– Windrows I through III (20 to 35 percent biosolids) behaved quite similarly; however, a significant difference between Windrow IV (45 percent biosolids) and remaining windrows was observed with regard to temperature and odors. The addition of 45 percent biosolids resulted in an apparent inhibition of microorganisms due to high temperatures experienced early in the process (perhaps due to higher volatile solids stimulating degradation and relatively low moisture content). Odors from qualitative and quantitative evaluation were much greater and oxygen content was much lower in Windrow IV than remaining windrows.

– Runoff analyses identified slightly elevated concentrations of several heavy metals as well as high fecal coliform counts suggesting that treatment of runoff for heavy metals and pathogens may be necessary.

– Mixing of biosolids and yard waste was accomplished using a front-end loader. Results of a mixing study showed that this method was adequate although time consuming.

– Moisture content fell below 40 percent during portions of this study which may have inhibited the stabilization process.

– As observed during pilot studies, most data collected (odor, oxygen uptake rates, volatile solids destruction, etc.) suggested that windrows were largely stable within three months; however, temperature remained well above ambient after 150 days.

It is recommended from results of this study that cocomposting be employed at yard waste to biosolids ratios greater than or equal to three to one in order to maintain the sludge fraction below 35 percent. Care should be taken to ensure that adequate woody (bulky) material is included in the mixture to maintain bulk density well below 594 kg/m^3 (1,000 lb/yd^3) throughout the first ten weeks of composting. Turning frequency should be maintained at a similar schedule to this study to maintain appropriate temperature and good mixing. Moisture content should be maintained above 40 to 45 percent.

Acknowledgement

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Cumulative Effect of Annual Additions of MSW Compost on the Yield of Field-Grown Tomatoes

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For three years, source separated municipal solid waste (MSW) compost was applied in the field at two rates (25 and 50 T/A) and planted with tomatoes. Average yield (lbs/plant) from plots amended with 50 T/A MSW compost was significantly greater all three years than the unamended controls. Yield from plots amended with 25 T/A MSW compost was significantly greater than the unamended control only in 1993. The average number of tomatoes per plant and the average weight of each tomato were also greater from the compost-amended plots. The addition of 50 T/A MSW compost for three years raised the pH of the soil from 5.8 to 6.4 and raised the percent organic matter 84 percent. The concentration of nitrate in plots amended yearly with 50 T/A MSW compost was three fold greater than the unamended control.

Introduction

Composting the organic fraction of municipal solid waste (MSW) is becoming a popular method of reducing the space needed for landfills, incinerators and other disposal methods. In 1994, 55 MSW composting projects were operating in the United States or in various stages of development (Goldstein and Steuteville, 1994).

Many of the early greenhouse studies reported that MSW composts could supply essential plant nutrients, but insufficient for optimum yields. Fuller *et al.* (1960) found the highest tomato yields were obtained from plants receiving MSW compost supplemented with both nitrogen and phosphorus. In another greenhouse tomato study, yields of MSW treated plants were superior to those grown in sandy soil alone, but were less than yields from plants grown in sewage sludge or fertilizer treated soil (Chu and Wong, 1987). Fritz and Venter (1988) reported positive growth responses in tomatoes amended with MSW compost in greenhouse experiments. Frey (1981) recorded decreased tomato growth as the amount of MSW compost increased from 25 percent to 100 percent in the potting substrate.

Most field studies with MSW compost in tomato culture utilize a single application. Ozores-Hampton *et al.* (1994) found that amending calcareous soils once with MSW compost increased growth and yield of field-grown tomatoes with negligible increases in heavy metal concentrations in fruit. Bryan and Lance (1991) found that tomatoes grown on compost-amended soils had positive yield response.

Maynard (1993) reported that average yield (lbs/plant) of tomatoes from plots amended with one application of 50 T/A MSW compost was 38 percent greater as compared to unamended controls while plots amended with 25 T/A increased 23 percent. Sodium and phosphorus contents in tomato fruit increased while the Cd and Be contents decreased in the MSW compost-amended soil (Stilwell, 1993). The MSW compost was added at the same rates for two more years to study the cumulative effect of annual additions of MSW compost on the yield of field grown tomatoes.

TABLE 1.
Average number (+SD) of tomatoes/plant, weight/tomato (oz), and yield (lbs/plant) in plots amended with 25 or 50 T/A MSW compost compared to unamended control

Treatment	Number	Weight (oz.)	Yield* (lbs.)
1992**			
Control	17.6±3.0	7.06±0.33	7.8±1.5a
25 T/A	20.8±2.9	7.34±0.49	9.5±1.7ab
50 T/A	22.0±2.5	7.86±0.83	10.8±1.5b
1993			
Control	39.4±3.1	6.88±0.37	16.9±1.1a
25 T/A	45.3±0.2	6.51±0.27	18.4±0.8b
50 T/A	45.8±0.3	6.80±0.25	19.5±0.6b
1994			
Control	24.9±0.4	7.02±0.34	10.9±0.5a
Control (limed)	25.6±0.5	7.04±0.34	11.3±0.3a
25 T/A	27.4±1.7	6.85±0.36	11.7±0.4ab
50 T/A	32.0±0.2	7.26±0.08	14.5±0.07b

*Means followed by the same letter within column within each year are not significantly different by Newman-Keuls Multiple Comparisons Test at the five percent level
**Data previously presented in Maynard (1993) and shown here for comparison purposes

Methods and Materials

Experiments were conducted at Lockwood Farm, Mt. Carmel, Connecticut on Cheshire fine sandy loam (Typic Dystrochrept), a loamy upland soil with moderate moisture holding capacity. Each plot was 10 × 10 ft. surrounded by three-foot aisles and replicated four times in a random block design. MSW compost was produced in a wet bag composting demonstration project in Fairfield, Connecticut (Beyea *et al.* 1992). The average values (dry weight) of major plant nutrients in the finished compost were 1.65 percent (Ca), 0.48 percent (K), 0.36 percent (Mg), 1.61 percent (N) and 0.33 percent (P) (Stilwell, 1993). The concentrations of the regulated elements were below EPA 503 limits (Stilwell, 1993). The compost was applied on June 19, 1992, May 18, 1993 and May 25, 1994 at rates of 25 or 50 T/A (dry weight basis) (½ inch and one inch thick of compost, respectively). The compost was incorporated into the soil by rotary tilling. Control plots received no compost. All plots were fertilized before planting with 10-10-10 (N-P_2O_5-K_2O) fertilizer at a rate of 1,300 lbs/A. In 1994, another set of unamended control plots received 2,200 lbs/A lime in addition to fertilizer (1,300 lbs/A).

The tomatoes (cv. Celebrity) were seeded in a greenhouse on April 27, 1992, April 2, 1993 and April 4, 1994 in Promix BX in standard 3601 plastic cell packs (2⅝ inches × 2¼ inches × 2⁵⁄₁₆ inches). Seedlings were irrigated with water soluble 20-20-20 (N-P_2O_4-K_2O) fertilizer (0.5 oz/gal) four weeks after germination. They were transplanted in the field on June 22, 1992, May 20, 1993 and May 26, 1994 in rows four feet apart with two foot spacing within the row. There were 10 plants per plot. Vegetative suckers were removed to the first flower cluster and the plants were staked. Tomatoes were harvested weekly until frost and marketable yield from each plot recorded. Weeds were controlled by hand cultivation and no pesticides were used. At the end of each growing season, plants were removed and the land was left fallow.

Soil from each plot was sampled in October at the end of harvest. Soil nutrients were measured by the Morgan method (Lunt *et al.*, 1950) using sodium acetate as the extractant. Percent organic matter was determined by loss on ignition.

Cumulative Effect of Annual Additions of MSW Compost
on the Yield of Field-Grown Tomatoes

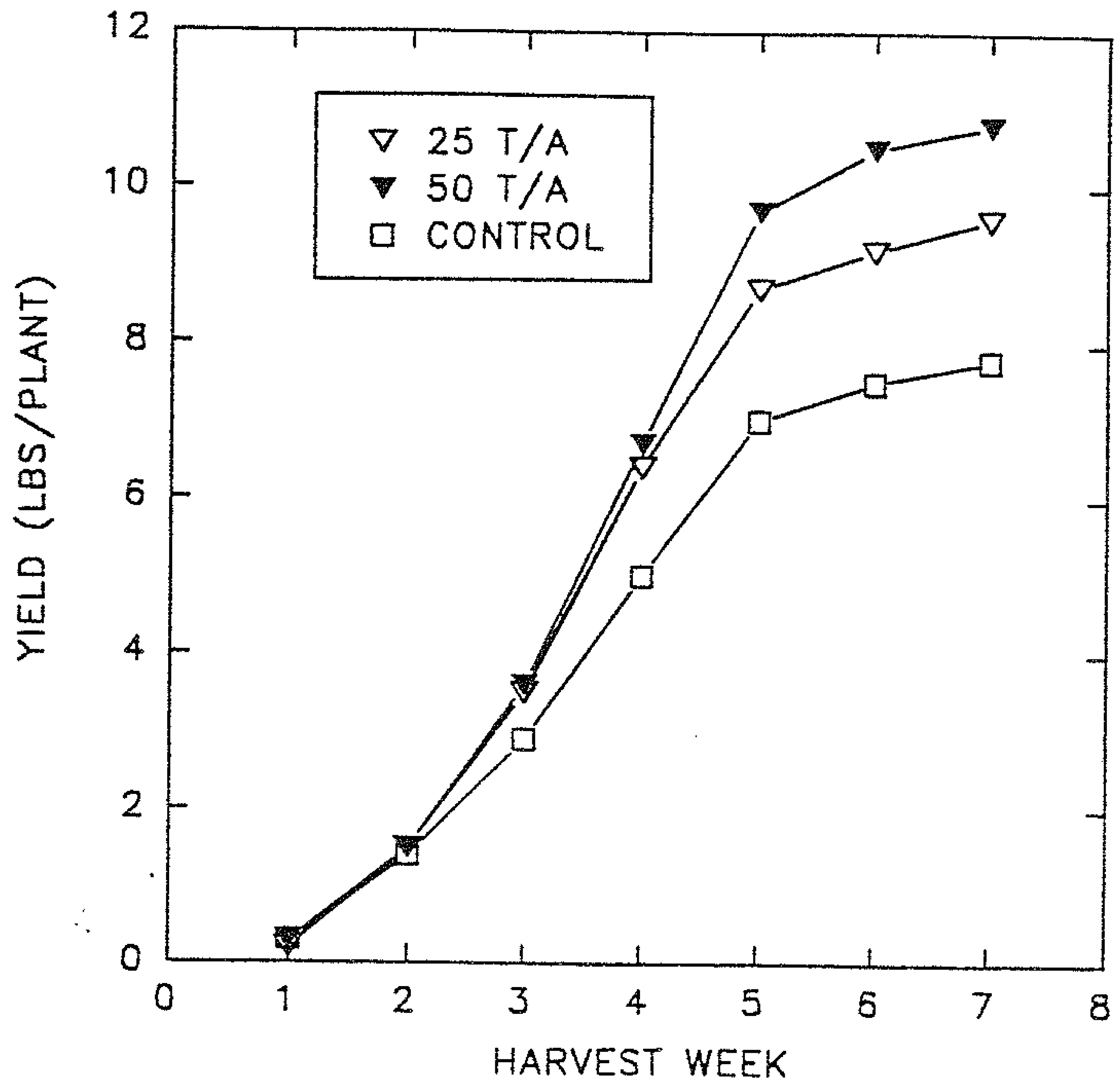

Figure 1. Cumulative yield (lbs/plant) of tomatoes in 1992 harvested weekly from plants growing in plots amended for one year with 25 or 50 T/A MSW compost compared to the unamended control

Results and Discussion

Yield

For all three years, yields from plots amended with 50 T/A MSW compost were significantly greater ($p \geq 0.05$) than unamended controls (Table 1) (Maynard, 1993). Yields in 1992, 1993 and 1994 were 38 percent, 15 percent and 33 percent greater respectively compared to unamended controls.

Yields from 25 T/A plots in 1992, 1993, and 1994 were 22 percent, 9 percent and 7 percent greater respectively than unamended control plots. The yield was significantly greater only in 1993. The differences in yield between 25 and 50 T/A treatments were not statistically significant but the yields from the 50 T/A plots were consistently higher.

The compost-amended plots produced greater yields throughout the entire growing season compared to the unamended controls. In 1992, the effect of compost on cumulative yield was evident by the third week (Figure 1). In 1993, the cumulative yield varied little among treatments but by the fourth week yields from the compost-amended plots were greater than from unamended controls (Figure 2). In 1994, cumulative yield from plots amended with 50 T/A compost was greater than the yield of other treatments by the second week (Figure 3).

Higher yield is due to increased number of tomatoes per plant and average weight of each tomato (Table 1). Compost-amended plots consistently produced more tomatoes per plant all three years compared to the unamended control plots. The increased number of tomatoes compared to the control was statistically significant in 1994 in the 50 T/A compost-amended plots.

Normally size and weight of tomato fruit are sacrificed when more fruit are harvested. This was not observed because plots amended with 50 T/A compost produced

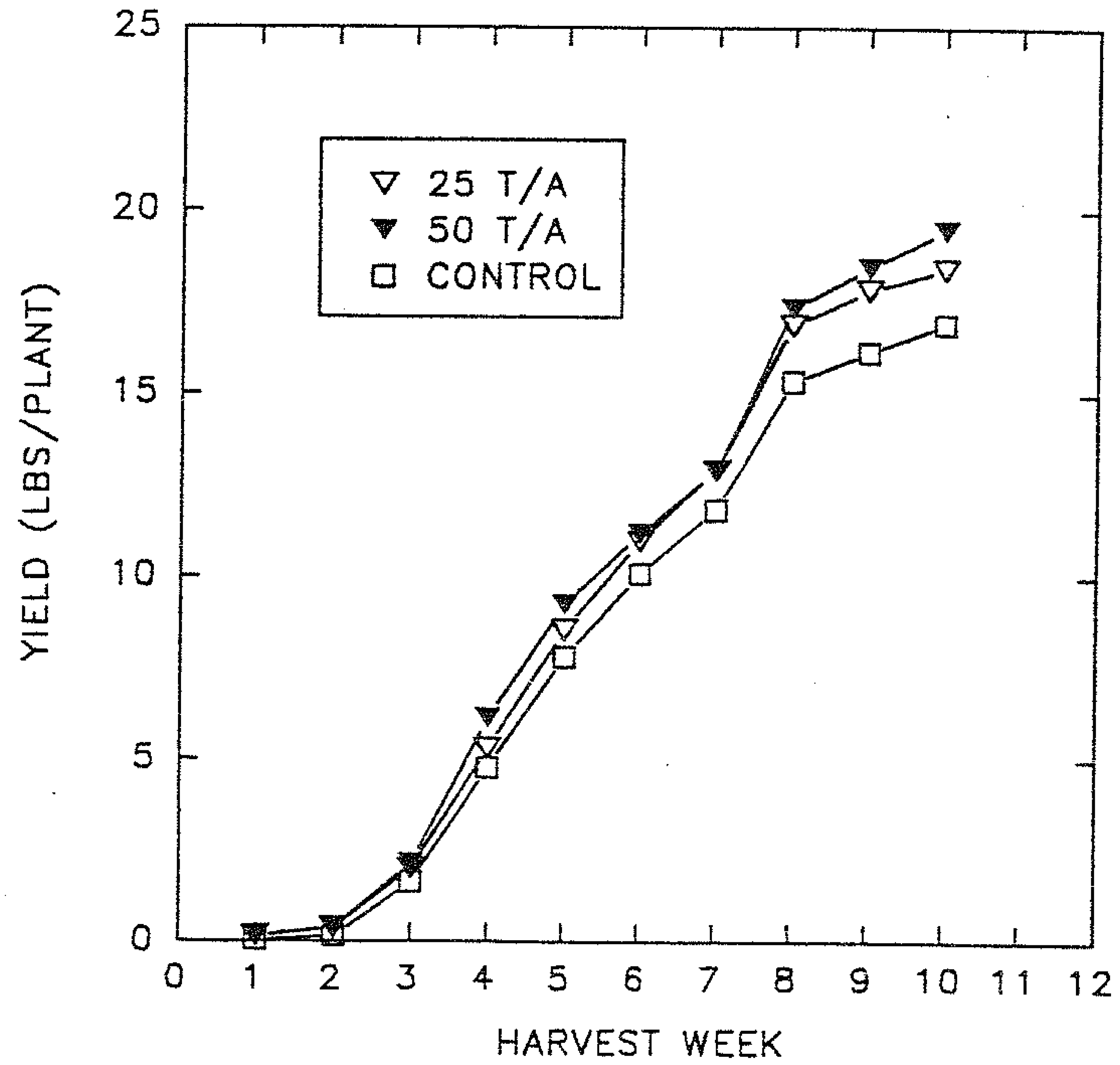

Figure 2. Cumulative yield (lbs/plant) of tomatoes in 1993 harvested weekly from plants growing in plots amended for two years with 25 or 50 T/A MSW compost compared to the unamended control

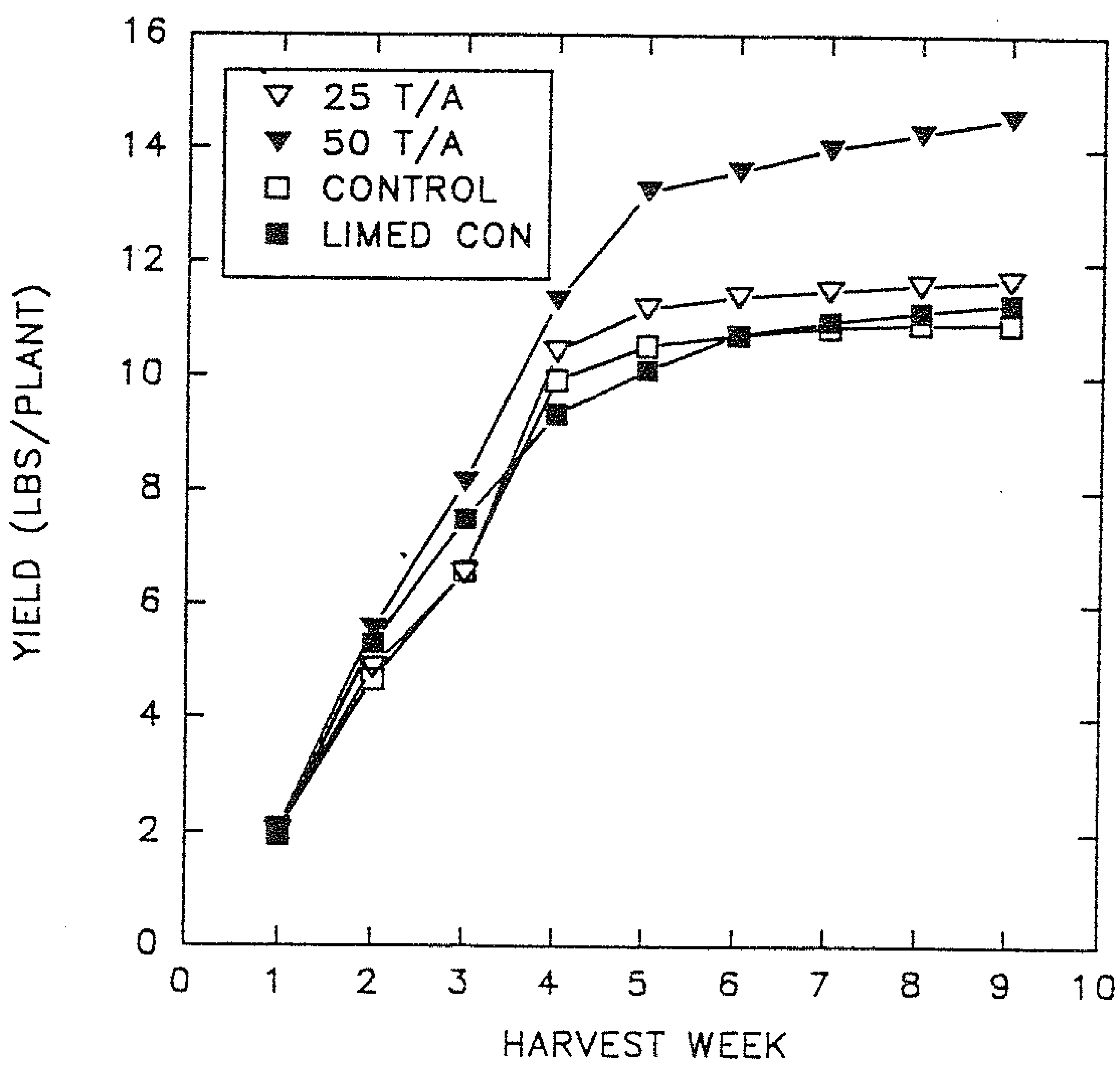

Figure 3. Cumulative yield (lbs/plant) of tomatoes in 1994 harvested weekly from plants growing in plots amended for three years with 25 or 50 T/A MSW compost compared to the limed and unamended controls

TABLE 2.
Analysis of soil from plots amended for three years with 25 or 50 T/A MSW compost compared to unamended and limed controls

	Control	Limed Control	25 T/A	50 T/A
pH	5.8	6.9	6.2	6.4
NO_3-N	3	4	6	10
NH_4-N	12	12	12	12
P	100	70	100	100
K	198	192	232	218
Ca	1,200	1,650	1,600	1,600
Mg	81	138	125	106
Org matter (percent)	4.4	4.7	6.5	8.1

(Values PPM unless otherwise indicated)

the heaviest tomatoes in two of the three years (Table 1). The average weight of fruit from plots amended with 50 T/A compost was consistently greater in 1992 and 1994 (Figures 4 and 6). In 1993, there were fewer differences but plots amended with 50 T/A compost produced the heaviest fruit in the fourth week (Figure 5).

Maturation of the crop was not greatly affected by the treatments. During all three years, the first ripe tomatoes were harvested on all plots on the same date. In 1992, 90 percent of the total yield was harvested on all plots within five weeks. In 1993, 90 percent of fruit was harvested within seven weeks. In 1994, at least 90 percent of the total harvest were picked within three weeks on the unamended control plots and plots amended with 25 T/A MSW compost. On the limed control plots and plots amended with 50 T/A MSW compost, only about 80 percent of the total harvest had been picked by this time. By the fourth week, at least 90 percent of the crop had been harvested on all plots.

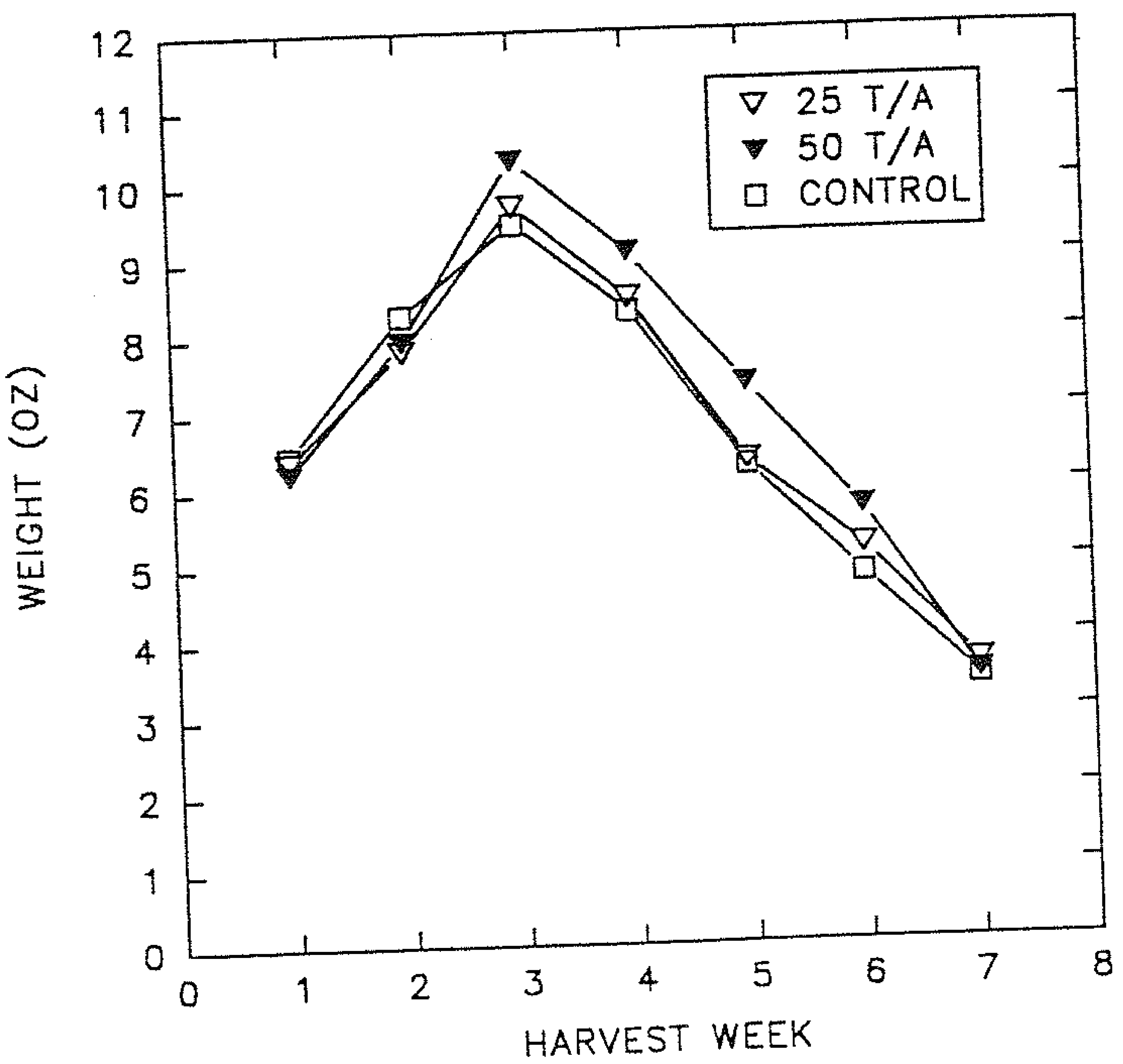

Figure 4. Average weight (oz) per tomato at each harvest in 1992 from plants growing in plots amended for one year with 25 or 50 T/A MSW compost compared to the unamended control

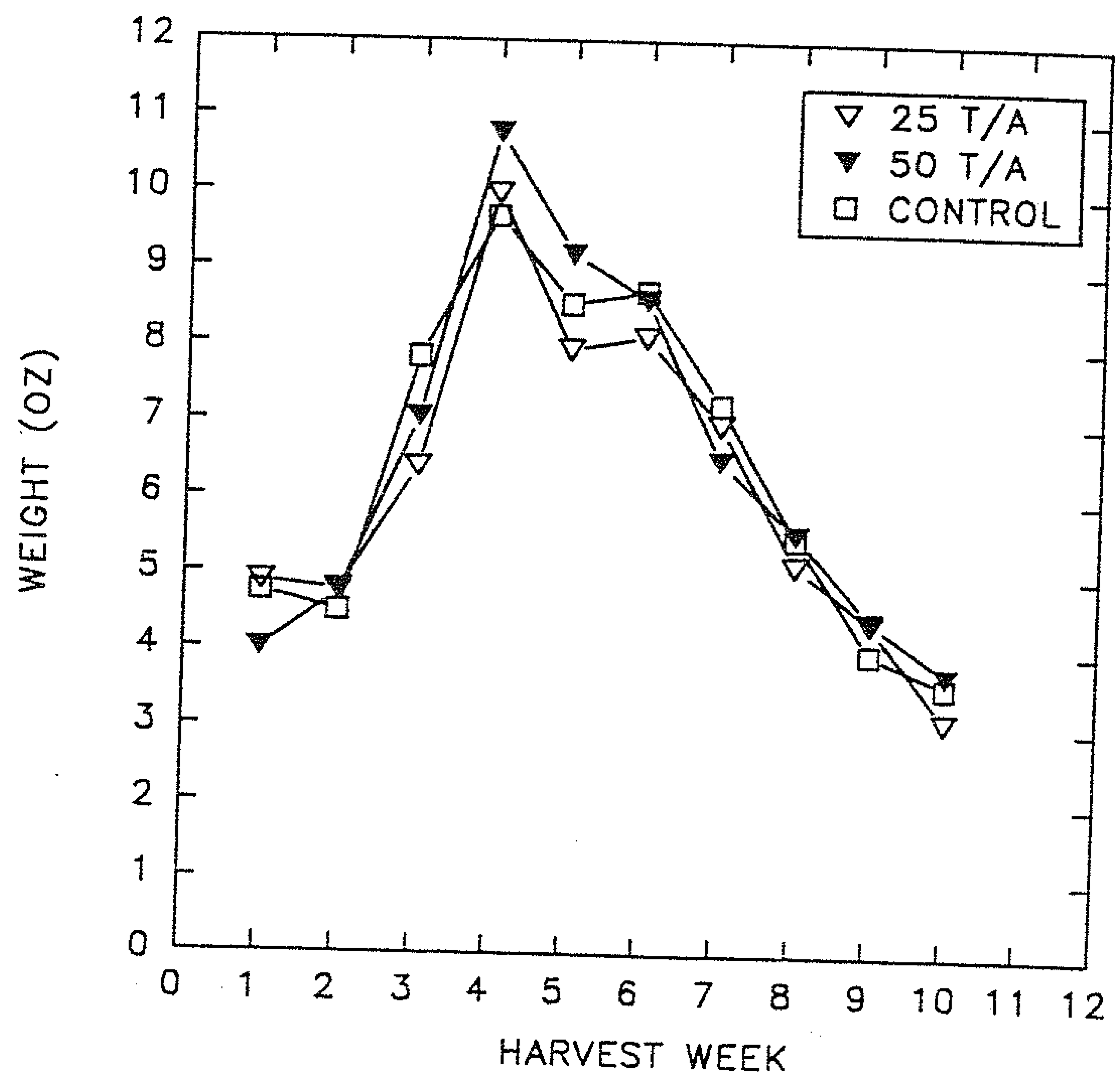

Figure 5. Average weight (oz) per tomato at each harvest in 1993 from plants growing in plots amended for two years with 25 or 50 T/A MSW compost compared to the unamended control

Soil Characteristics

The amendment of MSW compost for three consecutive years affected the physical and chemical characteristics of the soil (Table 2). The pH of the soil amended for three years with 50 T/A compost increased to 6.4 compared to 5.8 on unamended controls. Plots amended with annual amendments of 25 T/A MSW compost increased a pH of 6.2. Maynard (1993) reported pH values of 6.2 and 5.9 on the 50 T/A and 25 T/A plots from a single application. The MSW compost had a liming effect raising the pH into the range considered optimal for both microbial activity and nutrient availability. Increased levels of calcium and magnesium in the amended soil were also observed.

To determine if the yield increase on the compost-amended plots was due only to liming effects of the compost, additional control plots were established in 1994 to which lime as well as fertilizer was applied. The pH of these plots increased to an average of 6.9. Yields from plots amended with 50 T/A MSW compost were 28 percent higher than the limed controls (Table 1), suggesting that the liming effect of compost alone was not solely responsible for increased yields.

Nitrate-nitrogen also increased in the compost-amended plots compared to the unamended controls. The concentration of nitrate in plots amended yearly with 25 T/A compost was two-fold greater than the unamended control while the 50 T/A plots were three-fold greater (Table 2). Nitrate concentrations from the compost-amended plots after one application were less than the control (Maynard, 1993).

Nitrate, which plants can readily assimilate, can also be leached. This study shows that nitrate is available in the soil with annual additions of both compost and fertilizer. It appears that less inorganic fertilizer can be used to obtain optimum yields if compost is added annually. Most vegetables grown in compost-amended soil required at least

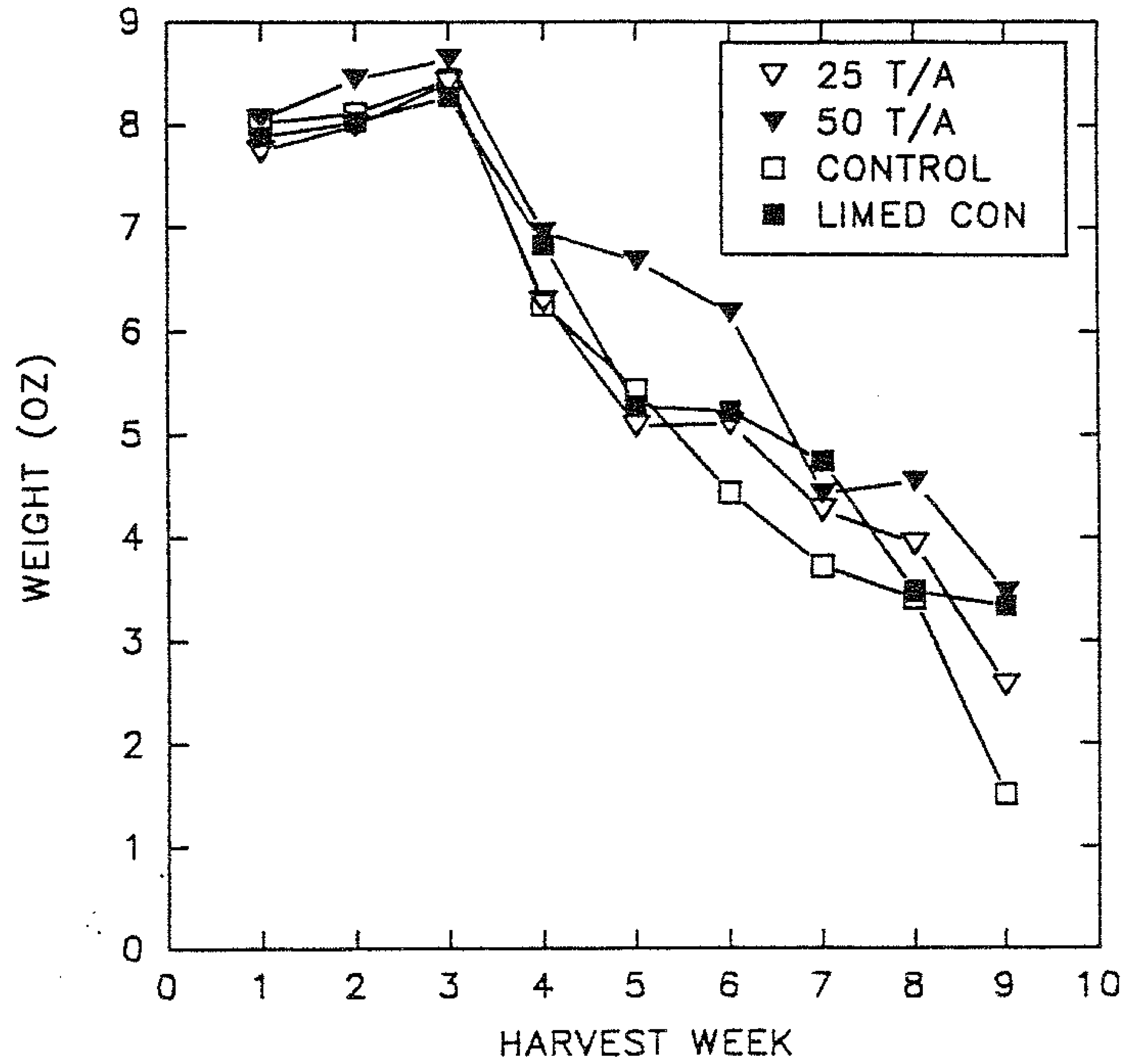

Figure 6. Average weight (oz) per tomato at each harvest in 1994 from plants growing in plots amended for three years with 25 or 50 T/A MSW compost compared to the limed and unamended controls

one-third less inorganic fertilizer to obtain optimum yields (Maynard and Hill, 1994).

The addition of 50 T/A MSW compost for three years increased the organic matter from 4.4 percent to 8.1 percent, an increase of 84 percent. After one application the organic matter had increased 38 percent (Maynard, 1993). Other studies have shown that the major benefits of MSW compost amendments to soil are derived from improved physical properties related to increased organic matter content (Gallard-Laro and Nogales, 1987; Shiralipour *et al.*, 1992). It is known that organic matter increases cation exchange capacity, improves aggregation of fine soil particles, and reduces crusting of the surface soil after summer rains. Organic matter also affects the supply and availability of nutrients with easily replaceable cations. Nitrogen, phosphorus and micronutrients, held in organic forms, are less prone to leaching. Increased organic matter also improves the water holding capacity of soils. Another study at the same site found that the amount of water held in the upper nine inches of the fine sandy loam soil increased from 1.3 inches to 1.9 inches after compost additions (Maynard and Hill, 1994). This research also found that annual additions of compost for 12 years lowered the bulk density from 1.21 g/cc to 0.97 g/cc which allows the roots to penetrate the more friable soil more effectively (Maynard and Hill, 1994).

Summary

Source separated MSW compost applied for three years at 50 T/A produced significantly higher yields of tomatoes for all three years when compared to unamended controls. Cumulative effect of the compost additions beyond the first year was minimal. The increase in yield in the first year was similar to the increase in the third year. The greater yields can be attributed primarily to increased organic matter, pH and nu-

trients, especially nitrate-nitrogen. There was a cumulative effect of yearly compost additions on soil properties. In subsequent years, it appears that lower levels of fertilizer can be applied in MSW compost-amended soils to lessen the possibility of nitrate leaching.

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Metal Levels in Garden Vegetables Raised on Biosolids Amended Soil

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Biosolids compost was applied annually over a four year period to a Christiana silt loam soil at the rates of 73 and 146 Mg/ha. Two study areas were established at the site with slightly different experimental designs. Composite soil samples were analyzed for pH and levels of Pb, Zn, Cu, Ni and Cd. Vegetables grown on these plots included bush Blue Lake green beans (*Phaseolus vulgaris*, L.), crookneck summer squash (*Cucurbita pepo*, L.), zucchini squash (*Cucurbita pepo*, L.) Golden Bantam sweet corn (*Zea mays*, L.), black-seeded Simpson lettuce (*Lactuca sativa*, L.), Bloomsdale long-standing spinach (*Spinacea oleracea*, L.) and dwarf blue curled Vates kale (*Brassica fimbriata*, L.). Plant tissue samples were analyzed for uptake of Pb, Zn, Cu, Ni and Cd. The soil pH was found to increase with increasing application rate. Control plots which received lime had significantly higher pH than unlimed control plots. Statisticially significant differences in soil metal levels between treated and control plots were observed in later years of this study. Metal uptake by vegetables raised in the two treatment areas decreased as the application rate increased in some cases and was unaffected in others. This effect is thought to be due to the increased soil pH due to biosolids application, the low levels of metals in the material and the strong metal-binding capacity of the biosolids.

Introduction

Municipal biosolids produced by wastewater treatment facilities must be disposed of in ways that are both inexpensive and nonpolluting. Currently, biosolids are disposed of by landfilling, incineration, landspreading and composting. In recent years, the beneficial use of biosolids in agriculture and landscaping has been documented (U.S.E.P.A., 1989a). The amount of biosolids produced by wastewater treatment facilities has increased due to improved techniques used in processing of wastewater. Many municipalities now operate composting plants which compost all or a significant portion of the biosolids produced at these facilities (Hornick *et al.*, 1984). Composting stabilizes biosolids (Willson *et al.*, 1980), reduces malodors (Hornick *et al.*, 1984), destroys pathogens (Burge *et al.*, 1978) and improves soil fertility (Giusquiani *et al.*, 1988) with some dilution of heavy metals (Hornick *et al.*, 1984). This humus-like material is an excellent soil conditioner, and also serves as a fertilizer, providing N and P and trace elements. Ground limestone usually is added, providing the added benefit of pH improvement in acid soils. The large quantities of biosolids produced in metropolitan areas have, however, created a situation in which supply in many cases exceeds demand.

While some microelements found in biosolids may serve to correct plant deficiencies, others are of concern because of toxicity to plants (Cu, Ni, Zn) and hazard to human health (Cd); (Nogawa *et al.*, 1978 and 1980; Saito *et al.*, 1977). The uptake of Cd, Zn, Cu and Ni by crop plants has been documented (Chaney and Giordano, 1977; Kuo *et al.*, 1985 ; Rappaport *et al.*, 1987). Research has provided information on the use of biosolids for fertilizer (Kirkham, 1977 ; Kloe, 1982) and the phytotoxic effects of heavy metals in crop plants (Chaney and Giordano, 1977; Davis, 1978). The availability of