
George A. Cummings
Department of Soil Science, North Carolina State University, Raleigh, NC 27650

Abstract. Effects of soil pH, tillage practices, P application, and the addition of clay at the planting site on tree size, fruit yield, fruit size, and tree longevity of peaches [Prunus persica (L.) Batsch] for 20 growing seasons are reported. Because of widespread tree death, ‘Loring’ trees were removed after 9 years and the orchard replanted to ‘Wimbo’. Soil pH below 5.6 resulted in poor tree growth, low fruit yield, and small fruit size compared to trees grown in soils at higher pH. In the final 10 years of the experiment, marked improvement in tree size, fruit yield, fruit size, and longevity were evident as soil pH increased. The effect of 3 tillage practices—normal plow to a depth of 20 cm, normal plow to a depth of 20 cm plus a 75-cm-diameter × 122-cm-deep hole at the planting site, and deep plowing to a depth of 58 cm—varied with cultivar. Both methods of soil modification (which penetrated the A₂ horizon) resulted in increased yield and tree size compared to normal plowing to 20 cm with ‘Loring’ during the first 9 years. During the final 10 years, fruit yield was lower and tree death greater in the deep-plow plots, but there were no differences in fruit yield, tree size, or tree longevity between the other tillage treatments. Phosphorus rates (0, 15, and 30 kg/ha annually) or clay additions did not influence tree size, fruit yield, or tree survival. Results of this study lend strong support for the maintenance of soil pH above 5.6 and good evidence that increase in tree growth, fruit yield, and tree longevity is further enhanced when soil pH is maintained above 6.0.

In the southeastern United States, peach tree short life (PTSL) is one of the primary limitations to profitable peach production. The solution of the PTSL problem has been an objective of numerous studies. Application of practices found to be beneficial in past studies has extended tree life, but has not solved the problem.

Raising the pH of acid soils is a beneficial practice. The reason for the benefit and the critical pH associated with harmful effects is not understood clearly. The reported effects of lime varied from the conclusive work of Auchter and Schrader (1) to a marked effect reported by Shaw (13). Rawl (11) reported that N, P, and K alone were not sufficient for optimum peach production and later reported a favorable response to lime application (12). Later work showed that lime application to the soil surface resulted in increased fruit yields (3). Perkins et al. (9) reported that lime incorporated to a depth of 35–40 cm exerted a greater influence on tree survival and fruit yield than when incorporated to a depth of 15–20 cm.

In acid soils of humid regions, the use of ammonium N sources contributes greatly to soil acidity and increases the need for liming. Low soil pH and foliar Mn toxicity symptoms induced by continued use of ammonium sulfate as an N source were alleviated by lime application (8). Under greenhouse conditions, Prince et al. (10) obtained a growth response with low rates of dolomite. Havis (5) also obtained growth responses from both dolomite and calcite.

Studies of physical modification of the soil profile prior to planting include the use of explosives at the tree site (7) and tillage to a depth of 40 cm (9) with or without lime. Both studies reported beneficial responses, although Perkins et al. (9) reported that deep tillage without lime was not beneficial. Soil modification by subsoiling between rows of one-year-old trees (6) proved beneficial to tree survival and fruit yield, but response varied with the use of herbicides and soil fumigation.

Responses to P have not been obtained unless soil P was extremely low (14). However, in acid soils, P may react with Al and render it insoluble. There is conclusive evidence that Al restricts the growth of peach roots (4). Aluminum in the soil solution is low at pH 5.5, but solubility increases rapidly as pH is lowered from that value (2). If soluble Al is related to poor performance of peach trees grown on sandy soils, then it would be logical to test whether P rates would diminish the harmful effects of Al. There are no reports concerning effects of adding clay to sandy soils.

In this study the long-term effects (20 years) of tillage methods, pH levels, clay addition, and P rates on tree growth, fruit yield and size, and tree longevity are reported.

Materials and Methods

An experiment was initiated in January 1962 at the Sandhills Research Station, Jackson Springs, N.C. on a Candor sandy soil (Aeric Paleudult, sandy, siliceous, thermic). Analytical values of samples obtained prior to imposing treatments and 19 years later from plots plowed to 58-cm depth are shown in Table 1. Mechanical analysis of the soil, 0- to 20-cm depth, indicated a content of 88% sand, 4% silt, and 8% clay; mineralogical analysis of the clay indicated the dominance of kaolinite. Variables included: 1) 3 types of soil modification prior to planting (normal plow to a depth of 20 cm, deep plow to a depth of 38 cm, and normal plow plus a 75-cm-diameter × 122-cm-deep hole bored at the planting site); 2) three P rates (0, 45, and 90 g/tree [0, 15, and 30 kg/ha]) applied annually except in the deep-plow treatments where all P to be applied for the expected life of the orchard was applied prior to plowing; 3) 3 soil pH levels (5.2–5.8, 5.6–6.2, and above 6.0); and 4) 2 rates of clay addition (none and 2.5 hl applied in a 1 × 2 m horizontal layer 15-cm deep at each tree site). Dolomitic lime and P were applied in...
Table 1. Soil analytical values of samples taken prior to treatment application and 19 years later.

<table>
<thead>
<tr>
<th>Date sampled</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>meq 100 g Ca</th>
<th>Mg</th>
<th>K</th>
<th>CEC (ppm)</th>
<th>P (%)</th>
<th>Organic matter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. 3, 1961</td>
<td>0-20</td>
<td>5.6</td>
<td>2.00</td>
<td>0.58</td>
<td>0.11</td>
<td>3.20</td>
<td>32</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>20-35</td>
<td>5.1</td>
<td>0.12</td>
<td>0.04</td>
<td>0.04</td>
<td>0.43</td>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>35-50</td>
<td>4.9</td>
<td>0.05</td>
<td>0.01</td>
<td>0.04</td>
<td>0.45</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>50-65</td>
<td>4.8</td>
<td>0.01</td>
<td>0.02</td>
<td>0.04</td>
<td>0.46</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Nov. 4, 1980</td>
<td>0-20</td>
<td>6.2</td>
<td>1.45</td>
<td>0.42</td>
<td>0.09</td>
<td>2.05</td>
<td>55</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>20-35</td>
<td>5.7</td>
<td>0.60</td>
<td>0.18</td>
<td>0.07</td>
<td>0.95</td>
<td>62</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>35-50</td>
<td>5.4</td>
<td>0.46</td>
<td>0.13</td>
<td>0.06</td>
<td>0.90</td>
<td>61</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Values for 1961 are means of 10 random samples taken over entire field. Values for 1980 are means of deep-plowed, high-pH, high-P plots.

The deep-plow plots and disced to a depth of 15 cm prior to plowing. Rates of lime application (0, 2240, and 4480 kg/ha) were calculated to raise pH to the same range desired in the surface soil. Rates of P application (0, 300, and 600 kg/ha) equaled the total amount of P to be applied in the other tillage plots for a 20-year period, the expected duration of the study. Treatments were arranged in 2-tree plots with soil modification treatments as main plots, lime treatments as subplots, and P and clay treatments randomized within lime treatments, with all replicated 3 times for a total of 324 experimental observations. Main plots and subplots—but not P or clay treatments—were separated by guard trees. Soil pH in the 0- to 20-cm depth was checked annually and adjusted by broadcast application of dolomitic lime over the entire area of each lime main plot.

Loring' trees (rootstock unknown) were planted in February 1962 on a 5.5 x 5.5 m spacing. In Summer 1971, trees were removed because of severe tree losses. The orchard was plowed to a 20-cm depth and fumigated with 1,2-dibromo-3-chloropropane (DBCP) in October 1971, and replanted without further soil preparation in February 1972 ('Winblo' on Lovell seedling rootstock). Fertilization with N and K was 360 g/tree of each annually, except during the first 3 years of establishment, when ¼, ½, and ¾ of that amount were applied respectively. From 1962 through 1970, lime was applied when soil pH declined below the midpoint of each pH range (5.4, 5.8, and 6.2). Since differences in the effect of the 2 upper pH ranges were small during the first 9 years, lime was applied from 1971 through 1981 when soil pH declined to the lower limit of each pH range (5.2, 5.6, and 6.0). Routine measurements taken annually include diameter at 25 cm above soil level, bloom date, yield per tree, fruit size, and soil pH.

Statistical analysis of the data each year indicated significant interactions on fruit yield in the early years of the study between tillage practice and soil pH level. However, since there were no significant interactions for total yield over all years, tree diameters in 1971 or 1981, or tree longevity, these data are not presented.

Results and Discussion

Tree growth as measured by trunk diameter was enhanced for both cultivars as soil pH level increased (Fig. 1). Growth rate was lower for 'Winblo' than for 'Loring' at all soil pH levels. With both cultivars, trunk size in the lowest soil pH range was consistently lower than the highest pH range and in most years lower than in the medium pH range. During the last 10 years of the study, trunk size at the highest pH range was consistently greater than trunk size at the medium pH range, but tree-size differences were much less between these two ranges during the first 9 years.

Spring frost resulted in total crop loss in 1976 and reduced yield on all trees in 1967, 1977, 1978, and 1980. Even in years of reduced yield, the favorable effect of increased soil pH was evident (Fig. 2 and 3). However, effect of pH on yield was much greater in the later years of the study. Yield did not differ between the 2 highest pH levels with 'Loring' in the first portion of the study, but marked differences occurred among 3 pH levels with 'Winblo' during the final 5 years.

The effect of low soil pH on tree survival was evident with both cultivars (Fig. 4). At the 2 higher pH levels only small
Fig. 3. Main effects of soil pH on yield per tree of 'Winblo' peach.

differences were noted with 'Loring' (1970–1971), until the final 2 years, but differences among the 3 pH levels were evident with 'Winblo' (1975–1981).

The adverse effects of low soil pH on yield were accentuated when total production per area was calculated (Fig. 5). The harmful effect of low soil pH was striking with both cultivars, but only with 'Winblo' were differences evident between the 2 higher pH ranges. Fruit size in all years after 1967 was largest at the highest pH range (Fig. 6). This occurred even in years when fruit load on all trees was reduced by spring frost.

Results of deep-tillage treatments on tree performance were not conclusive (Table 2). With 'Loring', either deep plowing or boring a large hole at the planting site increased trunk size and yield but not the number of living trees in 1971. With 'Winblo', deep plowing did not influence trunk size but it was associated with lower yields and greater tree death compared to the other tillage practices.

The addition of clay at the tree site, prior to establishment in 1962, tended to increase yield and longevity during the experimental period. Yields for 'Loring' were 57.8 MT/ha without clay and 61.4 MT/ha with clay, comparable yields for 'Winblo'

Table 2. Effect of physical modification of the soil profile on tree growth, yield, and longevity of peach cultivars Loring (9 years) and Winblo (10 years).

<table>
<thead>
<tr>
<th>Soil treatment</th>
<th>Trunk diameter (cm)</th>
<th>Yield (MT/ha)</th>
<th>Living trees/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loring</td>
<td>Winblo</td>
<td>Loring</td>
</tr>
<tr>
<td>Normal plow</td>
<td>14.8</td>
<td>11.3</td>
<td>51.0</td>
</tr>
<tr>
<td>Normal plow + hole</td>
<td>16.4</td>
<td>10.9</td>
<td>64.8</td>
</tr>
<tr>
<td>Deep plow</td>
<td>16.6</td>
<td>11.2</td>
<td>63.6</td>
</tr>
<tr>
<td>LSD 5 %</td>
<td>0.52</td>
<td>NS</td>
<td>5.4</td>
</tr>
</tbody>
</table>
were 40 and 43.5 Mt/ha, respectively. Application of P was not related to tree growth, fruit yield, or tree longevity.

The primary objective of this study was to determine the effect of applied variables on fruit yield and tree longevity. Under the conditions of this experiment, pH below 5.6 in the top 20 cm of soil reduced fruit yield and was associated with increased tree death compared to higher soil pH levels. Further, results from the later years of this study indicate the long-term desirability of maintaining soil pH above 6 compared to the 2 lower pH ranges. It should be noted that prior to 1971, soil pH was adjusted when it dropped below midpoint of the range, but after 1971 it was adjusted when pH dropped to the lower limit. This may account for lack of differences in the parameters measured between the 2 upper pH ranges during the first 9 years of the experimental period, while differences were marked during the final 10 years. It is probable that all plots in the middle pH range remained above pH 5.5 during the first, but not the 2nd, part of the study. This pH (5.5) is the point at which Al becomes soluble in the soil solution (2). Lime application was associated with decreased tree death in the early years of the experiment, but did not prevent widespread tree loss during the final year with ‘Loring’.

Since soil pH was related to increased tree size, it might be plausible to attribute increased fruit size to the larger tree size. However, the increased fruit size associated with soil pH was evident in years of light as well as heavy fruit load. This suggests that increased soil pH exerted an effect upon fruit size in addition to that related to increased tree growth.

Most of the coastal-plain soils in the peach-producing areas of the southeastern United States are characterized by a compact A2 horizon that is low in pH, organic matter, exchangeable bases, cation exchange, and water-holding capacity. The objective of physical modification of the soil was to alter the soil profile, thus increasing root proliferation and the soil volume explored by roots. Excavation of guard trees to a 122-cm depth in 1971 at the conclusion of the ‘Loring’ experiment showed clearly that increased root proliferation occurred where tillage penetrated the A2 horizon (25–35 cm). Either method of deep tillage increased trunk size and yield of ‘Loring’ during the first 9 years but not of ‘Winblo’ during the final 10 years. Deep plowing was detrimental to fruit yield and tree life with ‘Winblo’ (Table 2), and local modification by boring holes did not increase tree livability or yield compared to normal plowing. One adverse effect observed in sites with holes when trees were excavated in 1971 was that many roots appeared to be confined to the area originally excavated. Thus, the advisability of using either method that alters the soil profile below the normal plow depth is questionable. The experiment will be continued to determine differences of survival between the 2 higher pH ranges and of survival and yield differences between normal plow and normal plow plus the hole at the planting site.

The slow tree growth rate noted with ‘Winblo’ during the last 10 years, compared with ‘Loring’ during the first 9 years, may be related to the poor performance often observed when peaches are replanted on the same site. However, ‘Winblo’ was on Lovell rootstock which has been observed to result in less growth than some other rootstocks. In another experiment on the same soil type, ‘Loring’ growth rate has exceeded that of ‘Redhaven’ when both are on the same rootstock (D. Ritchie, personal communication).

This study was not designed to detect the reason for the harmful effects of soil acidity. However, P was included as a variable primarily to detect if the detrimental effect of high soluble Al resulting from low pH could be alleviated by reaction with P. No effect of P application upon tree performance was obtained, nor were significant interactions present.

Soil analysis values from samples taken after 19 years (Table 1) indicate a substantial effect of deep plowing on pH, organic matter, and mineral nutrients below the 20-cm depth. In contrast, values below the 0- to 20-cm depth in the other 2 tillage practices were similar to those obtained prior to the initiation of the experiment (data not shown). Yet, yield was lower and tree death higher in the deeply plowed treatment with ‘Winblo’, indicating that the increased soil fertility in the deeply plowed plots after 19 years did not increase yield or prolong tree life.

Data from this study present substantial evidence that soil pH below 5.6 severely limits tree growth, fruit yield/tree, fruit size, and years of productive tree life. With ‘Loring’ at the end of the first 9 years, soil pH above pH 5.6 did not prevent widespread tree loss. Yet, with both cultivars, the increased yield per tree and lower tree loss associated with increasing soil pH during the productive years of the orchard provides for a substantial increase in total fruit produced.

Literature Cited