{-1} applied annually from 1993 to 1994.
‡ 270 Mg ha^{-1} applied in 1993.

0.5 Mg m^{-3} at P = 0.01 and LSD = 0.21 Mg m^{-3}) because the soil was moldboard plowed following compost application every year and more mixing occurred with every plowing. The 90 Mg ha^{-1} yr^{-1} compost addition did not result in a measurable change in soil bulk density or higher water content. The lower water content in soil with 90 Mg ha^{-1} yr^{-1} compost may be due to less dilution effect and higher soil to compost ratio at the surface 0 to 10 cm depth.

Leaf Water Potential

Although corn was irrigated, the effect of compost on leaf water potential (φ_l) was significant in every year (Tables 5, 6, and 7). Significant differences in φ_l were observed between treatments in morning and afternoon measurements in 1993. Higher water potential in 1993 is likely associated with high salt loading (soluble salts in Truman and Wright were 1.7 and 1.6 S m^{-1}, respectively). This increase in stress occurred even though over 120 mm of rainfall fell four days before the measurements (Figure 1). Above average rainfall fell during the 1993 growing season (rainfall May to October, 636 mm) and plants did not experience extensive water stress as indicated by the measured values in that year. This is based on the point where initial photosynthetic inhibition during corn reproductive stage begins at 0.8 MPa (Boyer 1976).

TABLE 5.
Corn leaf water potential measured in 1993

Source	Compost rate§ (Mg ha^{-1})	Leaf water potential- φ_l¶ 8-26-93 MPa 0850-0955	1245-1345	Average	θ¥ (cm^3cm^{-3})	Grain Yield (Mg ha^{-1})
Control	0	0.24b	0.68b	0.46b	0.12	9.9a
Truman	270‡	0.51a	0.84a	0.68a	0.15	8.9a
Wright	270‡	0.43a	0.68b	0.56b	0.15	9.4a
Average		0.39	0.73	0.57	0.14	9.4
		P-value				
Compost		0.03				
Time		< 0.01				
Time*Compost		0.43				

‡ 270 Mg ha^{-1} amended in 1993.
§ Electrical conductivity: 1.7 and 1.6 S m^{-1} for Truman and Wright composts, respectively.
¥ Volumetric water content measured after leaf water potential measurements.
¶ Air temperature: 31.2°C; Rainfall before measurements: 123 mm on 8/22/93; Rainfall after measurements: 79 mm on 8/26/93; Irrigation: None; Solar radiation: 97.7 cal cm^{-2} day^{-1}

In 1994, the 270 Mg ha^{-1} Wright compost treatment resulted in lower φ_l compared to the control and other compost treatments (Table 6). The total soil volumetric water obtained after φ_l measurements showed higher water content for the 270 Mg ha^{-1} compost treatments (θ = 0.25 cm^3 cm^{-3} for Wright and θ = 0.23 cm^3 cm^{-3} for Truman) compared to either the 90 Mg ha^{-1} yr^{-1} compost or control treatments (Table 6). Although, water content levels were the same between the 270 Mg ha^{-1} compost treatments, the lower φ_l in the 270 Mg ha^{-1} Wright compost treatment one year after application may be suggesting more available water to plants, better hydraulic conductivity, and root distribution compared to that of 270 Mg ha^{-1} Truman compost. These quantitative observations measured in the field in 1994 did not agree with the measured laboratory available water holding capacity (AWHC), which showed no change in AWHC of the

TABLE 6.
Corn leaf water potential measured in 1994

Source	Compost Rate§ ($Mg\ ha^{-1}$)	Leaf Water Potential- φ_l (MPa): 7-29-1994¶ 0815-0915	7-29-1994¶ 1230-1330	7-29-1994¶ Avg.	8-1-1994£ 0815-0915	8-1-1994£ 1230-1330	8-1-1994£ Avg.	Average- φ_l (MPa): Morning	Afternoon	Overall	θ¥ (cm^3cm^{-3})	Grain Yield ($Mg\ ha^{-1}$)
Control	0	0.25a	0.74a	0.50	0.42a	1.08ab	0.75	0.34a	0.91a	0.63a	0.09c	11.1a
Truman	90+ 90†	0.17a	0.85a	0.51	0.47a	1.23a	0.85	0.32a	1.04a	0.68a	0.08c	11.7a
Truman	270‡	0.17a	0.74a	0.46	0.43a	1.04ab	0.74	0.30a	0.89a	0.60a	0.23ab	11.9b
Wright	90+ 90†	0.18a	0.84a	0.51	0.45a	1.09a	0.77	0.32a	0.97a	0.65a	0.10abc	11.5a
Wright	270‡	0.20a	0.51a	0.36	0.39a	0.82b	0.61	0.30a	0.67b	0.25a	12.0b	
Average		0.19	0.74	0.47	0.43	1.05	0.74	0.32	0.90	0.61		
				P-value								
Compost				< 0.01								
Time				< 0.01								
Time*Compost				0.01								
Date				0.03								
Time*Date				0.53								
Compost*Date				0.85								
Compost*Date*Time				0.86								

† 90 $Mg\ ha^{-1}$ applied annually from 1993 to 1994.
‡ 270 $Mg\ ha^{-1}$ applied in 1993.
§ Electrical conductivity of compost applied in 1994: 1.5 and 0.9 $S\ m^{-1}$ for Truman and Wright composts, respectively.
¥ Volumetric water content measured after leaf water potential measurements on 7/29/94 at 0-10 cm depth.
¶ Air temperature: 27.8°C; Rainfall before measurements: 18 mm on 7/22/94; Rainfall after measurements: None; Irrigation: None; Solar radiation: 99.9 cal $m^2\ day^{-1}$.
£ Air temperature: 31.1°C; Rainfall before measurements: 3 mm on 7/31/94; Rainfall after measurements: 18 mm on 8/1/94; Irrigation: None;
Solar radiation: 98.9 cal cm-2 day^{-1}.

TABLE 7.
Corn leaf water potential measured in 1995

Source	Compost Rate§ ($Mg\ ha^{-1}$)	Leaf Water Potential- φ_l (MPa): 8-9-1995¶ 0815-0930	8-9-1995¶ 1310-1420	8-9-1995¶ Avg.	8-18-1995£ 0810-0910	8-18-1995£ 1200-1300	8-18-1995£ Avg.	Average- φ_l (MPa): Morning	Afternoon	Overall	Grain Yield ($Mg\ ha^{-1}$)
Control	0	0.69a	0.89bc	0.79	0.42a	1.02a	0.72	0.56a	0.96bc	0.76bc	9.4a
Truman	90+ 90+	0.75a	0.95b	0.85	0.47a	1.10a	0.79	0.61a	1.03ab	0.82ab	9.3a
Truman	270‡	0.67a	0.83c	1.09	0.52a	1.03a	0.78	0.60a	0.93c	0.77c	9.6a
Wright	90+ 90+	0.74a	1.08a	0.91	0.56a	1.06a	0.81	0.65a	1.07a	0.86a	9.6a
Wright	270‡	0.75a	0.88bc	0.82	0.50a	1.06a	0.78	0.63a	0.97bc	0.80bc	10.5a
Average		0.72	0.93	0.89	0.49	1.05	0.78	0.61	0.99	0.80	
				P-value							
Compost				0.03							
Time				<0.01							
Time*Compost				0.61							
Date				0.36							
Time*Date				<0.01							
Compost*Date				0.41							
Compost*Date*Time				0.27							

† 90 $Mg\ ha^{-1}$ applied annually from 1993 to 1995.
‡ 270 $Mg\ ha^{-1}$ applied in 1993.
§ Electrical conductivity of compost applied in 1995: 1.3 and 1.6 $S\ m^{-1}$ for Truman and Wright composts, respectively.
¶ Air temperature: 27.8°C; Rainfall before measurements: 23 mm on 8/07/95; Rainfall after measurements: None; Irrigation: None; Solar radiation: 150.8 cal m2 day^{-1}.
£ Air temperature: 31.1°C; Rainfall before measurements: 33 mm on 8/14/95; Rainfall after measurements: 20 mm on 8/18/95; Irrigation: 3 mm on 8/17/95.
Solar radiation: 432.9 cal cm-2 day^{-1}.

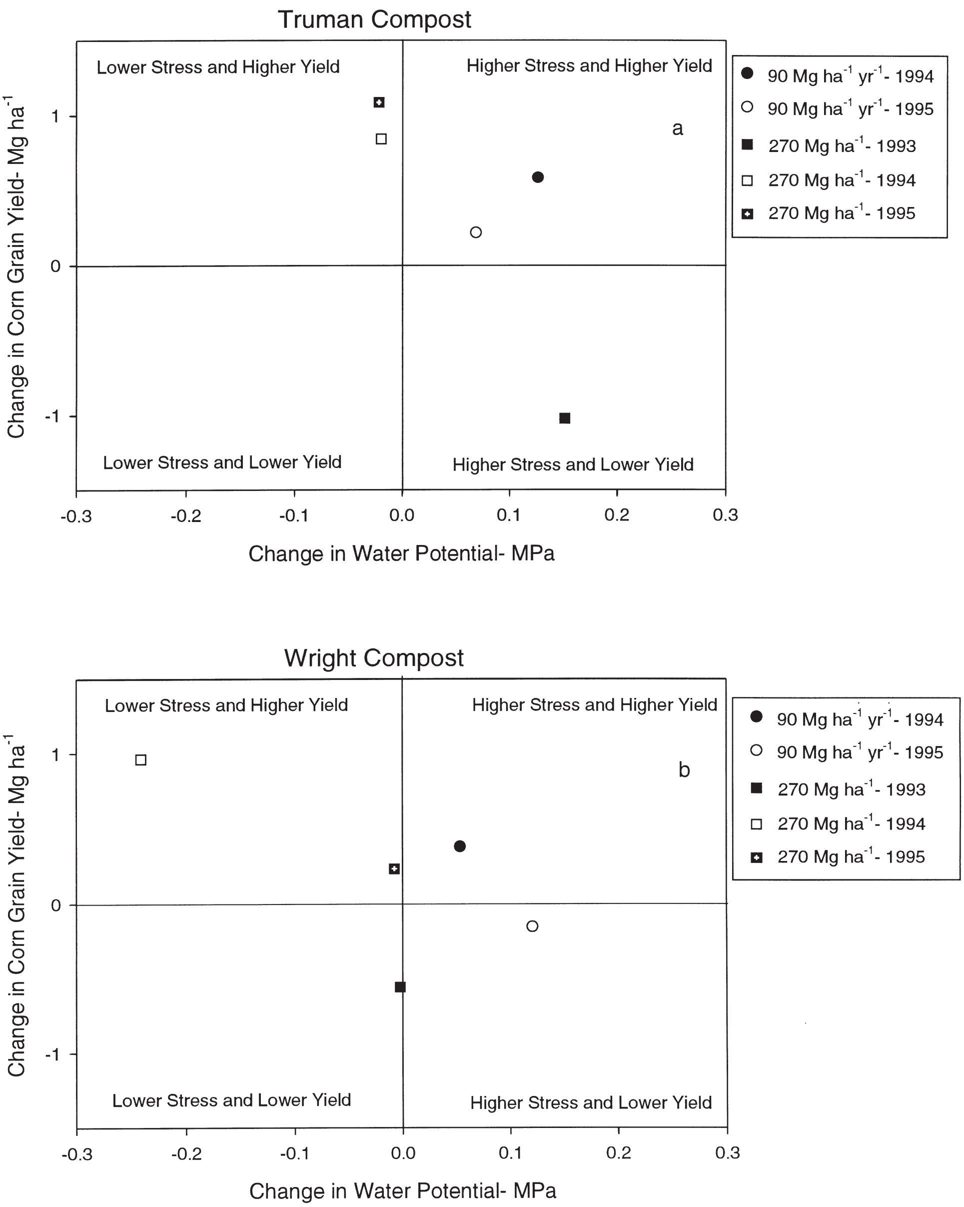

Figure 3. Relationship of change in corn grain yield to change in leaf water potential in soil amended with MSW compost a) Truman compost b) Wright compost. Each point represents average of four replications for each treatment.

soil due to compost addition. Even though, laboratory soil water retention curves were useful in showing general differences in water content, they were static measurements. Field measurements account for environmental conditions influencing evaporative demand, plant parameters such as root distribution and density, and soil water hydraulic conductivity and spatial variability. Leaf water potential measurements in the field take all these factors into consideration. Thus, a decrease or increase in laboratory measured AWHC was not necessarily correlated with more or less plant water stress. In 1995, higher φ_1 was again observed in the annual compost treatments, especially in the annual Wright compost treatment (EC = 1.6 S m^{-1}). Three years after the application of 270

Mg ha^{-1} compost, the effect of the compost on φ_l diminished. In 1996, the residual effect of compost (annual or one time) on φ_l was not significant (data not presented). Thus, plant water stress tended to increase when compost was applied at high rate in one application due to the ephemeral influence of salt on soil water. However, in subsequent years after compost application compost reduced or had no effect on water stress.

The change in φ_l against the change in corn grain yield showed that the 270 Mg ha^{-1} compost rate increased water stress and reduced corn grain yield compared to a fertilized control in the year of application (Figures. 3a and 3b). Although not statistically different, the negative effect of compost on corn grain yield was most apparent with the 270 Mg ha^{-1} Truman compost with nearly 1 Mg ha^{-1} yield loss for 0.2 MPa increase in water potential. The apparent negative relationship of φ_l to corn grain yield is likely due to the influence of salts which increases the soil osmotic potential affecting water availability. The overall effect of salts is decreased soil water potential causing plant roots to exert more force to extract water from the soil (Slatyer 1967). However, in subsequent (second year residual) year, the high compost rate decreased water stress and resulted in increased corn grain yield. There was no trend in the relationship of corn grain yield to water potential with the 90 Mg ha^{-1} yr^{-1} compost. This may be due to the lower annual compost application which was three times less than the one time compost application resulting in lower annual salt loading.

Conclusions

The addition of the MSW composts studied did not significantly affect available water based on laboratory measurements. However, measurements of leaf water potential are more realistic than laboratory measured AWHC in assessing the effect of compost on soil and plants because leaf water potential integrates the plant, soil, and environmental components. Overall a high compost rate applied one time increased plant water stress but did not significantly reduce grain yield compared to a fertilized control in the year of application. The increase in water stress was likely due to the salt loading, as both composts were relatively high in salinity. The salt effect on water potential was ephemeral. In the second year after the high compost rate application, compost increased plant water availability and resulted in increased yield compared to the annual compost application and the fertilized control treatments.

References

Bauer, A. and A.L. Black. 1992. Organic carbon effects on available water capacity of three soil textural groups. *Soil Sci. Soc. Am. J.*, 56: 248-254.

Bengston, G.W. and J.J. Cornette. 1973. Disposal of composted municipal waste in a plantation of young slash pine: Effects on soil and trees. *J. Environ. Qual.*, 2: 441-444.

Boyer, J.S. 1976. Water deficits and photosynthesis. *In*: Kozlowski (ed.). *Water Deficit and Plant Growth. Vol 4. Academic Press, New York. pp 153-190.*

Bremner, J.M and C.S. Mulvaney. 1982. Nitrogen-Total. *In*: A.L. Page (eds). *Methods of Soil Analysis*. Part 2. Am Soc. of Agr., Madison, Wisconsin. pp 595-624.

Bugbee, G.J and C.R. Frink. 1989. Composted waste as a peat substitute in peat-lite media. *Hortscience*, 24: 625-627.

Carlson, R.M., R.I Cabrera, J.L. Paul, J. Quick and R.Y. Evans. 1990. Rapid direct determination of ammonium and nitrate in soil and plant tissue extracts. *J. Plant Nutr.*, 21:1519-1529.

de Haan, S. 1981. Results of municipal waste compost research over more than fifty years at the Institute for soil fertility at Haren/Groningen, the Netherlands. *Neth. J. Agri. Sci.*, 29: 49-61.

Elliott, E.T. 1986. Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. *Soil Sci. Soc. Am. J.*, 50: 627-633.

Gupta, S.C., R.H. Dowdy and W.E. Larson. 1977. Hydraulic and thermal properties of a sandy soil as affected by incorporation of sewage sludge. *Soil Sci. Soc. Am. J. Proc.*, 41: 601-605.
He, X., S.J. Traina and T.J. Logan. 1992. Chemical properties of municipal solid waste composts. *J. Env. Qual.,* 21: 318-329.
Hsiao, T.C. 1990. Measurements of plant water status. *In*: B.A, Stewart and D.R. Nielsen (eds). *Irrigation of Agricultural Crops.* American Society of Agronomy Monograph 30, Madison, WI. pp. 243-279.
Keeney, D.R. and D.W. Nelson. 1982. Nitrogen-Inorganic forms. *In*: A.L. Page (ed.). *Methods of Soil Analysis*. Part 2. Am. Soc. of Agr., Madison, Wisconsin. pp 643-698.
Khaleel, R., K.R. Reddy and M.R. Overcash. 1981. Changes in soil physical properties due to organic waste applications: A Review. *J. Environ. Qual.,* 10: 133-141.
Klute, A. 1986. Water retention: Laboratory methods. *In*: A. Klute (ed.) 2nd ed. *Methods of Soil Analysis.* Part 1. American Society of Agronomy, Madison, WI. pp 635-651.
Kramer, J.P. 1983. Water relations of plants. Academic Press. New York.
Kreft, S. 1987. Soil physical properties as influenced by the addition of municipal compost. M.S. Thesis. University of Minnesota, St Paul, Minnesota.
Mamo, M., C.J. Rosen and T.R. Halbach. 1999. Nitrogen availability and leaching from soil amended with municipal solid waste compost. *J. Environ. Qual.,* 28: 1074-1082.
Munter, R.C. 1984. Quality assurance for plant tissue analysis by ICP-AES. Commun. *Soil Sci. Plant Anal.*, 15: 1285-1322.
Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. In: A.L. Page (ed.). *Methods of Soil Analysis.* Part 2. Am Soc. of Agr., Madison, WI. pp 539-579.
Pagliai, M., G. Guidi, M. LaMarca, M. Giachetti and G. Lucamante. 1981. Effects of sewage sludges and composts on soil porosity and aggregation. *J. Environ. Qual.,* 10: 556-561.
Shainberg, I., G.J. Levy, P. Rengasamy and H. Frenkel. 1992. Aggregate stability and seal formation as affected by drops impact energy and soil amendments. *Soil Sci.*, 154: 113-119.
Slatyer R.O, 1967. Plant-water relationships. Academic press. New York.
Statistical Analysis System. 1986. SAS/STAT user's guide. Version 6.03. SAS Institute Inc., Cary, North Carolina.
Tester, C.F. 1990. Organic amendment effects on physical and chemical properties of a sandy soil. *Soil Sci. Soc. Am. J.*, 54: 827-831.
Turner, M.S., G.A. Clark, C.D. Stanley and A.G. Smajstrla. 1994. Physical characteristics of a sandy soil amended with municipal solid waste compost. *Soil Crop Sci. Soc. Florida Proc.*, 53: 24-26.
United States Environmental Protection Agency (US EPA). 1993. Standards for the use or disposal of sewage sludge: Final rules 40 CFR Parts 257, 403, and 503. Federal Register. 58: 9284-9415.
van Genuchten, M.Th. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.*, 44: 892-898.
van Genuchten, M.Th., F.J. Leij and S.R. Yates. 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. Technical report #: EPA/600/2-91/065. USEPA.
Weil, R.R. and W. Kroontje. 1979. Physical condition of a Davidson clay loam after five years of heavy poultry manure applications. *J. Environ. Qual*., 8: 387-392.
Wright, J. and F. Bergsrud. 1991. Irrigation scheduling checkbook method. AG-FO-1322-C. Minn. Ext. Serv., Univ. Minn., St. Paul, Minnesota.