10-30-2024

Compost Comparison in High Tunnels

Elizabeth Maynard
Purdue University - Main Campus, emaynard@purdue.edu

Marian Rodriguez-Soto
marian.rodriguezsoto@in.nacdnet.net

Rebecca Koetz
Purdue University, busser@purdue.edu

Recommended Citation
Maynard, Elizabeth; Rodriguez-Soto, Marian; and Koetz, Rebecca, "Compost Comparison in High Tunnels" (2024). *Midwest Vegetable Trial Reports.* Paper 266.
https://docs.lib.purdue.edu/mwvtr/266

Compost Comparison in High Tunnels

Elizabeth T. Maynard[1], Marian Rodriguez-Soto[2], and Rebecca Koetz[3]
[1]Purdue University, 1101 Glendale Blvd. Ste. 101-A, Valparaiso, IN 46383
emaynard@purdue.edu
[2]Indiana Assoc. of Soil and Water Conservation Districts, 225 S. East Street, Ste. 142, Indianapolis, IN 46202
[3]Purdue Extension–Lake County, 2293 N. Main Street, Crown Point, IN 46307

Compost is frequently used in market garden production systems, both in the field and in high tunnels. Reasons for using compost include as a mulch for weed control, as a soil amendment to increase organic matter and biological activity, suppress plant disease, and/or supply mineral nutrients for the crop. Local sources of compost are desirable in order to minimize transport cost and promote recycling of nutrients within a region. Growers report varying experience with locally available composts. This trial was conducted to evaluate four composts for use in high tunnel tomato production, with primary emphasis on their value as sources of macronutrients. The results reported here document effects of the composts on tomato yield, leaf tissue nutrient concentrations, and soil nutrients at the end of the growing season.

Materials and Methods

To assess the effects of locally available compost in high tunnel tomato production, we trialed four compost products readily available within 30 miles of the Pinney Purdue Ag Center near Wanatah, IN, the location of this trial. Feedstocks included: 1) woodchip dairy bedding (BED, Heartland , Demotte, IN), 2) 50:50 decayed tree leaves (leaf mold) + woodchip dairy bedding (LFB, Perkins Good Earth Farm, Demotte, IN), 3) dairy manure (MAN, Dairy Doo, Morgan Composting, Sears, MI), 4) yard waste (YW, Porter County Crocker Compost Site, Valparaiso, IN). Compost analyses provided by the manufacturers indicated they met US Composting Council guidelines for the intended use. Samples of the compost products were also sent to a commercial lab (A&L Great Lakes, Fort Wayne, IN) to test for organic matter and carbon, C:N ratio, pH, soluble salts, and other nutrients before applying them in the trial. Compost density was determined by weighing 1 liter of each product.

This trial was conducted on a Tracy sandy loam soil and was replicated in two high tunnels. In high tunnel 1 organic practices were used and in high tunnel 2 conventional practices were used; the primary difference during the trial was in the type of fertilizer used in side-dressing. Soil tests performed in April 2023 showed 1.7% and 1.6% organic matter, pH 6.8 and 6.6, 199 and 97 ppm phosphorus (P), 133 and 108 ppm potassium (K), 170 and 160 ppm magnesium (Mg), and 800 and 650 ppm calcium (Ca) in high tunnel 1 and high tunnel 2, respectively.

The experiment was a randomized complete block design with seven treatments and three blocks in each high tunnel. Beds 4 ft on center with a 3-ft bed-top were the experimental blocks. Treatments included a 1X rate of each compost, 2X and 3X rates of the YW compost, and no compost (Table 1). The amount of compost used for the 1X rate was the quantity required to supply 90 lb/acre of available N during the season. We assumed that 20% of the total N in the compost would be available, so for the 1X rate, the compost supplied 450 lb/acre total N. The higher rates of YW compost were included in order to evaluate whether the 1X rate provided adequate levels of nutrients. Each treatment plot (experimental unit) was 6 ft long, with three tomato plants 1.5 ft apart, and 1.5 ft separating treatments. Within a week prior to transplanting tomatoes, composts were weighed, bagged and applied in each plot to the surface of the soil and then shallowly incorporated with a power harrow. No other soil amendments were applied before planting.

Tomato cultivar Red Deuce was seeded in the greenhouse on April 4, 2023, in 72-cell square flats. Untreated seed was used for high tunnel 1 and thiram-treated seed for high tunnel 2. Seedlings were fertilized in the greenhouse as needed with 100 ppm N solution from 3-2-3 (Envirokure, Philadelphia, PA; high tunnel 1) or 20-10-20 (JR Peter's, Allentown, PA; high tunnel 2). Plants were placed outside of the greenhouse on May 5, and transplanted to high tunnels on May 11. Transplants were watered in with 300 ppm N solution from sources described above. Transplants that did not survive were replaced on May 17. Plants were hand-watered after transplanting, and during the growing season were irrigated as needed through two lines of drip tape per bed. Plants were supported with a Florida weave system. Bed tops were hand weeded as needed throughout the season, however no other pest control methods were used since insect populations were being recorded (data not shown here) and significant pathogen damage was not observed.

Tomato leaf samples were collected on June 2, June 19, July 10, and July 31 (3, 6, 9, and 12 weeks after transplanting (WAT)) to determine need for additional fertilizer. One recently mature leaf from the center tomato plant in each plot was collected. Leaves for each treatment in each high tunnel were combined and sent to a commercial lab for tissue analysis (Brookside Labs, New Bremen, OH). Except for the no-compost treatment, if the tissue test indicated a macronutrient deficiency in a treatment, N and /or K were side-dressed in that treatment. This resulted in 30 lb/acre N applied to all treatments except no-compost on June 23, and 50 lb/acre K_2O applied to all treatments except no-compost on June 23 and July 18. In high tunnel 1 nutrient sources were 13-0-0 (Darling Ingredients, Irving, TX) and potassium sulfate (0-0-52, SQM, Los Condes, Santiago, Chile), and in high tunnel 2 urea ammonium nitrate (28-0-0) and potassium chloride (0-0-60) were used.

Tomato flowering was evaluated on June 21, 7 WAT. We counted the number of clusters on the main stem with open or past-bloom flowers or fruit (main stem clusters), the number of fruit with diameter > 5 mm on the main stem (main stem fruit), the number of clusters on branches with open or past-bloom flowers or fruit (branch clusters), and the number of fruit with diameter > 5 mm on branches (branch fruit).

Tomatoes were harvested on July 26, Aug. 10-11, Aug. 21-22 and Sept. 7-8. On the first three harvests fruit were graded into marketable and unmarketable (cull) and number and weight recorded. Reason for cull designation was recorded. All marketable and unmarketable fruit were checked for yellow shoulder disorder or other uneven color development (YSD) and the number of fruit recorded. On the final harvest date all fruit larger than 2 29/32 inch in diameter were harvested and categorized as red (at least turning) or green (not turning), counted and weighed. At this final harvest fruit were not graded into marketable and unmarketable. This harvest could indicate potential for yield if the crop were kept later into the fall, which was not possible in this experimental situation. Plants which had been replaced after original transplanting and were behind in development were harvested separately and are not included in results presented below.

Soil samples from each plot were collected in July and October and sent to a commercial lab (A&L Great Lakes) for further analysis to assess soil nutrients. On July 3 three 6-inch cores per plot were collected between the drip tape and row, combined, and air-dried before sending to lab for analysis of nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N). On October 10 (high tunnel 1) and October 17 (high tunnel 1) three 6-inch cores per plot were collected from the center of the row and kept cold until shipped overnight for tests of organic matter, P, K, Mg, Ca, soil pH, buffer pH, cation exchange capacity (CEC), NO_3-N and NH_4-N.

Analyses of variance (ANOVA) were used to evaluate interaction between high tunnel and treatment effects. Most interactions were not significant at $P = 0.05$ and so main effects of treatment and high tunnel were evaluated using ANOVA with high tunnel X treatment and rep within high tunnel as random effects. Single df contrasts were used to compare means of: 1) no compost to compost at 1X rate, 2) manure-based composts at 1X rate to YW compost at 1X rate, 3) composts containing the wood chip dairy bedding (BED and LFB) to the bagged dairy manure compost (MAN), 4) BED to LFB, and 5) linear and 6) quadratic trends for YW compost rates of 0X, 1X, 2X, and 3X. Fisher's protected LSD was used to assist in further evaluation of treatment differences. Contrasts and mean separations were considered significant if $P < 0.10$. Because leaf tissue nutrients were measured multiple times, ANOVA was performed on values measured 3 WAT, and then on the trends (linear, quadratic, and cubic) observed over time. The ANOVA included High tunnel and treatment as fixed effects and high tunnel X treatment as the error term. The relationship between 1) the percent of fruit with any degree of yellow shoulder disorder (%YSD), or the percent of fruit that were marketable, and 2) the mean Hartz Ratio for each treatment was explored with linear regression. All analyses were performed using JMP Pro version 16.1.0 (SAS Institute, Cary, NC).

Results and Discussion

Compost characteristics

The compost test results (Table 2) provided information used to calculate the application rate and estimate quantity of elements and organic matter added to the soil. Results indicated that composts were suitable for use in field application (Sullivan et al. 2018), although they did not all fall within the optimum range for vegetables compiled by Ozores-Hampton (2017). Each type of compost had at least one characteristic that set it apart from others. BED was notable for having ammonium-nitrogen 10 to 20 times higher than other composts, the highest level of soluble salts, which were just above the optimum maximum of 6 dS/m, and the highest density. LFB had the lowest potassium (K)–40% below the next highest–and the lowest density. MAN had markedly more phosphorus (P)–2.5 to 4 times higher in than in other composts–and the lowest magnesium (Mg). YW had the highest nitrogen (N) on a dry weight basis, and the lowest P, sodium (Na), and soluble salts. A full discussion of all these characteristics is beyond the scope of this report, but when they can help explain plant response or changes in the soil, it will be mentioned below.

Tomato leaf tissue nutrients

Tomato leaf tissue macronutrient concentrations differed among compost treatments on the first sampling date 3 WAT (June 2), and over the next 9 weeks (Figure 1 and Tables 3 and 4). The observed concentrations were compared with reported sufficiency ranges (Hochmuth and Sideman 2023). Typically, if additional nutrients are not supplied, leaf tissue concentrations tend to decrease over time as a plant ages, and that happened in this trial.

Nitrogen ranged from 2.25% to 4.28% on June 2. Compost treatments at the 1X application rate resulted in significantly higher N concentration than no compost, and as the application rate of YW increased from 1X to 3X the N concentration increased linearly from 3.41% to 4.28%. All treatments with compost were at or above the sufficiency level of 2.8%. By the second sampling date 6 WAT all treatments averaged close to or below the sufficiency level (2.5%) and therefore N was sidedressed as described above. At 9 WAT all treatments were above the sufficiency level (2.5%), and then declined to near the sufficiency level of 2.0% by 12 WAT.

Changes in N concentration over time differed between the 1X compost application rates and no compost: with the 1X rate the concentration started higher and tended to decrease over time, and without compost the concentration did not change as much. Increasing rates of YW compost led to larger variation (linear, quadratic, and cubic trends) in N concentration over time. Larger decreases in N concentration over time at higher YW rates is one example of this.

Phosphorus concentrations 3 WAT on June 2 did not differ significantly among all treatments, but a difference was found between the three manure-based composts (BED, LFB and MAN), which averaged 0.444%, and the 1X rate of the YW compost, 0.507%. This is somewhat surprising, given the higher concentration of P in the manure-based composts, and the reason is not clear. All treatments were above the high end of the sufficiency range 3 WAT (0.400%) and none below the sufficiency level (0.200%) by 12 WAT.

Changes in P concentration over the course of the season differed among treatments, with significant effects observed between 1X rates of compost and no compost (smaller decrease over time with no compost), between manure-based and YW compost (smaller decrease over time with manure-based compost), and related to the rate of YW compost (smaller decrease over time with no compost and largest with 1X rate).

Leaf K concentration ranged from 1.63% to 2.78% on June 2. In treatments with the 1X compost rate, K concentration averaged higher than without compost, and all compost treatments were above or within 0.1% of the sufficiency level (2.5%). In YW treatments K concentration increased linearly with increasing application of compost. By 6 WAT all treatments were below the sufficiency level of 2.5%, and so K was applied following the protocol above. K concentration remained below 2.5% 9 WAT and a second side-dressing was applied. By 12 WAT, K concentration in leaves was at or slightly below the sufficiency level of 1.5% in all treatments; no additional K was applied.

The changes in K concentration over time differed among treatments. In treatments with the 1X compost rate, K concentration started higher and so decreased more over the season than in the treatment without compost. At higher rates of YW compost, K also started higher and decreased more rapidly than at lower rates, and showed more variation over the season.

Calcium, Mg, and S concentrations were near or above the high end of the sufficiency range for the entire season. Differences occurred among the treatments on June 2 (3 WAT) and in the trends over time. At 3 WAT, compost at the 1X rate increased concentrations of Ca, Mg, and S compared to no compost, manure-based compost had higher concentrations of these elements than YW compost, and BED + LFB averaged higher than MAN. Mg concentration 3 WAT increased and S concentration decreased as the rate of YW compost increased, but Ca concentration did not respond to YW rate. Trends in concentration over the growing season showed a generally similar pattern of differences. These results reflect the higher levels of Ca, Mg and S in BED and LFB compared to MAN and YW (Table 2).

Tomatoes in high tunnel 1 had higher leaf concentrations of the macronutrients P, Ca, Mg and S than plants in high tunnel 2 at 3 WAT (Table 3). This probably reflects the history of amendment application. Over the last 10 years high tunnel 1 has had only organic N fertilizers, which also contain P, and potassium sulfate or potassium magnesium sulfate. In high tunnel 2 the primary N sources (urea, ammonium nitrate) have not included P, and both potassium chloride and potassium sulfate have been used.

Tomato leaf tissue micronutrient and sodium concentrations also differed among compost treatments on the first sampling date, June 2, and over the next 12 weeks (Figure 2 and Tables 5 and 6). Except for Zn, concentrations were within or above sufficiency levels (where sufficiency levels have been identified) throughout the season, and did not reach reported toxic levels. Zn was near or below the lower value of the sufficiency range through 9 WAT and dropped below the sufficiency level (20 ppm) for all treatments by 12 WAT.

Although the overall treatment effect for June 2 tissue concentrations was significant for only B and Na, single df contrasts indicated that the 1X compost rate averaged higher concentrations than no compost for B, Cu, Na and Zn, while the no compost treatment had higher concentrations of Mn than the average of the 1X compost treatments (Table 5). Na also averaged higher in the manure-based composts than YW, due to high concentrations in BED and MAN treatments. B, Cu and Zn increased in a linear fashion with increasing rate of YW compost. Differences in trends across time among treatments were most significant for Na, and the pattern of differences was generally similar to that observed for samples collected on June 2 (Table 6).

These differences in plant tissue micronutrient and sodium concentrations reflect the elemental content of the composts (Table 2). BED and MAN composts contained approximately twice the Na concentration of LFB, and ten times the concentration of YW compost. Cu and Zn were higher in BED and LFB composts than MAN, and lowest in YW. Mn was highest in YW compost, followed by MAN, and then BED and LFB. B was not measured in compost.

Tomatoes in high tunnel 1 had higher leaf concentrations of Fe and Na, and lower concentrations of B and Mn than plants in high tunnel 2 at 3 WAT (Table 5). Most likely this is due to the different history of amendment application.

Soil characteristics

Compost treatments influenced many soil characteristics depending on the type of compost and the application rate. On 3 July, 10 days after sidedressing N and K, soil NO_3-N averaged 16.8 ppm and showed high variability. The overall treatment effect was not significant, however soil NO_3-N increased linearly as the rate of YW compost increased (Table 7). In October soil NO_3-N was highest in the high rate of YW (12.1 ppm) and a significant linear effect with rate of YW was still detectable, but other treatments did not differ significantly. NH_4-N averaged 9.7 ppm in July and 4.7 ppm in October and did not differ among treatments at either sampling period. In October NH_4-N averaged higher in high tunnel 1 (5.71 ppm) than in high tunnel 2 (3.65). This could be due to the organic N fertilizer applied in high tunnel 1 that was still undergoing mineralization.

Compost application had significant influence on other soil characteristics measured at the end of the season (Tables 7 and 8). Averaged across all composts applied at the same rate, soil had more organic matter, P, K, Ca, and Mg, greater CEC, and lower percent Mg on cation exchange sites ($P < 0.1$) compared to no compost. On average, composts applied at the 1X rate did not significantly influence soil pH, or percent saturation of CEC by K or Ca. The overall average does not tell the entire story, however, because there were differences among composts for many of these characteristics. On average, manure-based composts increased P, K ($P < 0.1$), Ca, and CEC; and decreased soil pH and the percent Mg on cation exchange sites compared to YW compost. Again, the average masks differences among manure-based composts. MAN increased soil organic matter more than BED, increased P, K, and the percent K on cation exchange sites more than both BED and LFB, and increased Ca less than BED. MAN also increased soil pH by 0.14 points compared to no compost. In contrast, BED and LFB reduced pH by 0.18 points compared to no compost. MAN did not increase CEC as much as LFB, which in turn did not increase CEC as much as BED.

Many soil characteristics increased linearly in response to the rate of YW applied. Soil pH, organic matter, K, Ca, Mg, CEC, and the percent K on cation exchange sites all showed significant positive linear trends with the rate of compost applied. Organic matter also showed a significant ($P < 0.1$) quadratic trend, because soil organic matter increased more rapidly with higher compost application. The significant linear or quadratic trend does not necessarily mean that significant differences were found in the values for the different application rates, but it means that there was a discernable pattern in relation to the application rate.

The Hartz Ratio describes relative quantities of extractable K and Mg in the soil based on the amount of their positive charge; it is named for the scientist who initially described the negative correlation with tomato fruit color disorders (Hartz et al. 1999). In this trial, compost treatments altered the Hartz Ratio of the soil (Table 8). On average, composts applied at the 1X rate increased the ratio compared to no compost, and manure-based compost led to a higher Hartz Ratio than YW compost. These differences were driven by the high Hartz Ratio of soil amended with MAN, which was higher than the ratio for any other 1X treatment or no compost. The Hartz Ratio increased linearly with increasing rates of YW compost, and the high rate of YW had a Hartz Ratio not different from MAN. All ratios were below 0.6, the value above which coarse soils in the Midwest are at a low risk of yellow shoulder disorder for processing tomatoes (Francis et al. N.D.). Past research on processing tomatoes in the Midwest further elucidated that higher values of the Hartz Ratio were correlated with reduced yellow shoulder disorder, particularly in coarse soils (McIntyre et al. 2007).

Compost will have long-term impacts on the soil, and will influence microbial and physical characteristics that were not evaluated in this trial. However it is possible to identify some potential advantages and disadvantages of the different materials based on the observed short-term changes in soil chemistry. In this trial MAN led to larger undesirable effects on some soil chemical properties than other composts. Soil P increased to very high levels, and soil pH also increased. On the other hand, MAN had a favorable effect on soil K by increasing the soil test level and the percent K on cation exchange sites, which resulted in a higher Hartz Ratio than for other composts at the same rate; a beneficial change for tomatoes. Soil sodium (Na) was not measured, but Na in leaf tissue was. MAN resulted in high tissue concentrations of Na, as did BED. These two composts contained the highest concentrations of Na (0.11% for MAN and 0.14% for BED), so it seems likely that soil concentration was also high. Although plant tissue concentrations were not above the toxic level, it is possible that early in the season soil levels were high enough to interfere with uptake of other cations, or to cause damage to seedling roots.

All rates of YW increased soil pH at least as much as MAN, and higher rates had a larger effect; this could be detrimental over time. High rates of YW led to increases in Mg and the percent Mg on exchange sites, which could be detrimental in this soil because it already contains excessive

Mg. However, the Hartz Ratio also increased with application of YW, which indicates a more favorable balance of K and Mg in the soil. An advantage of YW was the smaller increase in soil P compared to BED and MAN, even at high rates. This would be especially important in situations where surface erosion, runoff, or leaching are likely to occur and move P offsite, causing pollution elsewhere.

BED and LFB resulted in similar soil tests results at the end of the season, except BED led to higher CEC and soil Ca. Soil P increased less than with MAN but more than with YW. Soil pH decreased instead of increasing, which is a benefit over both MAN and YW in this soil. The percent Mg on cation exchange sites also decreased, but because K on exchange sites did not increase, the Hartz Ratio did not improve as much with these composts as it did for MAN. Sodium concentration in tomato leaves was higher in BED than LFB, and this might reflect differences in soil levels of sodium. On a wet basis, BED compost contained 0.14% and LFB only 0.06% sodium.

Tomato growth and yield

Most plants had bloomed by June 2, 3 WAT. At 7 WAT the number of main stem clusters ranged from 3.3 to 4.5, main stem fruit from 2.67 to 5.83, branch clusters from 1.83 to 5.67 (Table 9), and branch fruit fruit from 0 to 1 (data not shown). Branch fruit was not analyzed with ANOVA because so many treatments had zero; treatments did not differ significantly based on 95% confidence intervals around the mean. The treatment effect was significant at P=0.0723 for branch clusters but not for main stem clusters or main stem fruit. However, single-df orthogonal contrasts showed significant differences among treatments for all three of these counts. The BED + LFB treatments averaged 25% more main stem clusters than MAN, and BED had 17% more main stem clusters than LFB. On average, treatments with compost had 45% more main stem fruit and 61% more branch clusters than treatments without compost. Main stem fruit and branch clusters both increased in a linear fashion in relation to the amount of yard waste compost applied. The larger number of main stem fruit in compost-based treatments, but not a larger number of main stem clusters, suggests earlier cluster development and fruit set with compost, and increasing earliness with higher rates. The larger number of branch clusters in treatments with compost suggests potential for larger yield with compost, and potential to increase yield more with higher rates of compost.

Tomato yield components are shown in Fig. 3 and Table 10. Marketable and total fruit include the first three harvests, July 26 through Aug. 22. Total red and green fruit include those harvests plus red and green fruit harvested Sept. 7-8. Marketable tomato number and weight per plant were 50% and 60% lower, respectively, without compost than when compost was applied at the 1X rate. The average weight of a marketable tomato was 20% lower without compost. Manure-based composts and YW compost produced the same weight per plant of marketable, total, and total red and green fruit, but manure-based composts averaged 10% and 6% fewer numbers of total, and total red and green fruit, respectively. Among the manure-based composts, MAN produced 22% fewer marketable fruit and a higher percentage of cull fruit (34.3%) than the average of BED and LFB (22.9% cull fruit).

Fruit number and weight showed significant linear and quadratic trends with the rate of YW compost. The linear effect was due largely to the increase from no compost to the 1X rate (e.g., 128% increase in marketable number and 170% in marketable weight per plant). Above the 1X rate, marketable fruit number and weight, total weight, and total red and green number remained relatively constant. Total fruit number tended to decrease and total red and green fruit weight tended to increase with higher application rates. Average marketable fruit weight increased with increasing application rate of YW compost. The percent cull fruit decreased in a linear fashion with increasing rate of YW compost.

In summary, among the composts, MAN tended to produce fewer tomatoes and lower yield per plant than other composts, although the difference was not always significant. As rates of YW increased above 1X, there was a trend for fewer total fruit and larger average fruit size in harvests 1-3, and a trend for more total yield of red plus green fruit over all harvests. The high rate of yard waste had a lower percent of cull fruit in the first three harvests.

The reasons fruit were classified as cull in the different compost treatments are shown in Fig. 4. The categories "other" and "color" together account for most of the culls. Other includes fruit that were eaten by rodents, decayed, or diseased. Color includes fruit that had yellow shoulder disorder covering more than 25% of the shoulder or 25% of the side of a fruit.

Yellow shoulder disorder was the main color disorder observed. It occurs on a continuum, from a barely detectable small yellow area on the fruit shoulder or side, to a majority of the shoulder area exhibiting a bright yellow color (Fig. 5). A significant relationship ($P = 0.0005$) was found between %YSD (percent of fruit showing any level of yellow shoulder disorder) and the reciprocal of the Hartz Ratio (Fig. 6), with $r2 = 0.653$. This indicates that a higher Hartz Ratio was associated with a lower incidence of yellow shoulder disorder, consistent with previous findings in processing tomatoes (Hartz et al. 1999).

The relationship between the percent of fruit that were marketable and the mean Hartz Ratio for each treatment was less consistent across treatments. When the MAN treatment was included, regressions were not significant (data not shown). When the MAN treatment was excluded, separate regressions for each high tunnel were significant, with $r2 = 0.742$, $P = 0.0275$, for high tunnel 1 and r2 = 0.713, $P = 0.0343$, for high tunnel 2 (Fig. 7). It is not clear why the MAN treatment was an outlier in the relationship between percent marketable fruit and Hartz Ratio—why it had a lower percentage of marketable fruit than would be expected based on the high Hartz Ratio of the soil. Given the high percentage of fruit culled due to "other" reasons, it is possible that something in the MAN treatment encouraged feeding by rodents or more decay, but additional work is needed to understand this.

Summary and Conclusions

The four composts, which ranged in total N (dry basis) from 1.00% to 2.25%, and C:N ratio from 13.4 to 14.5, improved yield compared to no compost and performed generally similarly in terms of tomato yield and fruit quality when applied at the 1X rate of 480 lb/acre total N. However, there was indication that MAN led to a higher percentage of culls; the reason is not clear. With higher (2X and 3X) rates of YW compost tomato yield tended to increase. All rates of application supplied enough N and nearly enough K through 3 WAT, but after that additional N and K were needed. After the growing season was over, increases in soil organic matter, K, Ca, Mg, and CEC were found with compost application; the amount of increase varied depending on compost content. Manure-based composts (BED, LFB, and MAN) increased soil P, which was not desirable because this soil already had high P levels. The Hartz Ratio, which describes the relative amounts of K and Mg in the soil, increased more with manure-based composts, especially MAN, and with higher rates of YW compost. Higher values of the ratio were positively associated with reduced incidence of yellow shoulder disorder, as has been previously reported for processing tomatoes. Soil pH decreased with two composts, BED and LFB, and increased with two composts, MAN and YW. Under the conditions of this trial and based on the information collected, the LFB compost led to the "best" results overall; second best would be the 2X or 3X rates of YW compost. Given the variable effects of compost on soil characteristics it is not possible to pick a "best" compost for all situations based on this trial.

Based on this comparison of compost use on a sandy loam soil in high tunnels for one season several preliminary conclusions arise. As source of N and K for tomatoes transplanted in May the rates used in this study (approximately 1.5–4.5 cu.yd./1000 sq.ft. and 480–1440 lb/acre total N) could be expected to support tomatoes for about 3 weeks, but additional nutrients would be needed to prevent deficiency later in the season. Depending on the type and rate, application of compost may increase the Hartz Ratio, and this might be useful in reducing the incidence of yellow shoulder disorder. Compost applications will lead to increased soil organic matter and nutrient content at the end of season and this should be considered when planning amendments for future crops. At high rates of compost, significant NO_3-N may remain in the soil that could be used by a following cash or cover crop. Compost may raise or lower soil pH, depending on the type of compost and rate applied. Choosing a "best" compost requires understanding the compost effects in a particular situation and prioritizing outcomes. For this trial, placing a high priority on tomato yield, lowering soil pH, and avoiding excess soil P results in the choice of BED or LFB as "best." If lowering pH were not a priority, then the middle or high rate of YW could be considered. Composts will have varying effects depending on the material and application rate, the soil and environmental conditions, and crop grown. All composts are likely to increase soil organic matter, nutrient content, and CEC, change soil pH, and supply a portion of the crops' nutrient needs, but identifying the best compost source and rate requires assessing changes and prioritizing results in a particular situation.

Acknowledgments

This material is based upon work that is supported by the National Institute of Food and Agriculture, US Department of Agriculture, under agreement number 2020-38640-31522 through the North Central Region SARE program under project number LNC20-438, PI Laura Ingwell. USDA is an equal opportunity employer and service provider. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the US Department of Agriculture.

H. Banas, J. Clemens, and M. Jackson assisted in field operations and data collection. Farmer Focus Group (C. Aquino, L. Aquino, D Appel, M. DeJong, D. Perkins, A. Massie) suggested comparing local composts. Laura Ingwell provided training and guidance for collecting data on insect populations and damage to fruit.

Literature Cited

Francis, D., T. Sporleder, S. Garrison, C. Gunter, A. Handa, T. Hartz, and M. Foolad. ND. “Hartz” Ratio. The Ohio State Univ. https://tomato.cfaes.ohio-state.edu/HartzRatioCalculator.htm/. 24 Apr 2024.

Hartz, T., G. Miyao, R. Mullen, M. Cahn, J. Valencia, and K. Brittan. 1999. Potassium requirements for maximum yield and fruit quality of processing tomato. J Am Soc Hortic Sci 124:199-204.

Hochmuth, G.J. and R.G. Sideman. 2023. Knott's Handbook for Vegetable Growers. 6th Ed. John Wiley & Sons, Hoboken, NJ. pp. 272-273.

McIntyre, A.A.C., D.M. Francis, T.K. Hartz, and C. Gunter. 2007. Fertility influence of the US Midwestern soils on yellow shoulder disorder in processing tomatoes. HortScience 42:1468-1472.

Ozores-Hampton, M. 2017. Guidelines for assessing compost quality for safe and effective utilization in vegetable production. HortTechnology 27:162-165.

Sullivan D.M., A.I. Bary, R.O. Miller, and L.J. Brewer. 2018. Interpreting Compost Analyses. Oregon State University Bulletin EM 9217. Corvallis, OR. https://extension.oregonstate.edu/sites/default/files/documents/em9217.pdf

Table 1. Treatments used in a comparison of composts for production of tomatoes in high tunnels, Wanatah, IN, 2023.

Trt. No.	Treatment	Compost type	Rate[i]	Lb/1000 sq.ft.
1	BED	Dairy woodchip bedding	R1	1570
2	LFB	Leaf mold and dairy woodchip bedding	R1	1640
3	MAN	Bagged dairy manure	R1	1570
4	YWA	Municipal yard waste	R1	1340
5	YWB	Municipal yard waste	R2	2680
6	YWC	Municipal yard waste	R3	4020
7	ZNO	No compost	R0	0

[i] Rate: R1=90 lb N per acre (estimated assuming 20% of total N available); R2=180 lb N per acre; R3=270 lb N per acre; R0=none. 90 lb per acre = 2 lb per 1000 sq.ft.

Table 2. Characteristics of four composts used for tomato production in high tunnels, Wanatah, IN, 2023.

Characteristic[i]	BED	LFB	MAN	YW	Optimum[ii]
Moisture (wet) (%)	34.31	46.65	46.87	66.08	30–60
Nitrogen (wet) (%)	0.66	0.63	0.66	0.77	
NH_4^+-N (ppm)	218	18	9	15	
Nitrogen (%)	1.00	1.17	1.24	2.26	0.5–6.0
P2O5 (%)	0.98	0.78	2.66	0.60	0.45–6.82
K2O (%)	1.00	0.64	1.12	1.09	0.12–4.22
Calcium (Ca) (%)	12.03	8.75	7.43	6.91	
Magnesium (Mg) (%)	4	3.2	0.89	1.51	
Sulfur (S) (%)	4.58	2.41	0.6	0.34	
Copper (Cu) (ppm)	147	122	65	32	< 450
Iron (Fe) (ppm)	0.47	0.39	1.48	0.44	
Manganese (Mn) (ppm)	285	285	562	991	
Zinc (Zn) (ppm)	335	316	286	111	< 900
Sodium (Na) (%)	0.22	0.11	0.21	0.02	
pH	7.1	7	7.3	8	5.0–8.0
Soluble Salts (dS/m) (1:5, g/g)	6.6	5.3	4.75	3.16	< 6.0
Organic Matter (LOI @ 550 (%)	28.76	33.82	33.12	71.78	40-60
Total Organic Carbon (C) (%)	14.38	16.91	16.56	31.29	
C:N Ratio	14.4	14.5	13.4	13.8	10-25
Density (wet) (lb./cu.yd.)	1220	920	1080	940	740–980

[i] Percent and ppm on a dry weight basis until otherwise noted.

[ii] Optimum range for use in vegetable production, as compiled by Ozores-Hampton, 2017.

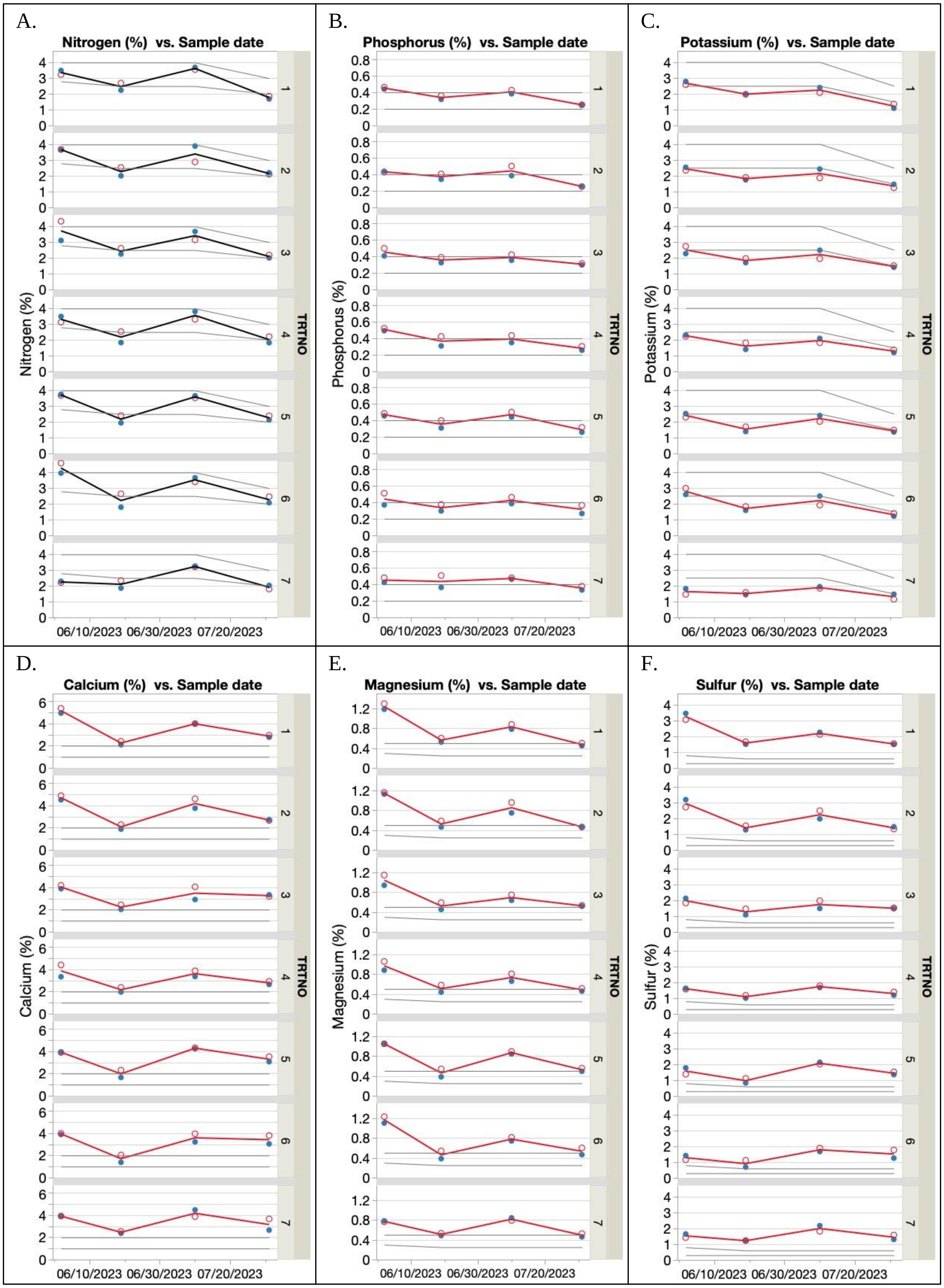


Figure 1. Concentration of macronutrients in tomato leaves 3, 6, 9, and 12 weeks after transplanting into soil amended with various composts or not amended, Wanatah, IN, 2023. Open circles: high tunnel 1; closed circles: high tunnel 2. A. Nitrogen. B. Phosphorus, C. Potassium. D. Calcium. E. Magnesium. F. Sulfur. Treatments: 1 = BED; 2 = LFB; 3 = MAN; 4 = YWA; 5 = YWB; 6 = YWC; 7 = ZNO. See text for treatment details. Horizontal lines on each graph indicate lower and upper bounds of sufficiency ranges (Hochmuth and Sideman 2023).

Table 3. Concentration of macronutrients in tomato leaves on 2 June, 3 weeks after transplanting into soil amended with various composts or not amended, Wanatah, IN, 2023.

	Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	Sulfur
			(%)			
High tunnel						
High tunnel 1	3.55	0.482	2.36	4.37	1.10	1.87
High tunnel 2	3.39	0.431	2.39	4.05	1.01	2.17
Treatment[i]						
1-BED	3.36 B[ii]	0.451	2.67 AB	5.15 A	1.24 A	3.25 A
2-LFB	3.67 AB	0.431	2.44 AB	4.70 A	1.14 AB	2.94 B
3-MAN	3.72 AB	0.451	2.49 AB	4.03 B	1.04 BC	1.98 C
4-YWA	3.31 B	0.507	2.26 B	3.86 B	0.97 C	1.59 D
5-YWB	3.72 AB	0.468	2.40 AB	3.91 B	1.05 BC	1.57 D
6-YWC	4.28 A	0.439	2.78 A	3.94 B	1.16 A	1.28 E
7-ZNO	2.25 C	0.450	1.63 C	3.91 B	0.77 D	1.52 D
Source[iii]			*P*-value			
High tunnel	0.4821	**0.0378**	0.8051	**0.0621**	**0.0322**	**0.0013**
Treatment	**0.0375**	0.5142	**0.0304**	**0.0138**	**0.0035**	**<.0001**
1,2,3,4 vs 7	**0.0071**	0.7457	**0.0036**	**0.0445**	**0.0005**	**0.0000**
1,2,3 vs 4	0.4343	**0.0767**	0.1877	**0.0116**	**0.0133**	**0.0000**
1,2 vs 3	0.5752	0.7641	0.7623	**0.0076**	**0.0306**	**0.0000**
1 vs 2	0.4674	0.5882	0.3423	0.1327	0.1649	**0.0219**
7,4,5,6: L	**0.0022**	0.5434	**0.0026**	0.8757	**0.0006**	**0.0566**
7,4,5,6: Q	0.4103	0.1408	0.4760	0.8259	0.4089	**0.0431**

[i] BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

[ii] Treatment means within a column followed by the same letters do not differ significantly at $P < 0.10$ according to Fisher's Protected LSD.

[iii] Source of variation and *P*-value from analysis of variance. Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. **Bold** font indicates $P < 0.10$.

Table 4. Significance of high tunnel and treatment effects on trends in concentrations of macronutrients in tomato leaves 3 to 12 weeks after transplanting into soil amended with various composts or not amended, Wanatah, IN, 2023.

Source[i]	Nitrogen	Phosphorous	Potassium (*P*-value)	Calcium	Magnesium	Sulfur
Linear trend						
High tunnel	0.2207	0.2195	0.3777	0.9273	0.1967	**0.0002**
Treatment[ii]	0.1101	**0.0218**	**0.0372**	**0.0190**	**0.0029**	**<.0001**
1,2,3,4 vs 7	**0.0138**	**0.0057**	**0.0055**	**0.0402**	**0.0003**	**0.0000**
1,2,3 vs 4	0.3168	**0.0285**	0.3149	0.1512	**0.0189**	**0.0000**
1,2 vs 3	0.7407	0.2279	0.2712	**0.0143**	**0.0216**	**0.0000**
1 vs 2	0.8871	0.3534	0.1669	0.3481	0.1285	**0.0411**
7,4,5,6: L	**0.0102**	0.6489	**0.0063**	0.2450	**0.0018**	**0.0048**
7,4,5,6: Q	0.6540	**0.0027**	0.7704	0.5322	0.3353	**0.0081**
Quadratic trend						
High tunnel	0.6431	0.1018	0.4066	0.6932	0.2079	**0.0755**
Treatment	**0.0858**	0.2304	0.7220	0.3274	**0.0171**	0.1740
1,2,3,4 vs 7	**0.0914**	0.2124	0.3735	0.1399	**0.0027**	**0.0505**
1,2,3 vs 4	0.7658	0.1518	0.6026	0.2894	0.2471	0.1002
1,2 vs 3	0.4624	0.1109	0.6664	0.8368	0.3449	0.3329
1 vs 2	**0.0842**	0.2049	0.7303	0.3634	0.3553	0.5124
7,4,5,6: L	**0.0087**	0.3700	0.1698	**0.0583**	**0.0012**	0.4826
7,4,5,6: Q	0.8352	0.4777	0.5711	0.4916	0.6874	0.7773
Cubic trend						
High tunnel	**0.0012**	0.5199	**0.0002**	0.8607	0.6458	**0.0369**
Treatment	0.3316	0.2815	**0.0916**	0.2974	**0.0540**	**0.0735**
1,2,3,4 vs 7	0.1223	0.2379	0.1002	0.6685	0.3672	0.3315
1,2,3 vs 4	0.4421	0.7107	0.7286	0.3124	0.1525	0.1138
1,2 vs 3	0.6389	0.1891	0.8814	0.0427	**0.0138**	**0.0107**
1 vs 2	0.8461	0.8760	0.7288	0.5957	0.6515	0.4760
7,4,5,6: L	**0.0474**	**0.0925**	**0.0069**	0.5659	**0.0324**	0.5545
7,4,5,6: Q	0.2818	0.2154	0.3659	0.6944	0.6941	0.3606

[i] Source of variation and *P*-values from analysis of variance. **Bold** font indicates $P < 0.10$.

[ii] Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. 1 = BED = composted dairy cattle bedding; 2 = LFB = BED mixed 50:50 with leaf mold compost; 3 = MAN = bagged composted dairy manure; 4 = YWA, 5 = YWB, 6 = YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

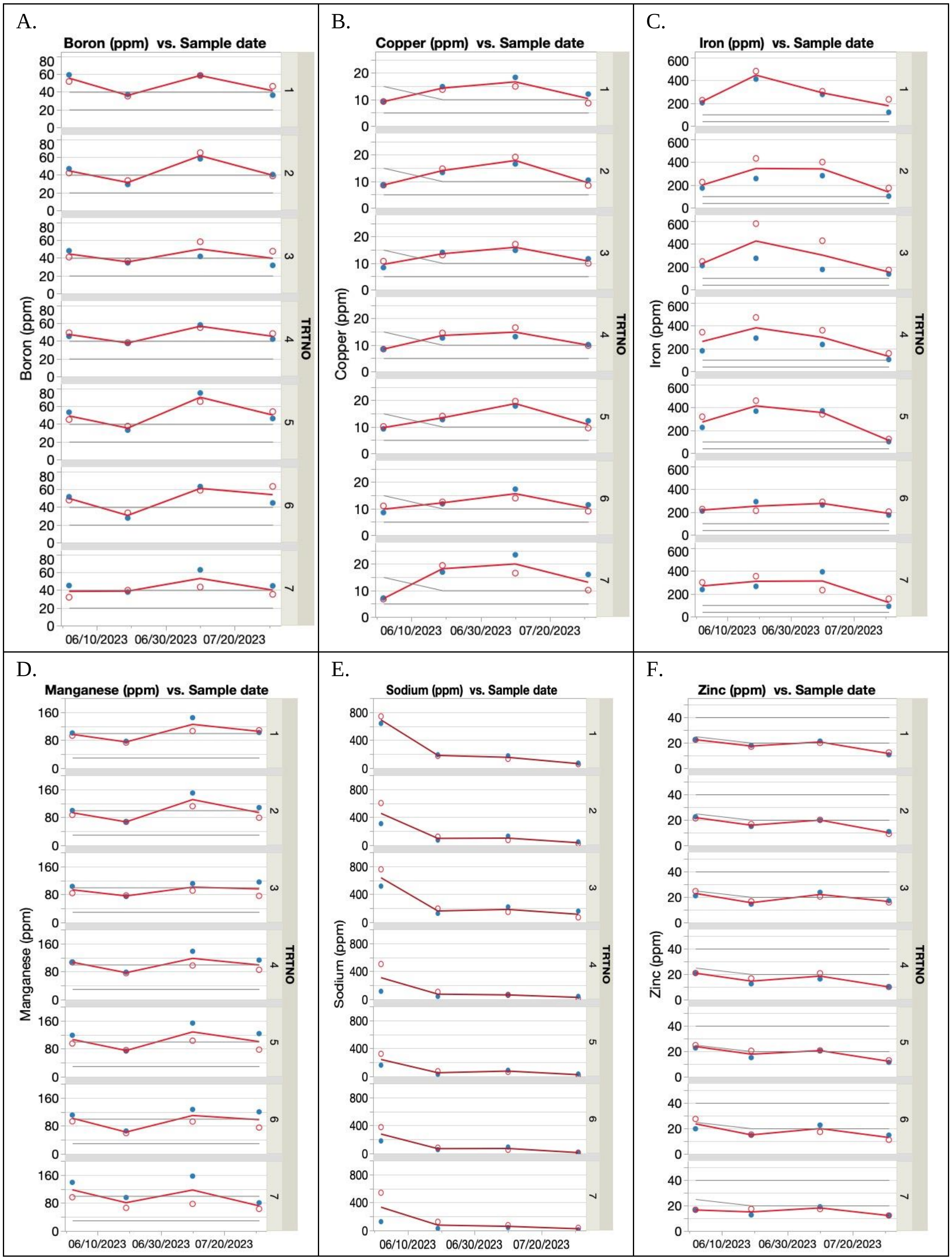


Figure 2. Concentration of micronutrients and sodium in tomato leaves 3, 6, 9, and 12 weeks after transplanting into soil amended with various composts or not amended, Wanatah, IN, 2023. Open circles: high tunnel 1; closed circles: high tunnel 2. A. Boron. B. Copper. C. Iron. D. Manganese. E. Sodium. F. Zinc. Treatments: 1 = BED; 2 = LFB; 3 = MAN; 4 = YWA; 5 = YWB; 6 = YWC; 7 = ZNO. See text for treatment details. Darker horizontal lines on each graph indicate lower and upper bounds of sufficiency ranges where available (Hochmuth and Sideman 2023).

Table 5. Concentration of micronutrients and sodium in tomato leaves on 2 June, 3 weeks after transplanting into soil amended with various composts or not amended, Wanatah, IN, 2023.

	Boron	Copper	Iron (ppm)	Manganese	Sodium	Zinc
High tunnel						
High tunnel 1	44.1	9.23	268	93	549	22.6
High tunnel 2	49.9	8.46	204	111	292	20.7
Treatment[i]						
1-BED	55.4 A	9.15	213	97	690 A	22.4
2-LFB	44.5 BC	8.55	198	93	455 B	21.8
3-MAN	44.5 BC	9.50	227	93	636 A	22.8
4-YWA	47.3 B	8.40	260	107	309 BC	20.8
5-YWB	49.1 AB	9.65	270	107	241 C	23.7
6-YWC	49.7 AB	9.75	216	102	277 C	23.6
7-ZNO	38.5 C	6.90	268	118	332 BC	16.5
Source[iii]			*P*-value			
High tunnel	**0.0264**	0.1436	**0.0156**	**0.0115**	**0.0011**	0.1625
Treatment	**0.0559**	0.1225	0.3596	0.2500	**0.0073**	0.1282
1,2,3,4 vs 7	**0.0183**	**0.0257**	0.1770	**0.0349**	**0.0262**	**0.0186**
1,2,3 vs 4	0.7838	0.3780	0.1587	0.1556	**0.0054**	0.4016
1,2 vs 3	0.1369	0.4153	0.5156	0.8473	0.4035	0.7198
1 vs 2	**0.0257**	0.5106	0.6729	0.7167	**0.0287**	0.7895
7,4,5,6: L	**0.0235**	**0.0112**	0.2487	0.1578	0.4010	**0.0121**
7,4,5,6: Q	0.1681	0.2925	0.3935	0.6704	0.6302	0.1978

[i] BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

[ii] Means within a column followed by the same letters do not differ significantly at $P < 0.10$ according to Fisher's Protected LSD.

[iii] Source of variation and *P*-value from analysis of variance. Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. **Bold** font indicates $P < 0.10$.

Table 6. Significance of high tunnel and treatment effects on trends in concentrations of micronutrients and sodium in tomato leaves 3 to 12 weeks after transplanting into soil amended with various composts or not amended, Wanatah, IN, 2023.

Source[i]	Boron	Copper	Iron	Manganese	Sodium	Zinc
			(*P*-value)			
			Linear trend			
High tunnel	**0.0391**	**0.0128**	0.3451	**0.0236**	**0.0005**	0.1228
Treatment[ii]	0.2784	0.3066	0.2049	**0.0683**	**0.0189**	0.3355
1,2,3,4 vs 7	0.4062	**0.0269**	0.4263	**0.0046**	**0.0670**	0.1207
1,2,3 vs 4	0.4851	0.9444	0.1806	0.2946	**0.0138**	0.6761
1,2 vs 3	0.9155	0.9821	0.4470	0.3469	0.8810	0.1032
1 vs 2	0.1849	0.9320	0.6442	0.8005	**0.0428**	0.8493
7,4,5,6: L	0.2379	0.0693	**0.0958**	**0.0202**	0.4334	0.1616
7,4,5,6: Q	0.7436	0.2811	**0.0710**	0.0986	0.5096	0.1793
			Quadratic trend			
High tunnel	0.9519	0.1529	0.5753	0.8876	**0.0003**	0.9132
Treatment	0.1949	**0.0640**	0.6876	0.7230	**0.0100**	0.6194
1,2,3,4 vs 7	0.1353	**0.0117**	0.4504	0.5522	**0.0503**	0.5152
1,2,3 vs 4	0.9016	0.5060	0.6689	0.6185	**0.0093**	0.9668
1,2 vs 3	0.7976	0.1622	0.9907	0.4467	0.3317	0.1661
1 vs 2	0.2202	0.3618	0.9815	0.6173	**0.0651**	0.9729
7,4,5,6: L	**0.0304**	**0.0094**	0.6702	0.2345	0.1701	0.2272
7,4,5,6: Q	0.5788	0.2616	0.2044	0.9160	0.6895	0.7737
			Cubic trend			
High tunnel	**0.0947**	0.9034	0.1505	**0.0008**	0.2971	**0.0245**
Treatment	0.2086	0.6135	0.2270	0.1209	**0.0252**	0.3687
1,2,3,4 vs 7	0.1724	0.3379	**0.0901**	0.4431	**0.0251**	**0.0598**
1,2,3 vs 4	0.4354	0.4739	0.5868	0.8510	**0.0077**	0.8522
1,2 vs 3	0.1039	0.7811	0.5929	**0.0132**	0.2158	0.4526
1 vs 2	0.5779	0.6017	**0.0735**	0.1719	0.2442	0.5157
7,4,5,6: L	**0.0547**	0.1463	0.9427	0.9124	0.7276	**0.0894**
7,4,5,6: Q	0.3629	0.5303	0.2577	0.9294	0.9357	0.6847

[i] Source of variation and *P*-values from analysis of variance. **Bold** font indicates $P < 0.10$.

[ii] Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. 1 = BED = composted dairy cattle bedding; 2 = LFB = BED mixed 50:50 with leaf mold compost; 3 = MAN = bagged composted dairy manure; 4 = YWA, 5 = YWB, 6 = YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

Table 7. Soil nitrate- and ammonium-N concentration in July and October and pH and organic matter in October for soil amended with various composts or not amended, Wanatah, IN, 2023.

	July		October			
	Nitrate-N	Ammonium-N	Nitrate-N (ppm)	Ammonium-N	pH	Organic matter
High tunnel						
High tunnel 1	11.1	9.8	6.76	5.71	6.83	2.24
High tunnel 2	22.4	9.7	5.84	3.65	6.44	1.91
Treatment[i]						
1-BED	24.2	10.0	5.77 B[ii]	4.77	6.40 D	1.83 DE
2-LFB	11.6	10.8	4.95 B	4.12	6.40 D	2.00 CD
3-MAN	9.0	9.0	4.38 B	3.85	6.72 B	2.15 BC
4-YWA	9.0	10.8	5.83 B	4.25	6.72 B	1.87 DE
5-YWB	23.1	9.9	6.67 B	3.92	6.77 AB	2.25 B
6-YWC	34.2	9.5	12.10 A	6.07	6.87 A	2.72 A
7-ZNO	6.2	8.2	4.40 B	5.80	6.58 C	1.73 E
Source[iii]			*P*-value			
High tunnel	0.4529	0.9285	0.4113	**0.0827**	**0.0072**	0.5127
Treatment	0.2088	0.8769	**0.0903**	0.6048	**0.0010**	**0.0016**
1,2,3,4 vs 7	0.4124	0.2979	0.6366	0.2211	0.5979	**0.0453**
1,2,3 vs 4	0.5137	0.6496	0.6601	0.9964	**0.0039**	0.2225
1,2 vs 3	0.3656	0.4963	0.6143	0.6519	**0.0007**	**0.0576**
1 vs 2	0.2719	0.7618	0.7133	0.6675	1.0000	0.1975
7,4,5,6: L	**0.0251**	0.6675	**0.0118**	0.9217	**0.0024**	**<.0001**
7,4,5,6: Q	0.5981	0.3612	0.2304	0.1191	0.6927	**0.0863**

---

[i] BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

[ii] Treatment means within a column followed by the same letters do not differ significantly at $P < 0.10$ according to Fisher's Protected LSD.

[iii] Source of variation and *P*-value from analysis of variance. Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. **Bold** font indicates $P < 0.10$.

Table 8. Soil phosphorus, potassium, calcium, magnesium, cation exchange capacity (CEC), base saturation and Hartz ratio in October for soil amended with various composts or not amended, Wanatah, IN, 2023.

	Phosphorus	Potassium	Calcium	Magnesium	CEC	Base saturation (%)			
			(ppm)		(meq/100 g)	K	Ca	Mg	Hartz ratio
High tunnel									
High tunnel 1	195	171	1205	287	9.27	4.8	65.0	26.0	0.283
High tunnel 2	108	115	1088	239	8.96	3.2	60.6	22.3	0.209
Treatment[i]									
1-BED	156 B[ii]	145 B	1350 A	258 BCD	10.75 A	3.5 C	62.9	20.2 D	0.254 BC
2-LFB	151 BC	120 BC	1183 B	250 CD	9.52 BC	3.3 C	62.0	22.0 D	0.214 CD
3-MAN	182 A	189 A	1133 B	237 DE	8.78 DE	5.5 A	64.5	22.5 CD	0.346 A
4-YWA	143 D	114 BC	1042 C	267 BC	8.33 E	3.5 C	62.3	26.5 AB	0.195 D
5-YWB	144 CD	140 B	1142 B	280 B	9.03 CD	4.0 BC	63.3	25.9 AB	0.233 CD
6-YWC	145 CD	201 A	1308 A	337 A	10.17 AB	5.0 AB	64.4	27.5 A	0.304 AB
7-ZNO	139 D	93 C	867 D	215 E	7.22 F	3.3 C	60.3	24.9 BC	0.177 D
Source[iii]					*P*-value				
High tunnel	**0.0225**	**0.0230**	0.1546	0.1109	0.5280	**0.0215**	**0.0400**	**0.0021**	**0.0465**
Treatment	**0.0006**	**0.0198**	**0.0002**	**0.0025**	**0.0006**	**0.0381**	0.5509	**0.0083**	**0.0109**
1,2,3,4 vs 7	**0.0013**	**0.0302**	**<.0001**	**0.0158**	**0.0002**	0.1990	0.1777	**0.0795**	**0.0187**
1,2,3 vs 4	**0.0011**	**0.0863**	**0.0014**	0.1698	**0.0029**	0.2422	0.6562	**0.0030**	**0.0205**
1,2 vs 3	**0.0002**	**0.0260**	**0.0082**	0.2099	**0.0039**	**0.0053**	0.3234	0.2484	**0.0050**
1 vs 2	0.3063	0.3053	**0.0057**	0.5837	**0.0114**	0.6999	0.7031	0.2045	0.2373
7,4,5,6: L	0.2452	**0.0024**	**<.0001**	**0.0002**	**0.0001**	**0.0222**	0.1019	0.1205	**0.0045**
7,4,5,6: Q	0.6294	0.2462	0.8868	0.8141	0.9737	0.3555	0.7714	1.0000	0.2624

[i] BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

[ii] Treatment means within a column followed by the same letters do not differ significantly at $P < 0.10$ according to Fisher's Protected LSD.

[iii] Source of variation and *P*-value from analysis of variance. Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. **Bold** font indicates $P < 0.10$.

Table 9. Flower cluster and fruit number on tomatoes grown in soil amended with various composts or not amended, Wanatah, IN, 2023.

	Main stem		Branch
	Clusters	Fruits (no/plant)	Clusters
High tunnel			
High tunnel 1	3.71	5.62	4.14
High tunnel 2	3.95	3.86	4.67
Treatment[i]			
1-BED	4.50	5.17	5.50 A[ii]
2-LFB	3.83	5.00	4.00 A
3-MAN	3.33	4.50	5.17 A
4-YWA	3.67	4.67	4.33 A
5-YWB	4.00	5.33	4.33 A
6-YWC	4.00	5.83	5.67 A
7-ZNO	3.50	2.67	1.83 B
Source[iii]		*P*-value	
High tunnel	0.9821	0.8401	0.6313
Treatment	0.1179	0.2116	**0.0723**
1,2,3,4 vs 7	0.2425	**0.0357**	**0.0090**
1,2,3 vs 4	0.4348	0.7977	0.5095
1,2 vs 3	**0.0253**	0.5319	0.6377
1 vs 2	**0.0863**	0.8751	0.1731
7,4,5,6: L	0.1250	**0.0194**	**0.0095**
7,4,5,6: Q	0.7296	0.3366	0.4279

[i] BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

[ii] Treatment means within a column followed by the same letters do not differ significantly at $P <$ 0.10 according to Fisher's Protected LSD.

[iii] Source of variation and *P*-value from analysis of variance. Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. **Bold** font indicates $P < 0.10$.

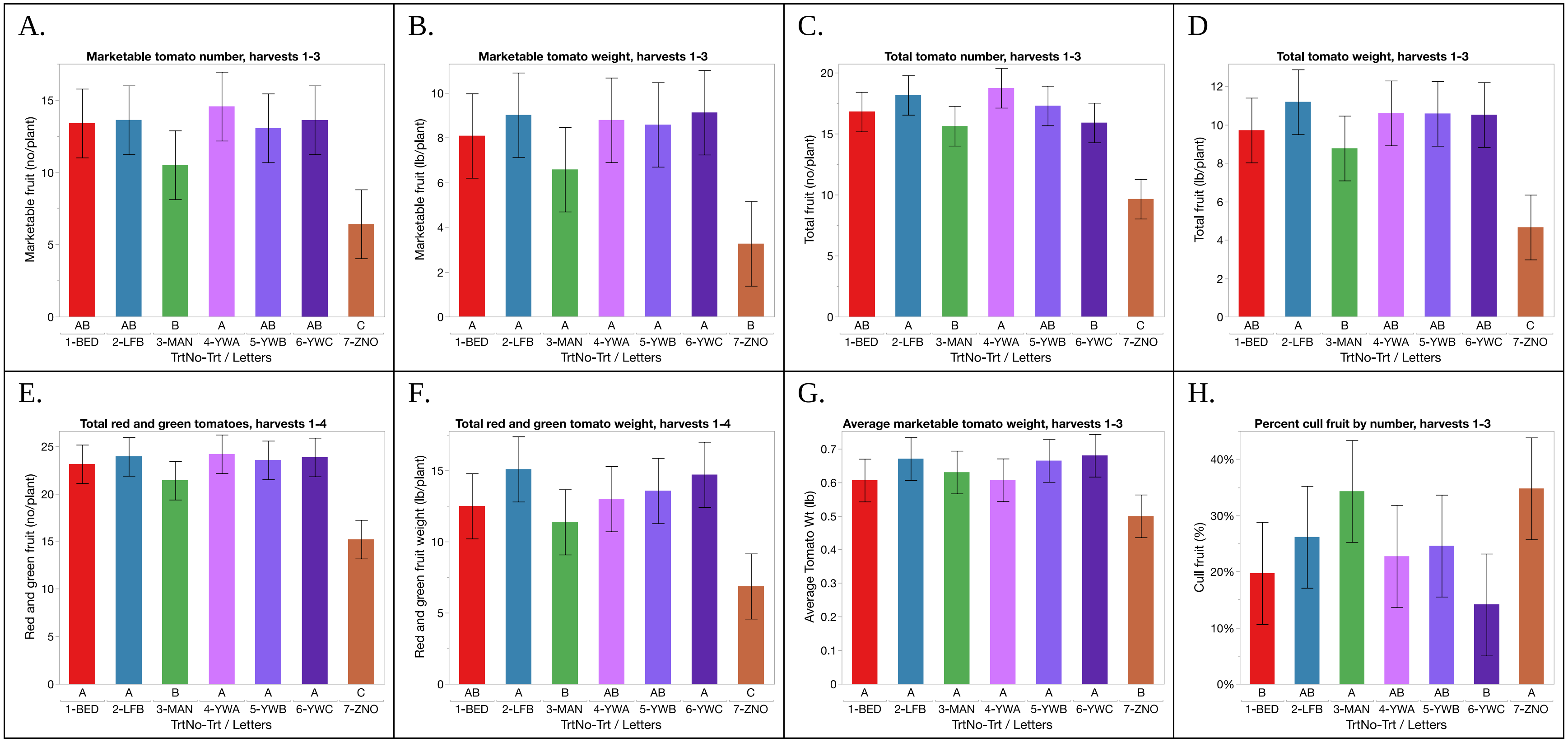


Fig. 3. Tomato fruit number (A, C, E), yield (B, D, F), average marketable fruit weight (G), and percent cull fruit (H) for tomatoes grown in high tunnels in soil amended with various composts or not amended, Wanatah, IN, 2023. A, B, G: Marketable fruit, harvests 1-3. C, D: Total fruit (marketable plus cull), harvests 1-3. E, F: Red and green fruit, harvests 1-4. H: Percent cull, harvests 1-3. BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC. Bars represent ±95% confidence interval. Bars labeled with the same letters do not differ significantly at $P < 0.10$ according to Fisher's Protected LSD.

Table 10. Marketable and total yield and fruit number per plant, average weight per marketable fruit, and percent cull fruit for tomatoes grown in high tunnels in soil amended with various composts or not amended, Wanatah, IN, 2023.

	Marketable fruit[i]		Total fruit[i]		Ave. marketable fruit wt[i]	Cull fruit[i]	Total red and green fruit[i]	
	(no)	(lb)	(no)	(lb)	(lb)	(%)	(no)	(wt)
High tunnel								
High tunnel 1	10.1	6.74	15.1	9.1	0.651	33.7	20.8	11.9
High tunnel 2	14.2	8.54	16.9	9.8	0.593	16.7	23.6	13.0
Treatment[ii]								
1-BED	13.4 AB[iii]	8.09 A	16.8 AB	9.7 AB	0.606 A	19.7	23.1 A	12.5 AB
2-LFB	13.6 AB	9.02 A	18.1 A	11.2 A	0.670 A	26.2	23.9 A	15.1 A
3-MAN	10.5 B	6.58 A	15.6 B	8.8 B	0.630 A	34.3	21.4 B	11.4 B
4-YWA	14.6 A	8.79 A	18.7 A	10.6 AB	0.607 A	22.7	24.2 A	13.0 AB
5-YWB	13.1 AB	8.59 A	17.3 AB	10.6 AB	0.664 A	24.6	23.5 A	13.6 AB
6-YWC	13.6 AB	9.13 A	15.9 B	10.5 AB	0.680 A	14.1	23.8 A	14.7 A
7-ZNO	6.4 C	3.26 B	9.6 C	4.7 C	0.500 B	34.8	15.2 C	6.9 C
Source[iv]								
High tunnel	**0.0238**	0.1289	0.1427	0.5364	**0.0858**	**0.0202**	0.2113	0.4766
Treatment	**0.0260**	**0.0342**	**0.0022**	**0.0132**	**0.0739**	0.1385	**0.0001**	**0.0184**
1,2,3,4 vs 7	**0.0025**	**0.0036**	**0.0001**	**0.0010**	**0.0127**	0.1333	**<.0001**	**0.0022**
1,2,3 vs 4	0.1829	0.4399	**0.0812**	0.4780	0.4795	0.4876	**0.0487**	0.9916
1,2 vs 3	**0.0837**	0.1370	0.1005	0.1442	0.8474	**0.0939**	**0.0116**	0.1158
1 vs 2	0.8986	0.5101	0.2620	0.2482	0.2173	0.3668	0.2967	0.1395
7,4,5,6: L	**0.0090**	**0.0060**	**0.0025**	**0.0030**	**0.0065**	**0.0280**	**<.0001**	**0.0024**
7,4,5,6: Q	**0.0184**	**0.0376**	**0.0005**	**0.0103**	0.2120	0.8717	**0.0001**	**0.0590**

[i] Marketable, total, average marketable fruit weight and cull fruit based on harvests 1 through 3. Total red and green fruit based on harvests 1 through 4.

[ii] BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.

[iii] Treatment means within a column followed by the same letters do not differ significantly at $P < 0.10$ according to Fisher's Protected LSD.

[iv] Source of variation and *P*-value from analysis of variance. Treatment effect is partitioned into six contrasts described by referencing the treatment numbers. L = linear and Q = quadratic trend vs yard waste application rate. **Bold** font indicates $P < 0.10$.

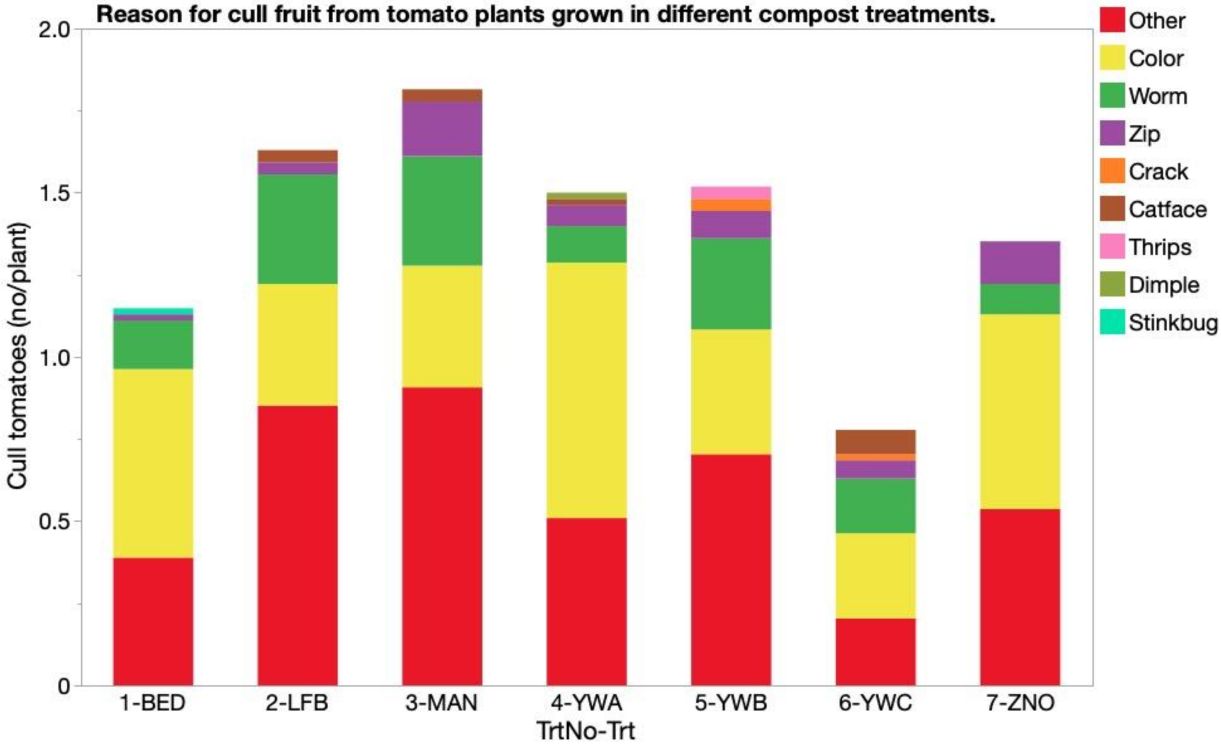
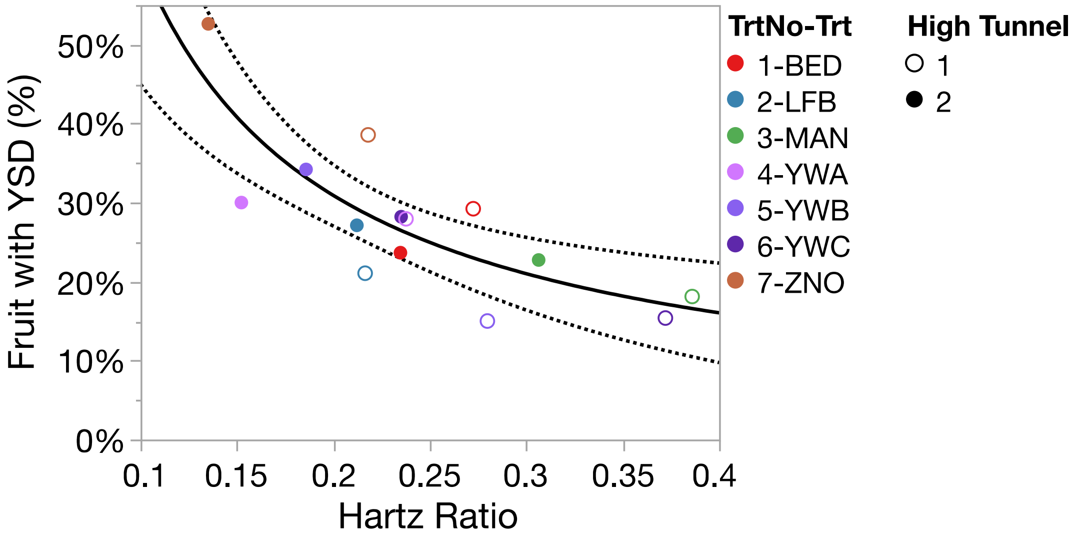


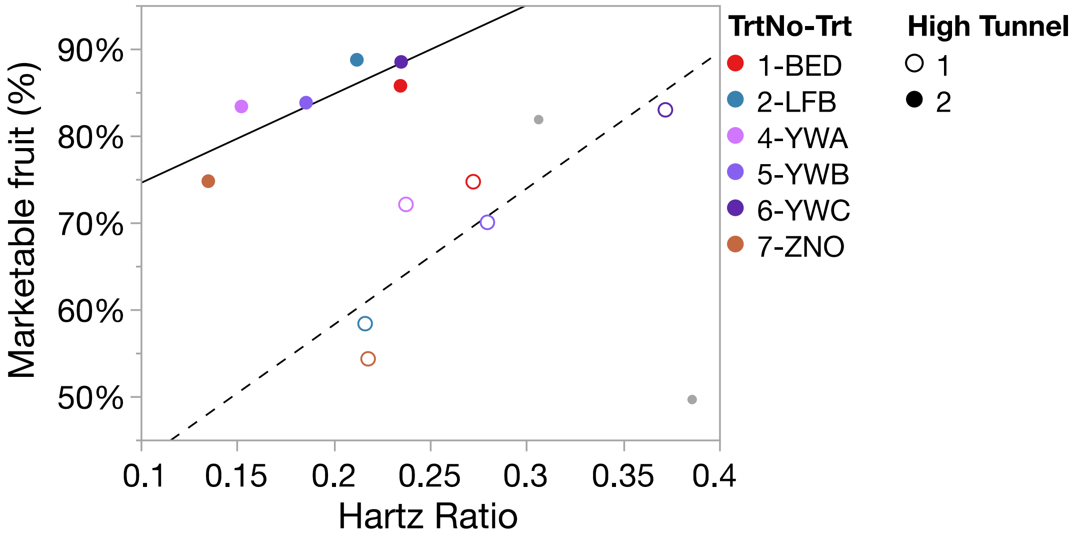
Fig. 4. Number of fruit classified as cull for different reasons when tomatoes were grown in high tunnels in soil amended with various composts or not amended, Wanatah, IN, 2023. Values are average per harvest for harvests 1-3. BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC. "Other" includes mainly rot and damage from rodent feeding.

Fig 5. Tomato fruit with yellow shoulder disorder. (*Photo by ET Maynard*)



Fruit with YSD (%) = 0.0117±0.0575 + 0.0594±0.0125*Recip(Hartz Ratio). r^2=0.653, P = 0.0005. Dotted lines represent 95% confidence interval for the curve.

Fig. 6. Percent of tomato fruit with yellow shoulder disorder (YSD) versus Hartz Ratio of soil amended with various composts or not amended in two high tunnels, Wanatah, IN, 2023. Individual fruit were classified as having the disorder whether or not they were otherwise marketable. If a portion of the fruit surface was yellow instead of red the fruit was classified as having YSD. BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.



High Tunnel 1: Marketable fruit (%) = 0.269±0.126 + 1.570±0.463*Hartz Ratio. r^2=0.742, *P* = 0.0275 (dashed line)
High Tunnel 2: Marketable fruit (%) = 0.644±0.0637 + 1.022±0.324*Hartz Ratio. r^2=0.713, *P* = 0.0343 (solid line)

Figure 7. Percent marketable tomato fruit versus Hartz Ratio of soil amended with various composts or not amended in two high tunnels, Wanatah, IN, 2023. One compost treatment (MAN) was omitted from regression because when included no significant relationship was found; it is indicated by small grey points. BED = composted dairy cattle bedding; LFB = BED mixed 50:50 with leaf mold compost; MAN = bagged composted dairy manure; YWA, YWB, YWC = municipal yard waste compost; ZNO = no compost. Application rate = N (total) 450 lb/A for BED, LFB, MAN and YWA, 900 lb/A for YWB, and 1350 lb/A for YWC.