DIVISION S-4—SOIL FERTILITY & PLANT NUTRITION

Food Waste Compost Effects on Fertilizer Nitrogen Efficiency, Available Nitrogen, and Tall Fescue Yield

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ABSTRACT

Composting of food waste is increasing as composting technologies improve and as social and environmental pressures demand alternatives to disposal in landfills. Few agronomic studies are available to document N availability following food waste compost application. The objectives of this study were (i) to determine food waste compost effects on N fertilizer uptake efficiency across a range of N fertilizer rates, (ii) evaluate the effect of food waste composts on grass yield and N uptake by tall fescue (*Festuca arundinacea* Schreb. 'A.U. Triumph'), and (iii) estimate the residual effects of compost application on N fertilizer requirements. We used a split-plot design with two compost treatments and a no-compost control as main plots, and NH_4NO_3 (34-0-0) applied at rates of 0, 17, 34, 50, and 67 kg ha^{-1} per grass harvest as subplots. A food waste + yard trimmings + paper (FYP) compost and a food waste + wood waste + sawdust (FW) compost were applied at rates of approximately 78 Mg ha^{-1} (870–1000 kg N ha^{-1}) before seeding tall fescue. Compost did not affect grass yield or N uptake in the first year of the study. Compost increased grass yield during the second and third seasons after application. Grass N uptake increased linearly with fertilizer N application rate in all years. Compost did not affect fertilizer N uptake efficiency (the linear slope describing grass N uptake vs. fertilizer N application). Nitrogen fertilizer requirements during the midseason growth period were reduced by 0.22 to 0.37 kg N ha^{-1} d^{-1} during the second season after compost application and by 0.13 to 0.26 kg ha^{-1} d^{-1} during the third season after compost application. Results of this study suggest that N mineralized from compost and N provided by fertilizer can be considered as additive components of N supply for crop growth.

COMPOSTING OF FOOD WASTE is increasing as composting technologies improve and as social and environmental pressures demand alternatives to disposal in landfills. Over 100 food waste composting facilities were active in the USA in 1999 (Glenn and Goldstein, 1999). Composting in aerated windrows is becoming a widely adopted method for rapid composting of wet, putrescible food waste at large composting facilities (Touart, 1999; Sikora and Sullivan, 2000). The bulking agent that is used to maintain porosity in aerated windrows plays a large role in determining final compost N concentration and plant-available N release after compost application to land (Sullivan et al., 1998a).

Composting transforms organic byproducts into drier, more uniform, and more biologically stable products that can act as slow-release sources of plant-available N. A high-rate compost application also changes the soil physical, chemical, and biological properties that control N availability for many years following application (Shiralipour et al., 1992; Dick and McCoy, 1993). Usually, composts supply only a part of the N needed to produce high-yielding crops; fertilizer N application is needed for maximum crop yields.

Most studies on N availability following compost application have focused on short-term effects. Composts with C:N ratios above 20:1 may reduce crop production via microbial immobilization of available N during the first year after application (Sims, 1990; Shiralipour et al., 1992). For composts with lower C:N ratios, 0 to 25% of the total N usually becomes plant-available during the first year after application (Brinton, 1985; Tester, 1989; Dick and McCoy, 1993). The recalcitrant organic compounds present in mature composts probably interact less with fertilizer N and organic matter N in soil than do most crop residues. Azam et al. (1985) demonstrated that plant residues high in recalcitrant C are usually less active in immobilization–remineralization transformations in soil than residues containing more labile C.

The interaction between compost and the cycling of soil and fertilizer N has been studied over the short term with labeled isotopes and factorial blends of compost plus fertilizer N. Sikora and Yakovchenko (1996), using ^{14}C-labeled soil organic matter, found that compost did not increase soil organic matter decomposition. They found that addition of soil stimulated a small amount of compost decomposition and N mineralization. Paul and Beauchamp (1994) reported immobilization of fertilizer ^{15}N and a very small amount of net N mineralization in a 12-wk incubation with composted beef cattle manure. Available N from compost was a reliable substitute for up to 50% of fertilizer N supplied to tall fescue in growth chamber studies (Sikora, 1998; Sikora and Enkiri, 1999).

Because composts contain stabilized organic matter,

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Abbreviations: ANR, apparent N recovery by tall fescue for midseason growth period; CEC, cation exchange capacity; FYP, compost derived from mixture of food waste + yard trimmings + paper; FW, compost derived from mixture of food waste + wood waste + sawdust.

they serve as a source of slow-release N in years following application. Johnston et al. (1989) reported that soil organic N concentrations in the Market Garden experiment at Woburn increased linearly in response to the quantity of farmyard manure compost or sewage sludge compost applied over an 18-yr period. After terminating compost inputs, soil organic N declined toward a new equilibrium level. During the first 5 yr after compost application ceased, the rate of organic soil N decline was about 3% per year. Long-term rates of N release were the same for N originating from sewage sludge compost or farmyard manure compost (Johnston et al., 1989). O'Keefe et al. (1986) measured an initial rapid mineralization phase for 28 wk with an aerobically incubated sewage sludge compost, followed by a stable N mineralization rate thereafter (29–73 wk). Paul and Beauchamp (1993) reported N recovery by corn grain + stover of 5, 3, and 6% of compost N applied during the three growing seasons following a one-time beef cattle manure compost application.

The objectives of this study were (i) to determine food waste compost effects on N fertilizer uptake efficiency across a range of N fertilizer rates, (ii) evaluate the effect of food waste composts on grass yield and N uptake by tall fescue, and (iii) estimate the residual effects of compost application on N fertilizer requirements. We chose tall fescue for this study because it has a high N requirement, it is highly efficient in recovering available N, and it is harvested multiple times per year, allowing precise measurements of crop N uptake.

MATERIALS AND METHODS

Compost Preparation

Composts were prepared as part of a food waste composting pilot project. Details on bulking agents and composting methods used in the pilot project have been reported previously (Croteau and Steuteville, 1995; Sullivan et al., 1998b). Compost mixtures were prepared by mixing food waste with bulking agents via a front-end loader. The food waste was a composite mix of vegetables, meat, fish, dairy, and bakery residuals containing 33 g N kg^{-1}. Bulking agents were fine yard trimmings (11 g N kg^{-1}), mixed waste paper (7 g N kg^{-1}), or wood waste + sawdust (1 g N kg^{-1}). Two mixtures were produced: food + yard trimmings + paper (FYP), and food + wood waste + sawdust (FW).

The mixtures were composted via a modification of the aerated static pile method (Willson et al., 1980). Forced air was supplied via perforated pipe under each pile. A layer of wood waste and sawdust was placed on the ground over the air supply pipes to promote consistent airflow and to absorb leachate from the pile. Both piles were covered with a layer of coarse yard trimmings as insulation. Piles had initial volumes of 38 m^3.

Piles were composted in an unheated building from 3 Feb. 1993 to 25 May 1993. Piles were turned after 21 d of active composting with a self-propelled windrow turner (Scarab Mfg., White Deer, TX) to improve aeration and to add water. The compost turner ground up the larger particles. It also incorporated the coarse yard trimmings from the insulative pile cover and the wood waste + sawdust from the pile base into the actively composting portion of each pile.

Table 1. Compost chemical and physical characteristics (dry weight basis).

		Compost	
Analysis	**Unit**	**FYP†**	**FW†**
Total P	g kg^{-1}	2.6	2.7
Total K	g kg^{-1}	10	11
Total Ca	g kg^{-1}	22	28
Total S	g kg^{-1}	2.7	2.9
Volatile solids	g kg^{-1}	400	420
Total N	g kg^{-1}	11.7	12.0
NH_4-N	mg kg^{-1}	28	20
NO_3-N	mg kg^{-1}	68	349
Total Zn	mg kg^{-1}	236	231
Total Cu	mg kg^{-1}	54	54
CEC	cmol (+) kg^{-1}	41	49
pH		6.7	6.7
Conductivity	dS m^{-1}	2.0	3.5
Particle size			
2.4–11 mm	g kg^{-1}	420	430
0.5–2.4 mm	g kg^{-1}	490	420
<0.5 mm	g kg^{-1}	100	150

† FYP = compost derived from mixture of food waste + yard trimmings + paper; FW = compost derived from mixture of food waste + wood waste + sawdust.

Pile temperature and aeration were monitored throughout the composting process. Temperatures during the first 70 d of active composting with forced aeration ranged from 30 to 80°C, and were greater than 55°C for at least 5 d. Composts were then cured in passively aerated piles for an additional 36 d; all piles were turned twice during curing. At the end of curing, CO_2 evolution rates determined by incubation at 37°C (U.S. Composting Council, 1997), were <2.5 mg CO_2-C g compost-C^{-1} d^{-1} for both composts. On the basis of respiration rate, the finished composts were rated as "stable composts with minimal impact on soil carbon and nitrogen dynamics" (U.S. Composting Council, 1997). Following curing, composts were screened to pass an 11-mm screen, and sampled for chemical and physical analysis (Table 1).

Compost Analyses

Compost volatile solids were determined by loss-on-ignition at 550°C. Total N was determined by Kjeldahl analysis (Bremner and Mulvaney, 1982). Inorganic N (NH_4-N and NO_3-N) was extracted with 2 *M* KCl. Nitrate-N was determined via an automated Cd reduction method, and NH_4-N was determined via an automated salicylate-nitroprusside colorimetric method (Gavlak et al., 1994). Cation exchange capacity (CEC) was measured via saturation with $NH_4C_2H_3O_2$ at pH 7. The displaced NH_4 in the CEC procedure was determined by an automated salicylate-nitroprusside colorimetric method (Gavlak et al., 1994). Total P, K, Ca, S, Zn, and Cu were determined via X-ray fluorescence (Knudsen et al., 1981). Compost pH and conductivity were determined after water addition (1:2 compost:water; v/v). Particle size was determined by sieving.

Field Experiment

The field experiment was a split-plot design with four replications. Compost treatments (no compost, FW compost, and FYP compost) were main plots, and the five fertilizer N rates (0, 17, 34, 50, and 67 kg N ha^{-1} per harvest) were subplots.

The field experiment was conducted on a Puyallup fine sandy loam soil (coarse-loamy over sandy, mixed, mesic Vitrandic Haploxerolls) at the WSU Puyallup Research Center in Puyallup, WA. During the year prior to our study (1992), silage corn (*Zea mays* L.) was grown on the study site, followed by a fall-seeded triticale (× *Triticosecale* Witt.) cover crop. We cut the triticale (8 cm above ground level) and removed the biomass 7 d prior to compost application. After the triticale

Table 2. Compost and N application rates for the field experiment.

	Compost application rate			
Compost feedstocks	**Dry matter†**	**Total N**	**NO_3-N**	**NH_4-N**
	Mg ha^{-1}	**kg ha^{-1}**	**kg ha^{-1}**	**kg ha^{-1}**
Food waste + yard trimmings + paper (FYP)	**74**	**866**	**5**	**2**
Food waste + wood waste + sawdust (FW)	**83**	**996**	**29**	**2**

† Target application rate was 78 Mg ha^{-1}. Actual application rate varied due to differences in compost moisture content.

was harvested, the site was moldboard-plowed and disked. Composts were applied 27 May 1993 (113 d after the initiation of composting) at a target dry weight application rate of 78 Mg ha^{-1} (Table 2), and were incorporated with a disk to a depth of about 10 cm.

Soil samples were collected immediately before compost application and were analyzed by routine agricultural soil testing methods (Gavlak et al., 1994). Preapplication soil test values (0- to 30-cm depth) were NO_3-N: 0.7 mg kg^{-1}; pH: 5.8; Bray 1 extractable P: 315 mg kg^{-1}; and $NH_4C_2H_3O_2$ extractable K, Ca, and Mg: 0.57, 4.5, and 0.83 cmol kg^{-1}, respectively. These soil test values indicated that only N fertilization was needed for near-maximum perennial grass production (Hart et al., 1996). Therefore, all plots received a broadcast application of NH_4NO_3 (34-0-0) at a rate of 34 kg N ha^{-1} prior to seeding. Soil test P was very high because of a history of manure application. Manure had not been applied at the site for at least 5 yr preceding our study.

A forage-type tall fescue (*F. arundinacea* 'A.U. Triumph') was seeded the day after compost application. Grass was managed to maintain active growth throughout the growing season. Plots were sprinkler-irrigated during the summer. Broadleaf weeds were controlled as needed with herbicides. Fertilizer N (NH_4NO_3; 34-0-0) was broadcast-applied at the start of each grass regrowth period. Potassium and S fertilizers were applied to all plots in 1994 and 1995 to eliminate possible nutrient deficiencies.

We harvested grass every 30 to 45 d during midseason growth (Table 3). Grass regrowth began with grass at 8-cm height and continued until grass reached the early boot growth stage (45- to 60-cm height). The first spring harvest in 1994 and 1995 was also taken at early boot growth stage, but it had a longer growth period. The 1994 spring harvest included grass biomass produced from 2 Nov. 1993 to 5 April 1994. The 1995 spring harvest included grass biomass produced from 10 Feb. 1995 to 13 April 1995.

Table 3. Nitrogen fertilizer application and grass harvest schedule. Midseason growth period, 1993–1995.

			Midseason growth period‡		
Year	**Fertilizer N applied†**	**Grass harvests**	**Begin**	**End**	**Days**
	kg ha^{-1}				
1993	**0, 34, 67, 101, 134**	**2**	**13 July§**	**17 September**	**66**
1994	**0, 66, 134, 202, 269**	**4**	**5 April**	**23 August**	**140**
1995	**0, 66, 134, 202, 269**	**4**	**13 April**	**29 August**	**138**

† Fertilizer N = broadcast NH_4NO_3 (34-0-0) at 0, 17, 34, 50, and 67 kg N ha^{-1} per grass harvest.

‡ Mid-season grass harvests were taken 10 Aug. and 17 Sept. 1993; 26 May, 23 June, 21 July, 23 Aug. 1994; and 16 May, 29 June, 27 July, 29 Aug. 1995.

§ Shorter growing period because of spring seeding of tall fescue on 27 May 1993.

Grass was harvested with a small plot forage harvester. At each harvest, we cut a 1- by 6-m swath (8 cm above ground level) from the center of each plot. Wet grass yields were determined in the field. We converted yield to a dry weight basis based on the solids content of a grass subsample dried at 60°C. The grass N concentration of each composite sample was determined via a combustion N gas analyzer (LECO Instruments, St. Joseph, MI.; Sweeney, 1989).

Several aspects of our experimental approach were carefully chosen for this research. We chose a relatively high rate of compost application in this study to facilitate accurate measurement of low quantities of available N release. We used intensive tillage prior to and immediately after compost application to facilitate incorporation of compost into soil without movement to adjacent plots. We chose N fertilizer application prior to each grass harvest during the growing season to minimize the potential for N loss by leaching and to provide adequate but not excessive N supply for near-maximum yield at each harvest. We chose NH_4NO_3 as our fertilizer N source to minimize the potential for gaseous NH_3 loss.

Regression Models

A split-plot analysis of variance was performed for midseason grass yield and N uptake for each year of the study (SAS Institute, 1985). The significance of the compost treatment effect in the analysis of variance was the key consideration in regression equation development. All compost treatments were combined into a single N response equation in 1993 because the analysis of variance showed no significant effect of compost treatment. Unique N response equations were developed for each compost treatment in 1994 and 1995 because compost treatments were significantly different.

We developed quadratic regression equations for yield (Table 4) and linear regression equations for N uptake (Table 5). For yield response to fertilizer N, we evaluated a model with pooled quadratic regression coefficients for all compost treatments vs. a model with unique quadratic coefficients for each compost treatment. We found that the quadratic coefficient for yield response to N was not different among compost treatments. Therefore, for 1994 and 1995 midseason yield, we fit a quadratic regression model with unique *y*-intercept and linear coefficient for each compost treatment and a pooled quadratic coefficient. We followed a similar equation development procedure for grass N uptake response to fertilizer N. A single equation for all composts was the best description for N uptake response to fertilizer N in 1993. We fit unique equations for compost treatments in 1994 and 1995. The fitted equations for N uptake response to fertilizer N had a unique *y*-intercept for each treatment and a pooled linear coefficient.

Equations

Equation [1] estimates the increase in midseason grass N uptake attributed to compost in kg ha^{-1}:

$$\text{Apparent N recovery (ANR, kg ha}^{-1}\text{)} = A - B \qquad [1]$$

where A is the y-intercept for compost treatment, kg ha^{-1} (Table 5), and B is the y intercept for no compost treatment, kg ha^{-1} (Table 5).

Equation [2] estimates the reduction in midseason fertilizer N requirement attributed to compost in kg ha^{-1}:

$$\text{Reduction in fertilizer N requirement (kg ha}^{-1}\text{)} = \text{ANR}/e_{\text{f}} \qquad [2]$$

where ANR is apparent N recovery (kg ha^{-1}; from Eq. [1]) and e_{f} equals fertilizer N uptake efficiency, the slope of the

Table 4. Quadratic regression equations for grass yield (Mg ha^{-1} dry weight basis).

Year	Compost treatment significance	Compost treatment(s)	*Y* Intercept		Linear coefficient		Quadratic coefficient	
			Value†	Std error‡	Value§	Std error‡	Value§	Std error‡
					$\times 10^{-2}$§	$\times 10^{-3}$§	$\times 10^{-5}$§	$\times 10^{-6}$§
1993	NS	all	4.2	0.1	2.37	3.10	−8.84	9.00
1994	*	FYP	5.9	0.2	4.03	2.09	−6.50	6.93
		FW	6.8		3.64			
		none	5.1		4.24			
1995	**	FYP	3.6	0.2	4.18	2.53	−6.00	8.38
		FW	4.1		4.18			
		none	3.1		4.35			

*** Indicates significance at $P = 0.05$ determined by split plot analysis of variance.**
**** Indicates significance at $P = 0.01$ determined by split plot analysis of variance.**
ns = nonsignificant.
† In 1993, a pooled regression model was chosen for all compost treatments. In 1994 and 1995, regression equations were developed for each compost treatment with unique y-intercept, unique linear slope and pooled quadratic coefficient. A complete description of the development of the regression model is given in Materials and Methods.
‡ All regression models used a pooled error term. Standard errors are the same for all compost treatments for a given year.
§ Actual values and standard errors for the linear and quadratic coefficients equal the reported values times the indicated factor.

line for grass N uptake vs. fertilizer N applied (Table 5). We also expressed the reduction in fertilizer N requirement on a daily basis by dividing the result of Eq. [2] by the number of days in the growth period (Table 3).

RESULTS AND DISCUSSION

Grass Yield and Nitrogen Uptake

We focus on midseason fescue growth and N uptake in this paper for several reasons. First, the midseason growth period provided a relatively consistent environment for comparison across the 3 yr of our study. Second, midseason soil temperatures were most conducive to decomposition of compost organic matter and mineralization of compost N. Third, use of the midseason growth data allows us to describe the reduction in N fertilizer requirements due to compost application in units of kg ha^{-1} d^{-1}. We could not apply the same units to the first harvest in the spring of 1994 and 1995, which included grass biomass produced in late fall and early spring.

Response to N fertilizer was highly significant ($P = 0.0001$) in all years. Yield response to N fertilizer was significant ($P = 0.05$) for linear and quadratic components. Nitrogen uptake response to N fertilizer was significant for only the linear component. Compost treatment (FY, FYP or none) was significant ($P = 0.05$) in 1994 and 1995, but not in 1993. The compost × fertilizer N interaction was not significant ($P = 0.10$) for N uptake in any year. The interaction was not significant for yield in 1993 or 1995. The interaction was statistically significant for yield in 1994 ($P = 0.03$), but it accounted for only 0.6% of the total variance in yield response attributed to compost and N fertilizer.

Grass yield and N uptake response for 1994 and 1995 spring harvests (Table 6) was similar to that observed for midseason yield and N uptake. For spring harvests in 1994 and 1995, compost and N fertilizer treatments were significant at $P = 0.05$, with a nonsignificant compost × N interaction.

Midseason yield response was best described by quadratic response curves in all years (Fig. 1a, 2a, 3a; Table 4). In 1993, compost treatments were not significantly different, so N fertilizer response data was pooled across all compost treatments (Fig. 1a). The available N supplied by compost in 1993 was probably limited by the decomposition of compost organic matter in soil. Compost volatile solids, a measure of compost organic matter concentration, were 400 to 420 g kg^{-1} at application (Table 1). Assuming the typical C concentration found in soil organic matter (58 g C kg^{-1} organic matter; Nelson and Sommers, 1982), compost C:N ratios were about 20:1 at application. Although our measurement of C:N ratio is only an approximate value, it is considerably greater than 15:1. Organic materials with C:N ratios above 15:1 typically induce temporary net N immobilization after application to soil (Gilmour, 1998).

For 1994 and 1995, the best-fitting regression model for grass yield was a regression line for each compost treatment with unique *y*-intercept and slope coefficients,

Table 5. Linear regression equations for grass N uptake (kg ha^{-1}) as a function of applied fertilizer N.

Year	Compost treatment significance	Compost treatment(s)	*Y* Intercept		Slope	
			Value†	Std Error‡	Value†	Std Error‡
1993	NS	all	88	2	0.43	0.02
1994	**	FYP	103	4	0.68	0.02
		FW	117			
		none	82			
1995	**	FYP	64	4	0.70	0.02
		FW	76			
		none	52			

**** Indicates significance at $P = 0.01$.**
ns = nonsignificant.
† In 1993 a pooled regression model was chosen for all compost treatments. In 1994 and 1995, regression equations were developed for each compost treatment with unique y-intercept and a pooled slope. A full description of the development of the regression model is given in Materials and Methods.
‡ All regression models used a pooled error term. Standard errors are the same for all compost treatments for a given year.

Table 6. Effect of compost and N fertilizer on grass yield and N uptake for spring grass harvests†.

Main plot or subplot treatment	df	Yield 1994	Yield 1995	N uptake 1994	N uptake 1995
		— Mg ha^{-1} —		— kg ha^{-1} —	
Compost					
None		1.83	1.66	53	38
FYP		1.93	1.98	58	45
FW		2.20	2.20	66	51
N fertilizer, kg ha^{-1}					
0		1.75	1.61	46	32
17		1.83	1.87	52	41
34		2.03	1.91	59	42
50		2.14	2.06	66	50
67		2.19	2.28	72	58
ANOVA					
Compost (C)	2	*	**	*	**
Nitrogen (N)	4	**	**	**	**
C × N	8	NS	NS	NS	NS
CV, %		10.3	11.2	10.7	11.8

* Indicates significance at $P = 0.05$.
** Indicates significant at $P = 0.01$.
ns = nonsignificant.
† Grass harvested at early boot growth stage. The 1994 spring harvest included grass biomass produced from 2 Nov. 1993 to April 1994. The 1995 spring harvest included grass biomass produced from 10 Feb. 1995 to 13 April 1995.

and a pooled quadratic coefficient (Fig. 2a, 3a). The similarity in yield response curves with and without compost suggests that compost provided a small amount of plant-available N in both years. Compost did not provide any additional benefits to increase yield beyond that attainable with N fertilizer.

Synergistic crop yield response interactions, where compost plus N fertilizer produces greater yield than either input alone, have been reported for soils that have a fertility limitation besides N. Compost applications can enhance crop N uptake by neutralizing soil acidity (Tester, 1989) or by providing available P (Schlegel, 1992). Such inherent fertility limitations were absent at our experimental site. Compost application did increase soil pH slightly in our experiment. Soil pH (0–10 cm) in September 1994 (480 d after compost application) was 5.5 without compost and 5.9 with compost in a companion field experiment (all variables identical except a higher compost application rate of 155 Mg ha^{-1}; Sullivan et al., 1998b). However, soil pH without compost in our experiment was in the range considered adequate for tall fescue production (Hannaway et al., 1999).

Other studies have sometimes demonstrated a synergistic yield benefit to coapplication of compost and fertilizer N. Usually, the mechanism for synergistic yield response from compost plus fertilizer N is difficult to explain (Johnston, 1993; Parkinson, 1999). Synergistic responses are likely due to a combination of factors (Sikora and Enkiri, 1999). Often, as in our study, yield benefits from compost application are reported only when the fertilizer N rate is below that needed for optimum crop production (Fauci and Dick, 1994; Hartz et al, 1996). The synchrony between crop N demand and N mineralized or immobilized by compost can be a key factor influencing crop response to combinations of compost plus fertilizer N (Myers et al., 1997). The frequency of N fertilizer application in our experiment (every 30–45 d during the growing season) reduced the opportunity for benefit from slow-release N from compost.

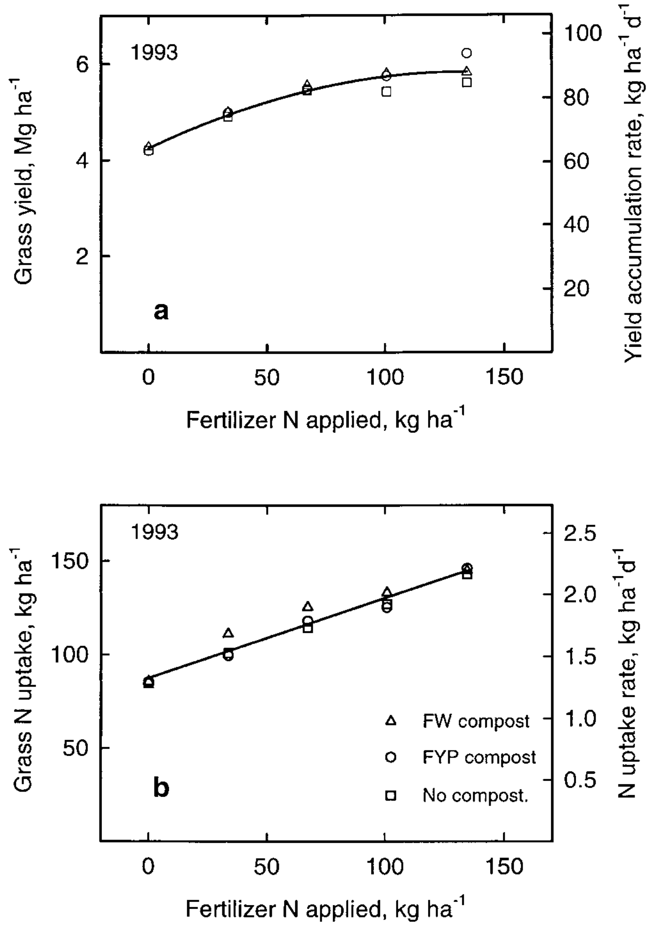

Fig. 1. Grass yield (a) and N uptake (b) for 1993 mid-season growth period (13 July–17 September). All compost treatments plotted with a common regression model because compost treatments were not significant at $P = 0.05$ (Tables 4 and 5). Yield and N uptake (left axis) are for same time period as yield accumulation rate and N uptake rate (right axis).

Fertilizer N application increased grass N uptake (Fig. 1b, 2b, 3b). The N uptake response was linear in the presence and the absence of compost (Table 5). As yield response to N fertilizer leveled off at high N fertilizer rates, the concentration of N in the grass increased. In 1993, compost application did not increase grass N uptake (Table 5). The best fitting regression model for N uptake response to fertilizer N was a linear model with the same slope and intercept for all compost treatments. In 1994 and 1995, the best fit regression model for N uptake response had a unique *y*-intercept for each compost treatment with a common slope (Table 5).

Fertilizer Nitrogen Uptake Efficiency

Compost application did not affect N fertilizer uptake efficiency (Fig. 1b, 2b, 3b). The linear slope for N uptake in each regression model estimates fertilizer N uptake efficiency. Grass N uptake efficiency was 43, 68, and 70% of fertilizer N applied in 1993, 1994, and 1995 respectively. Fertilizer N uptake efficiency in our study is within the range reported for intensively managed, cool-season grasses west of the Cascade Mountains in Oregon and Washington State (Yungen et al., 1977; Turner, 1979).

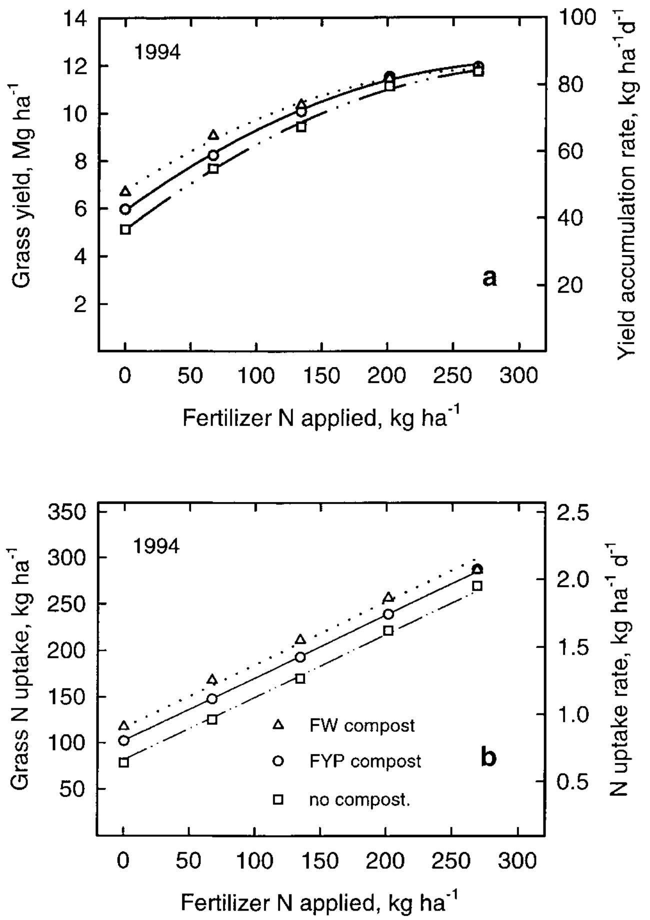

Fig. 2. Grass yield (a) and N uptake (b) for the 1994 midseason growth period (5 April–23 Aug. 1994). Unique regression model for each compost treatment because compost treatments were significantly different at $P = 0.05$ (Tables 4 and 5). Yield and N uptake (left axis) are for same time period as yield accumulation rate and N uptake rate (right axis).

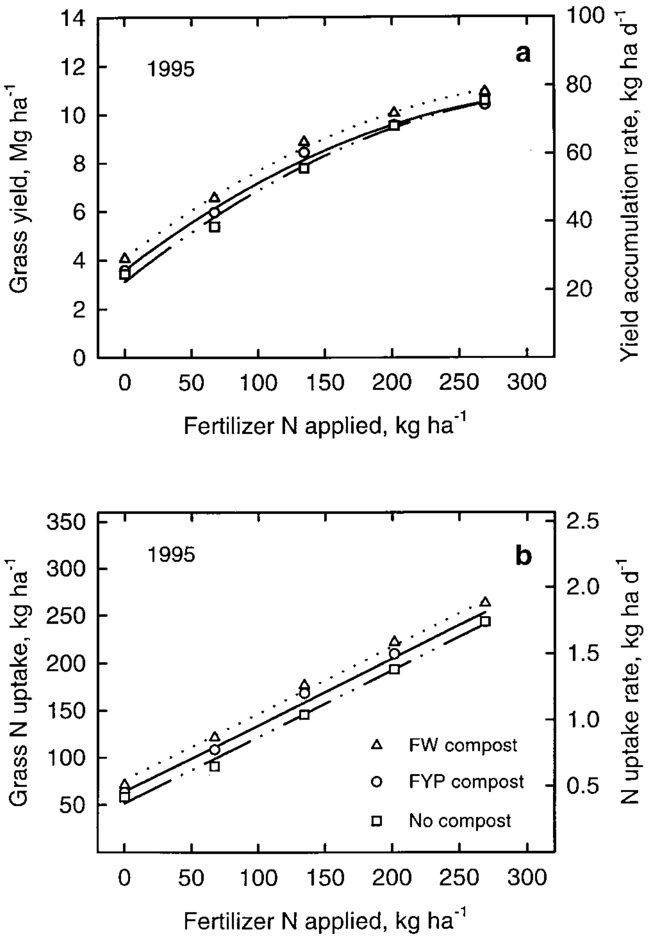

Fig. 3. Grass yield (a) and N uptake (b) for the 1995 midseason growth period (13 April–29 Aug. 1995). Unique regression model for each compost treatment because compost treatments were significantly different at $P = 0.05$ (Tables 4 and 5). Yield and N uptake (left axis) are for same time period as yield accumulation rate and N uptake rate (right axis).

The lower fertilizer N uptake efficiency observed in 1993 was probably related to the establishment of the newly seeded grass. A larger proportion of plant N uptake was probably incorporated into nonharvested biomass during the first growing season after seeding. Storage of 10 to 40% of applied ^{15}N has been reported for cool-season grasses (Whitehead and Dawson, 1984; Hansson and Pettersson, 1989).

Tall fescue was efficient in removing NO_3-N from the root zone in our study. Residual NO_3-N (0- to 90-cm depth) ranged from 34 to 36 kg NO_3-N ha^{-1} for compost treatments in July 1993, prior to the midseason growth period. We also measured soil NO_3 in 30-cm increments to a depth of 120 cm following the final grass harvest in each year of the study. Soil NO_3-N was less than 5 mg kg^{-1} at all depths with no differences among compost treatments or N fertilizer rates (data not shown).

Effect of Compost on Nitrogen Fertilizer Requirements

The increase in midseason grass N uptake with compost (apparent N recovery; ANR; Eq. [1]) was used together with an estimate of grass N uptake efficiency (Eq. [2]) to provide an indirect assessment of the amount of plant-available N supplied by compost application. We calculated ANR using *y*-intercepts in the regression models for N uptake (Table 5; Eq. [1]). For 1993, compost did not increase yield or N uptake. In 1994 and 1995, compost increased ANR. The FW compost increased ANR more than the FYP compost (Table 7). The calculated reduction in fertilizer N requirement with compost was 0.22 to 0.37 kg ha^{-1} d^{-1} in 1994 and 0.13 to 0.26 kg ha^{-1} d^{-1} in 1995 (Eq. [2]; Table 7). The

Table 7. Effects of compost application on apparent N recovery (ANR) and the calculated reduction in fertilizer N requirement during the midseason growth period.†

Year	Compost treatment	Apparent N recovery	Reduction in fertilizer N requirement		
		kg ha^{-1}		kg ha^{-1} d^{-1}	% of compost-N applied
1994	FYP	21	31	0.22	3.6
	FW	35	52	0.37	5.2
1995	FYP	12	17	0.13	2.0
	FW	25	35	0.26	3.5

† Apparent N recovery (kg ha^{-1}) calculated via Eq. [1], reduction in fertilizer N equivalent (kg ha^{-1}) calculated via Eq. [2].

N provided by compost, expressed as a percentage of the initial compost N applied, was 3.6 to 5.2% in 1994 and 2.0 to 3.5% in 1995. The results of our study support the conclusion of Gilmour (1998) that N mineralized from compost and N supplied from other sources can be considered as additive components of N supply.

The heterogeneity of the food waste, yard trimmings, paper, and wood waste + sawdust feedstocks used to prepare composts in our study make it difficult to compare our results with similar materials. A few observations can be made, however. The food waste used in our study probably performs similarly to raw manure or raw sewage sludge. Like sewage sludge or manure, food waste is high in microbially available C and N compounds, which are transformed to more stable forms by composting. Wood waste, sawdust, and paper are frequently used for cocomposting of sewage sludge or manure. First-year organic N mineralization rates for composted sewage sludge or manure + paper or wood chips are 0 to 20% (Tester, 1989; Sims, 1990; Hadas and Portnoy, 1994) second and third year crop N recovery is 3 to 6% of compost total N applied (Paul and Beauchamp, 1993). Pare et al. (1998) demonstrated that about half of the total N in composted manure + paper was present in slow-release forms not hydrolyzable in strong acid. Composted yard trimmings may have especially low N mineralization rates because of tannins, low-molecular weight phenolic compounds, and polyphenols contained in yard trimmings. These compounds, occurring in broadleaf evergreens (Prescott et al., 1996), conifers (Northup et al., 1995), and deciduous trees (Schimel et al., 1996) react with inorganic N to form organic N compounds that are resistant to degradation. Most of the yard trimmings used for composting in our study originated from conifers.

SUMMARY AND CONCLUSIONS

A high-rate application of food waste compost increased grass yield during the second and third seasons after compost application. The similar shapes of the yield response curves to fertilizer N with and without compost suggest that compost provided a small amount of plant-available N. Other possible effects of compost on soil physical, chemical, and biological properties were not reflected in grass yield.

Results of this study suggest that N mineralized from compost and N provided by fertilizer N application can be considered as additive components of N supply for crop growth. Grass N uptake increased linearly with fertilizer N application rate. Preplant compost application had no effect on fertilizer N uptake efficiency by tall fescue. The slope of the crop N uptake response to fertilizer N rate was the same with and without compost.

Plant-available N provided by food waste compost in the second and third seasons of our study was of a similar magnitude as that reported for composts derived from other putrescible, high N byproducts (e.g., sewage sludge and manures). Compost reduced N fertilizer requirements during the midseason growth period by 0.22 to 0.37 kg N ha^{-1} d^{-1} during the second season after application, and by 0.13 to 0.26 kg ha^{-1} d^{-1} during the third season after application. This reduction in fertilizer N requirements was small in relation to the amount of N fertilizer required for maximum yield (1.4–1.9 kg ha^{-1} d^{-1} in our study). The reduction in N fertilizer requirement during midseason growth was equivalent to 3.6 to 5.2% of compost N in the second year after application and 2.0 to 3.5% of compost N in the third year after application.

Our finding that preplant compost application had no effect on fertilizer N uptake efficiency by tall fescue has wider importance. The assumption that N supplied by organic sources (e.g., manure or compost) and fertilizer N are additive components of plant-available N supply is widely used in developing simple nutrient budgets for agronomic crops. This study verified that such additive models for available N supply from organic and fertilizer N sources were appropriate in a carefully monitored field experiment.

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