Journal of the American Pomological Society 68(1): 2-13 2014

# Growth and Yield of 'Honeycrisp' Apple Trees with Preplant Inoculation with Mycorrhizae and Soil-Incorporated Compost

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**Additional index words:** rootstock, nutrition, soil fertility, *Malus* x*domestica,* replant disease, precocity


## Abstract

Preplant soil-incorporated compost, mycorrhizal inoculation (MI) at planting and the combination of the two (compost+MI) were tested over nine years for growth, yield and foliar analysis of 'Honeycrisp' apple (*Malus xdomestica*) trees on two rootstocks, M.26 EMLA and G.16 planted in a site with mild replant disease. Mycorrhizal inoculation, measured in years 1, 5, 7 and 8, had no effect on foliar levels of most nutrients. Foliar Zn was increased by MI in year 5 from 14 to 17 $mg \cdot kg^{-1}$ in G.16 rootstock, but not with M.26 compared to an untreated control. In year 7, foliar Cu was increased from 7 to 8 $mg \cdot kg^{-1}$ by MI. Leaf N was higher with compost amended soil in years 2 and 3, lower in year 4, and similar to an untreated control in years 5 to 8. Leaf P and K were generally greater with compost until years 4 to 5 when they were similar to the untreated control. Levels of Ca, Mg, B, Mn and Fe were inconsistently affected by compost from year to year. Compost increased shoot growth in year 2, but not when combined with MI. In years 1 and 3, compost had no effect on shoot growth. MI did not affect shoot growth in years 1 or 2, but increased it in year 3 in G.16 trees, but not M.26. In the first three years, trees produced very sparse bloom. In year 4, compost increased the number of flower clusters in both rootstocks, but not in M.26 rootstock when compost was combined with MI. In year 5, compost did not increase bloom. MI did not affect bloom in years 4 and 5. MI did not affect trunk cross sectional area (TCA) of G.16 in any year when compared to the untreated control. Compost increased TCA of G.16 in years 3 and 5, but not when combined with MI, and this combined treatment reduced TCA in year 4 compared to compost alone. MI increased TCA of M.26 in years 3, 4, 5, 7, 8 and 9. Compost increased TCA of M.26 in years 3, 4, and 5, and when combined with MI, increased TCA in years 3 and 5, but not in year 4. MI did not affect yield until year 8 for G.16 when it was reduced compared to the control. MI increased yield of M.26 in year 9, but had no effect in other years. Compost and compost+MI increased yield in years 6 and 8 in both rootstocks, and had reduced yield in trees on G.16 rootstock in years 7 and 9 as a result of biennial bearing. Compost and compost+MI trees on M.26 rootstock had reduced yield in year 9. Cumulative yield from years 4 through 9 was not affected by rootstock, compost or MI. The addition of compost or MI was found to increase tree growth and yield, but these effects were inconsistent between the two rootstocks and did not occur consistently in every year.


The majority of new apple orchards in New England and elsewhere are planted in sites that were previously planted to apple trees, which can reduce tree growth and yield compared to sites previously free of apple trees, a phenomenon known as the replant problem. In many cases, the replant problem is attributed to biological causes such as the presence of soil-borne pathogens, nematodes or the absence of beneficial microorganisms (Braun, 1991; Caruso et al., 1989; Kandula et al., 2006; Mai and Abawi, 1981; Mazzola, 1999; Slykhuis, 1990). In other cases, abiotic causes such as poor fertility, soil compaction or elevated arsenic residues (Benson et al., 1978; Merwin and Stiles, 1989; Utkhede et al., 1992), are the cause of replant problems. Because of the many possible causes, a multi-pronged approach is needed to address poor tree growth of apple trees in replanted sites.

Cultural practices to remedy replant disease involve a reduction in populations of pathogens, or an alteration of the microbial population in soil. Soil fumigation with

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biocides or nematicides to eliminate pathogens can improve growth of trees in replant soils (Mai and Abawa, 1981). However, this is not widely practiced in the northeastern U.S. because of inconsistent effectiveness and the potential for phytotoxicity due to the consistently cool soil temperatures in spring when most trees are planted (Benson et al., 1975; Merwin et al., 2001). Cover crops such as Sudan grass, *Tagetes*, 'Saia' oats and *Brassica juncea*, that discourage replant disease and nematodes, are variable in their effectiveness in counteracting replant symptoms (Merwin, 1995; Merwin et al., 2001), and require additional time prior to planting which prevents growers from using this method.

Over the life of an orchard, alterations occur in the soil microbial population which may inhibit beneficial microorganisms and possibly exacerbate apple replant disease (Mazzola, 1999). Mycorrhizae, an important part of the microbial community, benefit apple tree growth (Covey et al., 1981), and their absence in apple is associated with symptoms of replant disease (Caruso et al., 1989). Inoculation of roots prior to planting is not commonly practiced since trees are infected in the nursery and are commonly mycorrhizal in the orchard (Miller et al., 1985). However, mycorrhizal inoculation at planting can increase tree growth in apple seeds grown in unsterilized soil (Plenchette et al., 1981), and in soil from an orchard with replant disease (Catska, 1994). Inoculation at planting can be rapidly accomplished compared to fumigation or planting cover crops, but long-term studies involving inoculated trees in an orchard setting have not been conducted.

Soil replacement with nonreplant soil or organic matter such as peat or compost can alleviate replant disease (Peryea and Covey, 1989). Addition of organic matter or compost can act as soil replacement which is a method addressing the biological component of replant disease (Havis, 1962; Peryea and Covey, 1989). The increase in tree growth from the addition of organic matter or compost is attributed to alleviation of replant disease and to improvements in soil attributes such as fertility (Autio et al., 1991; Granatstein and Dauer, 1999; Neilsen et al., 1994), which is often less than ideal in replanted orchards (Merwin and Stiles, 1989). In addition to nitrogen, preplant incorporated compost can increase the potassium status of apple trees (Moran and Schupp, 2003), and increase tree growth and yield as late as seven years after planting (Moran and Schupp, 2005). Compost addition to soil can address many issues and can be accomplished more rapidly than cover cropping, and does not have the environmental or toxicological problems associated with fumigation, but the high cost of this method has prevented its use on a large scale. Where low cost sources are available, the addition of compost may allow growers to more rapidly replant orchards without the need for fumigation or cover cropping.

Selecting tolerant rootstocks may be the most feasible method for overcoming replant disease (Isutsa and Merwin, 2000; Leinfelder and Merwin, 2006). Several rootstocks in the Geneva series exhibit good tolerance to replant disease compared to M.9 and M.26 (Leinfelder and Merwin, 2006; St. Laurent et al., 2010). However, rootstock evaluation under field conditions requires several years to complete, so ongoing research is needed to more rapidly identify genotypes with superior tolerance of replant conditions.

The objective of this study was to compare preplant soil-incorporated compost, mycorrhizal inoculation at planting and two rootstocks on the long-term growth and yield of 'Honeycrisp' apple trees in a site previously planted to apple trees.

## Materials and Methods

The study was conducted in a site that was previously planted to apple trees with the previous orchard removed in Oct. 2000. The new trees were planted into the old orchard rows. On 28 May 2002, 'Honeycrisp' apple trees were planted into one of four preplant

treatments which were: 1) an untreated control, 2) mycorrhizal inoculation (MI), 3) compost, and 4) compost and MI (compost+MI). Each plot consisted of four trees at a spacing of 1.83 m between trees and 5.50 m between rows. Two of the trees in each plot were grafted to Malling 26 EMLA (M.26) rootstock and the other two to Geneva 16 (G.16) rootstock. Trees on M.26 had a caliper of 1.3 cm and on G.16 a caliper of 1.0 cm. 'Pristine'/Malling 9 trees were planted as a buffer between each plot. The soil was a Paxton very stony fine sandy loam.

The endomycorrhizal inoculant (BioOrganics®, New Hope, PA, USA) contained a minimum of 50 spores per $cm^3$ and several species which were *Glomus brasilianum, G. clarum, G. deserticola, G. intraradices, G. monosporus, G. mosseae*, and *Gigaspora margarita*. The inoculant was mixed according to the product instructions which were to mix 40 mL of inoculant per liter of water to form a slurry and apply as a root dip just prior to planting. For compost treatments, compost was applied and leveled to a uniform thickness of 0.15 m over an area of 1.83 m by 1.83 m for a total of 0.5 $m^3$ of compost per tree (331 kg per tree wet weight; 39% water content; 1.03% total N content or 2 kg of total N per tree). The rate of compost was based on previous research in which a large rate of compost increased bloom and yield of apple trees (Moran and Schupp, 2005). Compost was tilled to a depth of 15 cm until thoroughly incorporated. Compost, purchased from a local supplier, was made from leaf litter, vegetable waste and horse manure at a ratio of 3:1:1 by volume. The compost contained on a dry weight basis: 18.4% total carbon, 1.0 % total N, 0.27 % P, 0.50 % K, 0.9% Ca, 31 $\mu g \cdot g^{-1}$ B, 237 $\mu g \cdot g^{-1}$ Mn, 140 $\mu g \cdot g^{-1}$ Zn, 9030 $\mu g \cdot g^{-1}$ Fe, and 22 $\mu g \cdot g^{-1}$ Cu. The compost had a pH of 7.0, and an electrical conductivity of 2.0 $mS \cdot cm^{-1}$. Electrical conductivity and pH were measured according to the methods of Warncke (1986).

Since trees on each rootstock contained a different number of lateral shoots (feathers), trees were headed at planting to a height of approximately 70 cm above the ground. Trees were subsequently trained as a vertical axe and were attached to a galvanized conduit stake.

Monoammonium phosphate, 11% N and 23% P (9.1 g N and 18.7 g P per tree), was applied at a rate of 62 $kg \cdot ha^{-1}$ 10 May 2002 and was tilled into all treatment plots prior to planting. A soil test prior to planting determined a need for phosphorus. Phosphorus was added to all treatments despite the ability of mycorrhizae to increase P acquisition. Trees were inoculated with MI as an experimental treatment to alleviate replant disease rather than to test P acquisition ability. After planting, control and MI plots were fertilized with urea and ammonium nitrate in the first year at a rate of 5.9 g N per tree since foliar analysis indicated below optimum levels for nonbearing trees (Stiles and Reid, 1991). In May of the fourth year, the control and MI plots were fertilized with urea at a rate of 80 g per tree (36.8 g N), potassium chloride at a rate of 77 g per tree (38 g K) and potassium-magnesium-sulfate at a rate of 204 g per tree (37 g K and 23 g Mg). Compost plots did not receive supplemental fertilization in order to determine the impact of the compost on tree nutritional status. However, in year 5, soil and foliar analysis indicated a steep decline in the level of K, so compost trees were fertilized in subsequent years along with control and MI treatments. In the seventh year, all treatments received potassium-magnesium-sulfate at a rate of 549 g per tree (100 g K and 60 g Mg) and boron at a rate of 2.7 g per tree.

In the fourth year after planting, all trees were hand-thinned to one fruit per cluster after June drop in early July. Beginning in the fifth year, trees were chemically thinned with follow up hand-thinning to one fruit per cluster. Pests and diseases were controlled as needed, and the orchard was not irrigated.

One year prior to planting, one composite soil sample was taken to depth of 15 cm from 10 locations in the orchard. In July of the first six years except year 4, three soil samples were taken to a depth of 15

cm and a distance of approximately 35 cm from the trunk from each control and compost plot. The three samples from each plot were pooled as one sample for analysis. Soil samples were analyzed for organic matter content, K, Ca, Mg and pH in years 1, 2, 3, 5 and 6. Additionally, in years 1, 5 and 6, soil was analyzed for Mn, Zn, Cu and Fe. In year 6, soil from MI plots were analyzed in addition to compost plots. Soils were submitted to the Maine Agricultural and Forest Experiment Station Soil Testing Service for standard soil test analysis (pH 4.8 ammonium acetate extraction, Hoskins, 1997). Soil pH was measured using a 1:1 DI-$H_2O$: dry soil ratio. In late July in years 1 to 8, except in year 6, samples of 25 midshoot leaves were collected from M.26 trees in the control and compost treatments. Trees on G.16 rootstock displayed more severe zonal chlorosis and were not used for foliar analysis for this reason, but samples were collected from G.16 in years 1, 3, 4 and 5. It is unknown if this leaf disorder causes any deleterious effect on the tree (Robinson and Watkins, 2003), and it remains unclear how it influences interpretation of foliar analysis. Leaf analysis was conducted on the MI treatment in years 1, 5, 7 and 8 years after planting. With no initial effect of MI on foliar analysis or tree growth, foliar analysis was not performed on MI treatments in years 2, 3 and 4. Leaves were washed in warm tap water containing mild detergent, rinsed three times in distilled water, and dried at 70°C. Leaves were analyzed for N using a Leco CN-2000 Analyzer, and for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), zinc (Zn), manganese (Mn), copper (Cu) and iron (Fe) by inductively coupled plasma emission spectrometry after dry ashing (Chapman and Pratt, 1961).

In the first three years, the number and length of current season shoots was measured on each tree. Shoots less than 10 cm in length were not included. The total number of flower clusters on each tree was counted in May of years 2 through 5. Beginning in the 4$^{th}$ year, yield was measured as number and weight of fruit per tree. In October of each year, trunk circumference was measured 25 cm above the graft union and used to calculate trunk cross sectional area (TCA).

In the year prior to planting, the replant disease potential of the soil was measured with an apple seedling assay. Soil, collected from several locations within the future planting site, was pasteurized by heating to a temperature of 71°C for one hour. Following cold stratification, seeds were directly germinated in 15 cm pots containing either untreated or pasteurized field soil and grown in a heated greenhouse with a night temperature maintained at 18°C. There were ten pots of each soil with one seedling in each pot. Shoot length was measured 23 days after germination, but shoots subsequently became invaded by thrips so shoot dry weight was not measured.

The experiment was a randomized block design with MI and compost treatments as the main plots and rootstock as the subplot. Location within the orchard site was the method of blocking, and the study had a total of seven blocks. For foliar analysis data collected on M.26 only, analysis of variance of main plots was conducted as a block design with no subplot. Treatments were replicated seven times. Because measurements were taken on the same trees each year, data were analyzed as repeated measures with SAS® software (SAS Institute 2000, Cary, NC) using the MIXED procedure with an autoregressive covariance structure. The Tukey-Kramer least squares test was used for means separation of treatment and rootstock differences within a year. Data for number of flower clusters and TCA, with heterogeneous variances, were log-transformed for analysis. Using the CORR procedure of SAS®, correlations were conducted between foliar nutrients and shoot growth in years 1 and 2, and between foliar nutrients and yield in years 5 and 7.

## Results and Discussion

The greenhouse seedling assay for replant disease indicated a 40% increase in shoot length with soil pasteurization. Shoots in untreated soil grew to a mean length of 5.7 cm after 3 weeks which was significantly less than in pasteurized soil where seedlings grew an average of 8.0 cm.

An impact of MI on soil properties was not anticipated, so soil analysis was conducted on MI treatments in year 5 only. Mycorrhizal inoculation had no effect on soil properties in year 5 (data not shown). Compost had a significant effect on soil pH, K, Ca, and Mg with interactions between compost and year for K, Ca, and Mg. Soil pH fluctuated from year to year, but remained above 6.0 (Fig. 1). Compost increased soil pH but not significantly until year 5. Potassium was increased by compost, but this diminished with time and was not significant in year 5. Calcium was increased by compost and remained greater than in control plots into year 6. Magnesium was increased by compost in years 1, 3, 5 and 6, but not in year 2.

Soil organic matter, P, Zn, Mn, Cu, and Fe were affected by compost in the years in which they were measured, but with an interaction between year and P, Mn and Fe, so the effect on these soil properties was not consistent from year to year (Fig. 2). Organic matter was increased by compost in year 1, but not in years 5 or 6. Compost increased P in year 1, but not in years 5 or 6. Soil Zn and Mn were increased by compost in year 1, but not in years 5 or 6. Compost decreased Cu and this persisted into year 6. An increase in soil pH and high levels of P can reduce copper availability in soil (Havlin et al., 1999), and both these occurred with compost. Iron was similar in both treatments in years 1 and 6, but was lower in compost-amended soil in year 5. Compost increased soil B in year 1 to 1 mg·kg$^{-1}$ compared to 0.8 mg·kg$^{-1}$ in the control plots (data not shown). Soil B was not affected by compost in years 5 (0.5 mg·kg$^{-1}$) or in year 6 (0.4 mg·kg$^{-1}$). Compost increased Na to 91 mg·kg$^{-1}$ compared to 10 mg·kg$^{-1}$ in control plots in year 1 (data not shown). By year 5, Na was similar in both plots and below 20 mg·kg$^{-1}$.

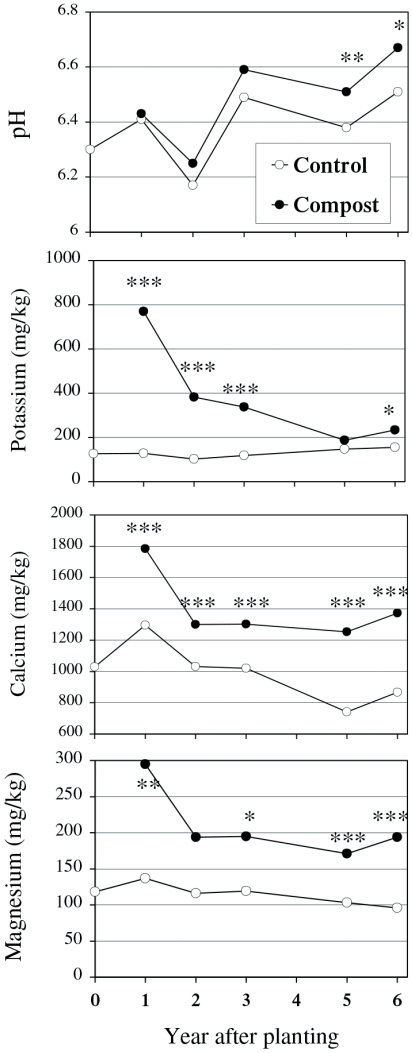


**Fig. 1.** Soil pH, potassium, calcium and magnesium content of compost-amended soil prior to and in subsequent years after planting with 'Honeycrisp' apple trees. *, **, *** indicates significance within a year at P 0.05, 0.01 or 0.001, respectively. Others are nonsignificant.

Leaf nutrient status of trees varied from year to year for every nutrient measured, and

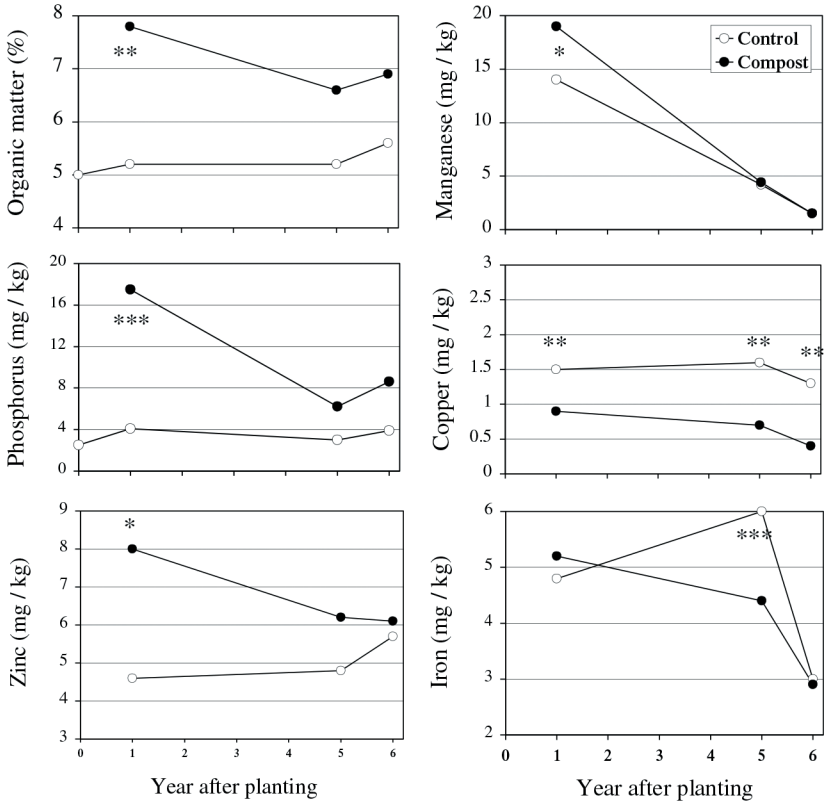


**Fig. 2.** Soil organic matter, phosphorus, zinc, manganese, copper and iron content of compost-amended soil after planting with 'Honeycrisp' apple trees. *, **, *** indicates significance within a year at P 0.05, 0.01 or 0.001, respectively. Others are nonsignificant.

some nutrients were affected by rootstock, compost and MI in some years but not others. The effect of rootstock, measured in years 1, 3, 4 and 5, was significant in some cases. In year 1, foliar nutrients were similar in both rootstocks for each nutrient except B which was lower in G.16 (data not shown). In years 3 to 5, levels of foliar P, Ca and Cu were similar in both rootstocks, but N, Mg, B and Mn were lower in G.16. Level of K was higher in G.16 in year 3, but the same in both rootstocks in years 4 and 5. Levels of Fe and Zn were lower in year 3 in G.16, but similar in both rootstocks in years 4 and 5. Mycorrhizal inoculation at planting increased the foliar level of K from 1.1% in the control to 1.4% with MI treatment and to 1.6% with compost+MI in year 1, but not in years 5, 7 and 8 (data not shown). Foliar analysis of MI treatments was not done in years 2, 3 and 4 since there was minimal effect on foliar analysis and tree growth in years 1 and 2, but was subsequently continued when MI had a consistent effect on tree growth after year 2. The effect on K in year 1 was attributed to the root dip materials rather than to MI. Mycorrhizal inoculation increased foliar Zn in year 5 from 14 to 17 mg·kg$^{-1}$ in G.16 rootstock, but levels of Zn were similar in the two treatments with M.26. In year 7, foliar

Cu was increased from 7 to 8 mg·kg$^{-1}$ by MI. Mycorrhizal inoculation otherwise had no effect on foliar nutrients. The main effect of compost was significant for P, K, and B, and interactions between year and compost were significant for N, P, K, Ca and Fe. Trees planted in compost-amended soil had greater leaf N in year 2, less N in year 4, and a similar level to the control in other years (Table 1). Leaf P was increased by compost in years 2 through 5, but not years 1, 7 or 8. Leaf K was increased by compost in years 1, 2 and 3, but not in other years. Leaf Ca in control trees was relatively unchanged from year to year in contrast to compost trees which fluctuated from year to year. Compost trees had lower leaf Ca in years 1 and 3 and higher leaf Ca in year 5 compared to control trees. Leaf Mg was lower in compost trees in year 3, but similar to control trees in other years. Compost decreased leaf B in years 2, 3 and 5, but B was similar to the control in other years. Leaf Fe was increased by compost in year 2 and decreased in year 4, but similar to the control in other years. Leaf Mn was lower than the control in year 4 and similar in other years. Leaf Cu and Zn were not affected by compost.

**Table 1.** Leaf nutrient concentration on a dry weight basis of 'Honeycrisp'/M.26 apple trees in the eight[z] years following planting in compost-amended soil.

| | Nutrient concentration (g·kg$^{-1}$) | | | | | Micronutrient concentration (mg·kg$^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | N | P | K | Ca | Mg | B | Fe | Mn | Cu | Zn |
| *Year 1* | | | | | | | | | | |
| None | 0.232[y] | 0.014 | 0.11 b | 0.084 a | 0.037 | 26 | 70 | 119 | 10 | 27 |
| Compost | 0.228 | 0.014 | 0.13 a | 0.073 b | 0.033 | 26 | 69 | 124 | 11 | 24 |
| *Year 2* | | | | | | | | | | |
| None | 0.203 b | 0.018 b | 0.14 b | 0.086 | 0.022 | 37 a | 66 b | 47 | 17 | 21 |
| Compost | 0.249 a | 0.031 a | 0.21 a | 0.086 | 0.021 | 34 b | 76 a | 52 | 16 | 23 |
| *Year 3* | | | | | | | | | | |
| None | 0.252 | 0.017 b | 0.14 b | 0.082 a | 0.028 a | 34 a | 60 | 38 | 19 | 29 |
| Compost | 0.265 | 0.021 a | 0.19 a | 0.069 b | 0.023 b | 30 b | 64 | 32 | 18 | 28 |
| *Year 4* | | | | | | | | | | |
| None | 0.255 a | 0.016 b | 0.19 | 0.083 | 0.021 | 39 | 55 a | 47 a | 13 | 25 |
| Compost | 0.219 b | 0.024 a | 0.19 | 0.081 | 0.023 | 39 | 48 b | 29 b | 13 | 20 |
| *Year 5* | | | | | | | | | | |
| None | 0.222 | 0.020 b | 0.16 | 0.081 b | 0.025 | 49 a | 44 a | 45 | 6 | 14 |
| Compost | 0.221 | 0.024 a | 0.16 | 0.095 a | 0.025 | 44 b | 40 b | 32 | 6 | 14 |
| *Year 7* | | | | | | | | | | |
| None | 0.246 | 0.017 | 0.15 | 0.081 | 0.025 | 29 | 48 | 32 | 7 | 11 |
| Compost | 0.259 | 0.018 | 0.14 | 0.086 | 0.025 | 28 | 47 | 31 | 7 | 12 |
| *Year 8* | | | | | | | | | | |
| None | 0.23 | 0.016 | 0.13 | 0.090 | 0.026 | 29 | 41 | 29 | 3 | 16 |
| Compost | 0.25 | 0.017 | 0.15 | 0.098 | 0.027 | 26 | 42 | 33 | 3 | 14 |

[z] Foliar analysis was not conducted in year 6.

[y] Within year and column, means followed by the same letter are not significantly different at P = 0.05 level. Where no letters are indicated, treatment effect was not significantly different.

**Table 2.** Annual shoot growth and flowering of 'Honeycrisp' apple trees on two rootstocks and following planting in compost-amended (C) soil or mycorrhizal inoculation (MI) at planting.

| | | Annual shoot growth (cm/tree) | | | Flower clusters (number per tree) | |
|---|---|---|---|---|---|---|
| Rootstock | Treatment | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
| G.16 | Control | 83[z] b | 158 bc | 144 bc | 1[y] cd | 117 ab |
| | MI | 84 ab | 140 c | 188 a | 4 bc | 176 a |
| | C | 52 b | 213 a | 173 ab | 41 a | 21 bc |
| | C + MI | 48 b | 175 bc | 145 bc | 22 ab | 11 c |
| M.26 | Control | 112 a | 136 c | 150 abc | 0 d | 34 bc |
| | MI | 123 a | 142 c | 159 abc | 1 cd | 79 ab |
| | C | 87 ab | 189 ab | 124 c | 20 abc | 21 bc |
| | C + MI | 84 ab | 163 bc | 120 c | 9 bcd | 9 c |

[z] Means separation by LSMEANS, 5% level of significance. Means followed by the same letter are not significantly different.
[y] Data for number of flower clusters were log-transformed for analysis, but actual means are presented.

The main treatments of rootstock, compost and MI did not affect shoot growth (Table 2). However, there was a significant interaction between year, rootstock and compost, and a marginally significant interaction of MI and compost for shoot growth. M.26 trees had more shoot growth than G.16 in year 1, but not in subsequent years. In year 3, G.16 had greater shoot growth than M.26 with the compost treatment. Compost did not significantly affect shoot growth in year 1, but increased shoot growth in year 2, except when combined with MI. In year 3, compost had no effect on shoot growth. MI did not affect shoot growth in years 1 or 2, but increased it in year 3 in G.16 trees, but not M.26.

There were significant interactions between compost, MI and year for their effect on the number of flower clusters per tree. The trees did not bear flowers until year 3 when bloom was very sparse in all treatments. In year 4, compost increased the number of flower clusters in both rootstocks,

**Table 3.** Trunk cross-sectional area (TCA; $cm^2$) at 25 cm above the graft union in October of each year of 'Honeycrisp' apple trees on two rootstocks and following planting in compost-amended (C) soil or mycorrhizal inoculation (MI) at planting.

| Rootstock | Treatment | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| G.16 | Control | 0.8[z] b | 1.4 bc | 3.0 b | 6.3 ab | 8.8 b | 12.7 | 16.4 bc | 21.7 b | 25.2 b |
| | MI | 0.8 b | 1.3 bc | 3.3 ab | 7.5 a | 10.2 ab | 13.7 | 17.3 abc | 23.9 ab | 27.2 b |
| | C | 0.8 b | 1.5 b | 3.6 a | 7.4 a | 11.0 a | 13.3 | 18.8 ab | 23.6 b | 29.1 ab |
| | C + MI | 0.7 b | 1.2 c | 3.1 b | 6.2 b | 10.0 ab | 12.9 | 18.3 abc | 23.7 b | 28.9 ab |
| M.26 | Control | 1.5 a | 2.0 a | 3.0 b | 5.1 c | 7.0 c | 12.1 | 15.9 c | 21.8 b | 26.2 b |
| | MI | 1.6 a | 2.2 a | 3.6 a | 7.0 a | 10.4 ab | 14.2 | 21.4 a | 29.6 a | 35.1 a |
| | C | 1.5 a | 2.2 a | 3.6 a | 6.0 b | 9.3 ab | 13.0 | 17.7 abc | 22.3 b | 26.5 b |
| | C + MI | 1.5 a | 2.1 a | 3.5 a | 5.7 bc | 8.9 b | 12.8 | 17.5 abc | 22.4 b | 27.7 b |
| | | | | | | | NS | | | |

[z] TCA data were log-transformed for analysis, but actual means are presented. Means separation by LSMEANS, 5% level of significance. Means followed by the same letter are not significantly different. NS indicates nonsignificance.

but not in M.26 rootstock when compost was combined with MI. In year 5, compost did not increase bloom. In year 5, there was a trend for a greater amount of bloom in MI trees, but this was not significant.

The main effects of year, rootstock and MI affected trunk girth (Table 3). A significant interaction occurred between rootstock and MI, and between MI and compost. M.26 had greater TCA than G.16 at planting (data not shown) and in October of years 1 and 2. By year 3, both rootstocks had similar TCA. Mycorrhizal inoculation did not affect TCA of G.16 in any year when compared to the untreated control. Compost increased TCA of G.16 in years 3 and 5, but not when combined with MI, and in year 4 this combined treatment reduced TCA compared to compost alone. In years 3, 4, 5, 7, 8 and 9, MI increased TCA of M.26. Compost increased TCA of M.26 in years 3, 4, and 5, and when combined with MI, increased TCA in years 3 and 5, but not in year 4.

The main effects of rootstock, compost and MI did not significantly affect annual yield but interactions between year, compost and rootstock were significant (Table 4). Trees began bearing fruit in year 4 and were still increasing in production in year 9. Trees in this study were slow to begin bearing fruit and did not have an appreciable amount of bloom until year 4, and this delay in bearing was due in part to pruning at planting. Yield was not affected by MI until year 8 in G.16 when it was reduced compared to the control. Mycorrhizal inoculation increased yield of M.26 in year 9, but had no effect in other years. Compost and compost+MI increased yield in years 6 and 8 in both rootstocks. Compost and compost+MI trees on G.16 had reduced yield in years 7 and 9 compared to the control trees. Compost and compost+MI trees on M.26 rootstock had reduced yield in year 9. Cumulative yield from years 4 through 9 was not affected by rootstock, compost or MI.

Total annual shoot growth in year 1 was negatively correlated with foliar P (r = -0.40), K (r = -0.31) and Mg (r = -0.33), but not with other nutrients. In year 2, shoot growth was positively correlated with foliar N (r = 0.50) and K (r = 0.57), but negatively correlated with B (r = 0.42). Shoot growth in year 3 and yield in year 4 were not correlated with foliar nutrients. Yield in year 5 was positively correlated with foliar Ca (r = 0.49), but negatively correlated with foliar K (r = -0.54) and B (r = -0.72). In year 7, yield

**Table 4.** Annual and cumulative yield of 'Honeycrisp' apple trees on two rootstocks and following planting in compost-amended (C) soil or mycorrhizal inoculation (MI) at planting.

| | | Yield (kg per tree) | | | | | | Cumulative yield |
|---|---|---|---|---|---|---|---|---|
| Rootstock | Treatment | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | (kg per tree) |
| G.16 | Control | 0.1[z] | 2.5 | 1.4 c | 13.2 a | 17.2 cd | 46.1 ab | 83.2 |
| | MI | 0.1 | 4.2 | 0.8 c | 16.1 a | 9.3 e | 46.1 ab | 76.6 |
| | C | 1.2 | 1.6 | 12.9 a | 2.4 c | 32.5 a | 25.5 c | 76.2 |
| | C + MI | 0.3 | 1.5 | 10.6 a | 2.6 bc | 30.0 a | 22.8 c | 67.8 |
| M.26 | Control | 0.0 | 0.6 | 0.2 c | 8.6 b | 14.6 de | 41.9 b | 65.9 |
| | MI | 0.0 | 1.3 | 1.7 bc | 12.3 ab | 19.6 cd | 51.2 a | 86.0 |
| | C | 0.2 | 2.3 | 7.9 ab | 10.3 b | 22.1 c | 28.8 c | 71.6 |
| | C + MI | 0.2 | 0.8 | 8.0 ab | 6.1 bc | 23.8 bc | 29.0 c | 67.8 |
| | | NS | NS | | | | | NS |

[z] Means separation by LSMEANS, 5% level of significance. Means followed by the same letter are not significantly different. NS indicates nonsignificance.

was positively correlated with foliar Ca (r = 0.48) and Mg (r = 0.47). In year 8, yield was positively correlated with foliar K (r = 0.51).

The increase in tree growth with compost can be attributed to increased leaf N and K in year 2. However, in year 1, tree growth was slightly reduced by compost application. The large amount of compost and short interval of time between soil incorporation of compost and tree planting could have resulted in high salinity. Soil K was substantially increased by compost and was high enough to create an imbalance with soil Ca resulting in a reduction in leaf Ca in year 1. The reason for an association of higher yield with lower levels of foliar K in year 5 is not clear since foliar levels of K were no longer different due to compost. The negative correlation between yield and B and positive correlation with Ca in year 5 could be due to levels of B being within the optimum to high (35 to 55 $mg \cdot kg^{-1}$) range for apple, whereas foliar levels of Ca were low to deficient (0.7 to 1.2 $mg \cdot kg^{-1}$) (Stiles and Reid, 1991). After year 5, foliar levels of B fell below the optimum range and levels of foliar Ca remained below optimum in all treatments. Addition of compost to soil improves apple tree growth and yield when a significant impact on nutrition occurs (Moran and Schupp, 2003). Increase in tree growth is somewhat related to the amount of compost added (Granatstein and Dauer, 1999), and the large amount of compost used in this study may account for the greater impact on tree growth compared to previous studies (Autio et al., 1991; Leinfelder and Merwin, 2006). Few strong correlations occurred between shoot growth, yield and levels of nutrients. This lack of correlation does not imply that these nutrients had no effect, but rather, that their variation within this one site was too narrow for a significant effect.

The addition of organic matter or MI was found to increase tree growth and yield, but these effects were inconsistent between the two rootstocks and confounded by biennial bearing with G.16 rootstock. Compost increased yield in some years, but because of biennial bearing, cumulative yield after nine years was not greater with compost since yield was decreased in this treatment in "off" years. However, trees planted in compost-amended soil were more precocious than control trees, and produced substantially more flower clusters in year 4. MI trees were similar in precocity to control trees.

A seedling bioassay indicated mild replant disease as defined by less than a 50% increase in shoot growth in pasteurized soil (Gilles and Bal, 1988; Merwin et al., 2001). Previous research shows that a seedling bioassay can over predict tree response to soil disinfestation with fumigants since the effect of fumigants under field conditions can be overshadowed by other limiting factors such as soil fertility (Merwin et al., 2001). The effect of compost in this study was more likely due to improvements in soil fertility and tree nutrition rather than counteracting the effects of replant disease.

Mycorrhizal inoculation increased growth and yield, but the effect was inconsistent between the two rootstocks and from year to year. Improvement in nutrition is one of the benefits of mycorrhizae (Benson and Covey, 1976; Covey et al., 1981; Gilmore, 1971), but the small and temporary increase in zinc and copper with MI in our study were the only changes in nutritional status that occurred with MI. However, preplant fertilization with P may have negated any impact on P status with MI. The increase in growth that occurred with compost was reduced when compost was combined with MI, particularly with G.16 rootstock. The reason for this cannot be determined from the data collected in this study. However, compost raised soil P and this may have interacted with mycorrhizal symbiosis (Gnekow and Marschner, 1989). In addition, differences in root growth were observed when a small subset of whole trees were dug up in year 4. The roots of G.16 trees were finer and more numerous compared to M.26, and this may have resulted in the different response to the preplant treatments.

An increase in tree growth with MI under natural conditions is consistent with previous findings where preplant inoculation increased growth of apple seedlings in unsterilized soil (Plenchette et al. 1981). Mycorrhizal species vary in how they impact the growth of apple trees (Benson and Covey, 1976; Geddeda et al., 1984; Miller, 1983; Reich, 1988; Ridgway et al., 2008), but this has not been studied under field conditions, but may be why artificial inoculation can in some cases improve tree growth. Root infection was not measured in this study, but previous research indicates that inoculation increases root infection and tree growth in unsterilized soil with replant disease (Catska, 1994; Kandula et al., 2006; Ridgway et al., 2008). The soil in this study did not have a severe replant problem, and this may be why the impact on tree growth was small. Other benefits of mycorrhizae may also have contributed to the increase in tree growth and yield such as and improved water relations (Augé, 2001; Runjin, 1989), but these were not measured.

Selection of rootstock is another method of improving tree growth in replant sites. In this study, G.16 had greater shoot growth in year 3 and was more precocious than M.26, but this did not result in greater yield. Replant tolerance of G.16 at the beginning of this experiment was not known, but other Geneva rootstocks have since shown better tolerance. Planting tolerant rootstocks may be a more cost effective choice than compost addition for sites with replant disease (Leinfelder and Merwin, 2006).

Compost amended soil increased yield, but this was offset by biennial bearing. Compost was an expensive method for improving tree growth and yield, but may be more useful where low-cost sources are available or when other alternatives are not allowed. Mycorrhizal inoculation increased tree growth and yield, but not as early or as much as compost, but was not as costly. These results indicate that compost or MI can be used to improve tree growth in orchards that are rapidly replanted to apple trees.

**Acknowledgements**

The author acknowledges the generous assistance of Susan Erich and laboratory staff in conducting soil tests. This research was supported by the University of Maine Agricultural and Forest Experiment Station, publication number 3348.

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