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Effects of Long-Term Fertilizer and Management Practices on Growth and Yield of Pears Grown in a Clay Adobe Soil

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M. N. Westwood, E. S. Degman, and J. H. Grim

INTRODUCTION

Any consideration of the effects of pruning, soil moisture, soil management, or fertilizer practice on growth and fruiting of orchard trees must ultimately be concerned with the various interactions of all these factors, because a change in any one factor can alter the tree's response to the other factors.

In addition to the cultural variables mentioned above, tree performance is also related to soil type, climate, rootstock, species, and even variety within a species. These variables not only interact with each other, but with the cultural variables as well.

Obviously, it would be difficult to examine all nine of the variables listed above in a single experiment. A minimum of two levels of each variable would be needed and each treatment would have to be replicated several times. A single replicate of such a test designed as a factorial (to combine each variable in all possible combinations with each other variable) would require 512 treatment plots. Orchard tests of this scope could not be carried out with the facilities and personnel available.

To obtain a more complete understanding of the importance of some of these variables to fruit production, a number of smaller tests were conducted between 1942 and 1963 at the Southern Oregon Experiment Station at Medford. Only one soil type (Meyer clay adobe) was used, and pear (*Pyrus communis*) was the only species tested. The three varieties—Anjou, Bartlett, and Bosc—were examined with respect to different levels of pruning, nitrogen fertilizer, and to different kinds of culture (i.e., sod, cover cropping, mulching, and cultivation). Effects of the treatment on tree growth, fruit set, fruit size, and yield were determined along with changes in soil moisture, pH, and nitrate content as related to treatment.

REVIEW OF LITERATURE

Soil moisture

Much work has been done to determine the best irrigation practice for pear trees growing in clayey soils (*4, 6, 7, 8, 10, 15, 22, 27, 38*). Aldrich and Work (*7*), Aldrich, *et al.* (*6, 10*), and Degman (*15*) all reported that the growth rate of pear fruits was reduced if the available soil moisture in clayey soil fell below 50% (based on P.W.P. = 17 and F.C. = 32%).[1] Lewis, *et al.* (*27*) found that 70% available moisture was needed in Meyer clay adobe soil for maximum growth of Anjou pear fruits at Medford, Oregon. On the other hand, Hendrickson and Veihmeyer (*22*) reported that Bartlett pear showed no reduction in growth until the permanent wilting percentage was reached in the upper 4 feet of a clayey soil in California. The report by Work (*38*), however, leaves little doubt that pear trees in clay adobe soils in Medford are unable to utilize fully the moisture in the lower half of the available range. Furthermore, he pointed out that during periods when evaporation was high, fruit growth could be increased by irrigation, even though the available moisture was well above 50%.

Soil suction at the root must be lower than the suction tension (DPD) of the plant in order for water to be taken up. At low rates of uptake, the suction of the soil at wilting is very nearly equal to the suction in the plant, but for high uptake rates, large differences between the two are possible (Gardner *19*). He further showed that, in Chino clay soil, the wilting point varied from 16 to 23% soil moisture, depending upon the transpiration rate. Thus, both water content and soil suction at wilting are influenced by dynamic factors. In the case reported by Work (*38*), apparently the root density and the capillary conductivity were not high enough to meet the transpiration demands and still permit optimum fruit growth. In a recent study of factors affecting foliage efficiency of apple trees, Westwood, *et al.* (*36*) showed that Golden Delicious fruits were 24% smaller when grown under sub-optimal as compared to ample soil moisture. At no time during the growing season, however, was there any visible wilting on trees in the sub-optimal moisture plot.

In regard to relatively coarse textured soils, Hendrickson and Veihmeyer (*21, 23*) and Veihmeyer (*33*) reported no reduction in tree or fruit growth until soil moisture was reduced to just above the permanent wilting percentage. Also, Allmendinger, *et al.* (*11*)

[1] Permanent wilting percentage (P.W.P.) is the percentage of moisture at which the plant wilts and will not recover when placed in a saturated atmosphere. Field capacity (F.C.) is the percentage of moisture retained against gravity in a saturated soil.

found that apples grown in a mixed soil consisting of equal parts of field soil, sand, and peat were not affected until four-fifths of the available moisture was used up. In contrast, however, Furr and Degman (*16*), Furr and Magness (*17*), Taylor and Furr (*32*), and Furr and Taylor (*18*), working in coarse and medium-textured soils, found that under certain conditions tree and fruit growth were reduced before the permanent wilting percentage was approached. In some cases (*12, 18*) this could be explained by the fact that some areas of the root zone were drier than others, and the roots in moist soil were not able to supply the needs of the whole tree. It was pointed out (*34*) that in a soil wet to field capacity, water does not move readily into the drier soil nearby. When the water content is below field capacity, the capillary conductivity is sufficiently small that redistribution of moisture in the soil profile is usually negligible (*19*).

Root distribution varies considerably with soil type and depth (*30*). Aldrich, *et al.* (*10*) found that pear roots were unevenly distributed by depth in clay adobe soil and that moisture extraction was positively correlated with root concentration in different zones. In citing his own and other research tests, Work (*38*) stated that tree root distribution is much more extensive in coarse-to-medium textured soils than in fine textured ones, and also that capillary movement is better in coarse than in fine textured soils. Thus, in clayey soils the complete use of available moisture is never realized, due to both poor root distribution and poor capillary movement. Under such conditions the soil in contact with the roots is probably much drier than soil only a short distance away (*19, 38*). This would explain why irrigations have resulted in better fruit growth during periods of stress, even though the *average* soil moisture was well above 50% available. We do not wish to imply that capillary movement of water is not important directly adjacent to roots, but under conditions of stress, capillary conductivity may be too slow to permit efficient removal of water by the plant roots. Aldrich, *et al.* (*10*) found about twice as much available water was extracted from the 1-2 foot zone as from the 3-4 foot zone. As pointed out by Gardner (*19*), there are two aspects of water availability: the ability of the plant to absorb water with which it is in contact, and the ease with which water moves in to replace that used by the plant. Water movement by capillary conductivity in soils becomes very small when the water content decreases below field capacity, and becomes extremely small as soil suction increases, but even at high suctions it does not reach zero. At 1 bar suction Chino clay has a capillary conductivity of about 10^{-3} cm/day. At 10 bars it is reduced to slightly over 10^{-5} cm/day (*19*).

The closure of stomata during the day is related indirectly to soil moisture. Furr and Magness (*17*) reported that, as soil moisture was depleted, stomata of apple leaves closed earlier in the day, and fruit growth was reduced. Others (*16, 29*) reported that early stomatal closure was related both to low soil moisture and high evaporating power of the air. Both fruit growth and total carbohydrate production were reduced when stomata closed early in the day.

In summary, several factors must be considered in evaluating tree performance as related to moisture supply. Major factors are soil type, irrigation frequency and depth of water penetration, extent of root distribution, and the intensity and duration of external moisture stress. All of these factors are closely interrelated, and a single one cannot be evaluated apart from the others.

Fertilizers and cover crops

Of the major fertilizer elements, only nitrogen has been consistently beneficial to pear trees in the Medford area (*15*). Degman (*14*) reported that Anjou pear trees set heavier crops when high rates of nitrogen were applied. Trees to which he applied 10 pounds of nitrogen per tree—either as an alfalfa mulch, a combination of straw plus $(NH_4)_2SO_4$, or as straight $(NH_4)_2SO_4$—set heavier and yielded more fruit than trees given only 1.5 pounds nitrogen. The increase was due primarily to greater set of seedless fruits. His test was of short duration, so long-term effects of such high annual rates of nitrogen could not be given. Also, no cover crop was grown in the plots, so the effect of cover on the amount of nitrogen needed was not determined. In general, however, more nitrogen is needed when a non-legume cover is used than when clean cultivation is practiced.

In addition to needing more nitrogen, trees in a grass sod differ in other ways from those in cultivated soil. Howard (*24*) reported that both apple and plum roots would not grow into a grass sod, even with ample moisture present. Instead of the tree roots becoming co-extensive with the grass roots, the tree roots grew downward away from the sod (and from the fertile top soil layer). This adverse influence of the sod was thought to be caused by the high level of carbon dioxide present. The sod contained five times as much carbon dioxide as clean cultivated soil during the summer months. Trees performed better in sod if holes or trenches were dug in the root zone to permit better gas exchange.

Aldrich and Grim (*5*), working with the Anjou pear, found that the nitrogen level *per se* in the trees was not solely responsible for increasing fruit set. When they increased the nitrogen in the flower clusters of unpruned trees with fertilizer so that it equalled that in clusters of pruned but unfertilized trees, the fruit set was not equal. The pruned but unfertilized trees set much more fruit than did unpruned, fertilized trees.

Pruning

Various kinds of pruning were found by Aldrich (*2*) and Aldrich and Grim (*5*) to improve the fruit set of Anjou pear. Relative to nonpruning, heavy pruning resulted in the greatest increase in set, while moderate pruning resulted in a set intermediate between the two extremes. Also, the removal of half the unopened blossom clusters resulted in a moderate increase in percentage set. But since all pruning treatments reduced the number of flowering spurs per tree, percentage set was increased while the total bearing surface was reduced. In terms of the total number of fruits per tree, however, heavily pruned trees had the most, followed by those with moderate pruning, cluster removal, and nonpruning. Both pruning and defoliation increased the water content of the leaves during the growing season. Thus, part of the increase in set could have resulted from a more favorable water balance in fruits and leaves during critical periods prior to the final fruit drop.

The relation of pruning to irrigation practice was studied over a 10-year period by Aldrich *et al.* (*4*). With Anjou pear grown in a clay adobe soil, light pruning was as satisfactory as heavy, if ample irrigation water was applied. But when trees were deficient in soil moisture, heavy pruning resulted in better yields than light pruning.

Degman (*13*) showed that Bartlett pear does not respond to pruning in the same way as Anjou. Nonpruned Bartlett trees produced much more fruit than pruned ones, in contrast to Anjou trees which, on shallow soil, produced three times the yield when pruned as when nonpruned. However, Anjou trees on a deep soil (in which the trees were very vigorous) yielded only slightly more when pruned than when nonpruned.

Fruit thinning and leaf/fruit ratio

In fruit thinning tests with apple (*20*), peach (*31, 35, 25*) and pear (*3, 8, 1, 28*), it was generally found that increasing the leaf/fruit ratio caused the remaining fruits to be larger, but not in direct proportion to the increase in number of leaves per fruit. Thus, thinning reduced ultimate yield while improving fruit size. In general, about 40 leaves per fruit were required to give the proper balance between fruit size and yield. Aldrich (*3*) found that pear fruits fed by shoot leaves grew better than those fed by a comparable area of spur leaves. Pruned trees thus had some advantage because they had proportionately more shoot-leaf area than did unpruned trees (*4*).

Aldrich and Work (*8*) pointed out the effect of timing and amount of thinning on floral initiation in pear. The earlier the thinning and the greater the leaf/fruit ratio, the more floral initiation occurred. Maximum floral initiation occurred in Bartlett, Anjou, and

Bosc pears before July 1, and to be effective in stimulating bloom for the next year, thinning had to be complete before 60 days past full bloom.

PART I—ANJOU

Materials and Methods

Three tests were done in Block 1 at the Southern Oregon Experiment Station, starting in 1943, using Anjou trees 27 years old. The soil, Meyer clay adobe, was irrigated by furrows. This soil is dark colored and very clayey. Upon drying, it develops wide cracks and is self-mulching and is thus in the Grumusol group. Pollinizers were Bartlett trees placed every fifth or seventh tree in every fifth row. Trees were spaced 25 feet by 25 feet.

Test 1 treatments (amounts given are per tree per year)

1. Alfalfa hay—400 pounds, applied as a mulch under the trees (to provide 10 pounds nitrogen).

2. Barley straw—400 pounds as a mulch plus 40 pounds of $(NH_4)_2SO_4$ (to provide 10 pounds nitrogen).

3. $(NH_4)_2SO_4$ only—50 pounds (to provide 10 pounds nitrogen).

4. Compaction—Repeatedly ran over soil with a farm tractor while soil was still wet after each irrigation, plus 7.5 pounds $(NH_4)_2SO_4$ (1.5 pounds nitrogen).

5. No compaction—No tillage and no walking on soil, plus 7.5 pounds $(NH_4)_2SO_4$ (1.5 pounds nitrogen).

6. Control—Normal discing after irrigations and normal walking on soil, plus 7.5 pounds $(NH_4)_2SO_4$ (1.5 pounds nitrogen).

Treatments 1, 2, and 3 were designed to supply 10 pounds nitrogen per tree, but in different forms. The alfalfa hay contained about 2.5% nitrogen and the barley straw about 0.5% nitrogen. The alfalfa mulch contained moderate quantities of other essential elements in addition to the nitrogen shown. Each treatment plot consisted of three trees (surrounded by untreated buffer trees), and each plot was replicated five times. Each tree in the test had received 2 pounds of nitrogen as $(NH_4)_2SO_4$ annually for the 10 years prior to the beginning of the test. Treatments were applied each fall, beginning in 1943. The test was terminated in 1948.

Soil samples were taken for pH determinations on April 26, 1946, from trees in each plot. The samples were taken with a soil auger in the treated area under the trees, 6 feet out from the trunks. Equal parts (weight/volume) of dry soil and distilled water were mixed and pH readings were made in duplicate on a standard pH meter. The pH values were converted to H^+ concentrations, averaged, and the averages converted back to pH for entry in the tables.

Moisture determinations were made from soils taken from under each tree in each plot, 6 feet from the trunks and at depths of 0-1 feet, 1-2 feet, and 2-3 feet. The samples were weighed immediately and then dried 48 hours at 110° C. to reach a constant weight. In 1945, samples were taken 15 times; in 1946, 11 times; and in 1947, 6 times. The plots were irrigated three or four times during each of the years (see appendix for details), usually midway between two sampling dates.

Flower cluster and fruit set counts on entire trees were made on each of the 15 trees in each treatment from 1944 through 1947. Set was recorded as the number of fruits setting per 100 blossoming clusters.

Test 2 treatments

1. Heavy annual pruning.
2. Moderate annual pruning.
3. One-fourth of tree moderately pruned, three-fourths unpruned.
4. Three-fourths of tree moderately pruned, one-fourth unpruned.
5. No pruning.

Fruit set counts were made on whole leaders for both pruned and unpruned portions of each tree in treatments 3 and 4. In these treatments, yields from the pruned and unpruned portions were not kept separate. All treatments were carried out from 1943 through 1948.

Test 3 treatments

1. Trees originally planted 25 feet by 25 feet were thinned in 1948 (when trees were 31 years old) by removing alternate diagonal rows, leaving diagonal rows 35 feet by 35 feet apart (with half the original number of trees per acre).
2. Control—None removed. Trees spaced 25 feet by 25 feet (70 trees per acre).

The trees in both plots were given the same kind of pruning, irrigation, and fertilizer (140 pounds nitrogen per acre as $(NH_4)_2SO_4$ annually), and yield records were kept from the time the trees were removed to the present.

A fourth Anjou test was started in 1944 in Block 4 and terminated prior to the 1960 growing season. Following this test, corrective treatments of lime and nitrogen were applied to some of the old plots. Block 4 consists of a solid block of Anjou trees with no provision for cross-pollination. The border row on the south side of the block was not used, as it is adjacent to a block of Bartlett trees and thus set heavier crops than the other rows in the block (*37*).

Fruit set and fruit growth measurements were taken on only two trees per plot, while yields were recorded for five trees each year. Fruit set was determined on entire trees for the two trees per plot. Tissue samples were taken in early or mid-summer and analyzed for nitrogen by the Kjeldahl method.

Test 4 treatments

1. Sod—A permanent crop of Alta fescue was maintained.

2. Cover crop—An annual crop of rye (*Secale cereale*) and hairy vetch (*Vicia villosa*) was sown in the fall each year. It was disced under in early summer after seeds had matured, and then plots were clean cultivated the rest of the summer.

3. Clean cultivation—Rye was sown each fall and disced under as soon as possible in the spring, with discing between irrigations the rest of the season.

Each treatment plot consisted of nine trees—a square with three trees on a side, and each was replicated five times. All plots were contained in a single orchard block, and there were no buffer trees between plots. Each tree received 4 pounds of nitrogen as $(NH_4)_2SO_4$ annually from 1944 through 1958, and irrigation was applied uniformly by furrow over all treatment plots.

Soil samples for pH were taken in 1946, 1954, 1957, and 1958 from each record tree in each plot. Determinations were made in the same way as described in Test 1. Soil moisture samples were taken several times per season under each record tree (as previously described) from 1946 through 1958 (see appendix for dates and details).

Statistical evaluation of data from all tests was done by using a standard analysis of variance, from which least significant differences (L.S.D.'s) were computed at the 5% probability level.

In 1960 all plots were eliminated and the whole block was placed under clean cultivation. During the dormant period prior to the 1961 season, lime[2] was applied at the rate of 90 pounds per tree (about 3 tons per acre) to some of the old plots. Some plots received 3 pounds of nitrogen as NH_4NO_3, while others received none.

[2] An industrial by-product with negligible impurities and with a calcium carbonate equivalent of 110% was used.

Results and Discussion

Test 1 (cultural, nitrogen, and compaction)

The effects of culture and nitrogen on tree growth during a 4-year period are shown in Table 1. Mulches resulted in more wood growth than did $(NH_4)_2SO_4$ alone. The high level of nitrogen generally caused more wood growth than the low level, but low nitrogen plus no compaction resulted in as much growth as some of the high nitrogen treatments. Pruning was done uniformly without regard to treatment, so the amount of wood removed gave a good index of total growth throughout the trees. Compaction resulted in the least growth of any low nitrogen treatment and was strikingly lower than no compaction.

The effects of the treatments on various aspects of fruiting and tree growth are shown in Table 2. Alfalfa mulch resulted in greater yields than any other treatment, although other high nitrogen treatments were generally similar in other respects. Of the high nitrogen treatments, $(NH_4)_2SO_4$ alone resulted in much less trunk area increase than did the mulched trees. The other data presented do not indicate why this occurred. Of the low nitrogen treatments, no compaction resulted in significantly higher set, yield, and trunk growth than did compaction. The control, which had an intermediate amount of compaction, resulted in intermediate fruit set and yield. Trees in high nitrogen plots generally bore better than those in low nitrogen

Table 1. EFFECT OF CULTURAL AND NITROGEN TREATMENT ON KIND AND AMOUNT OF PRUNINGS FROM MATURE ANJOU PEAR TREES GROWN IN MEYER CLAY ADOBE SOIL (BLOCK 1, 1944 THROUGH 1947)[a]

Treatment[b]	Total N applied	Wood removed			Total length of new wood
		Old	New	Total	
	lbs.	*lbs.*	*lbs.*	*lbs.*	*meters*
400 lbs. alfalfa mulch only	10	80.3	27.4	108	548
400 lbs. straw + 40 lbs. of $(NH_4)_2SO_4$	10	91.3	29.4	121	531
50 lbs. $(NH_4)_2SO_4$	10	72.1	26.7	99	504
Compaction + 7.5 lbs. of $(NH_4)_2SO_4$	1.5	66.4	19.2	86	308
No compaction + 7.5 lbs. of $(NH_4)_2SO_4$	1.5	80.9	29.6	110	476
Control (7.5 lbs. $(NH_4)_2SO_4$)	1.5	73.1	22.4	96	382
L.S.D.[c] (.05 level)		15.9	2.7	16	52

[a] Values in table are average amounts per tree annually.
[b] Amounts per tree applied annually.
[c] Least significant difference.

Table 2. EFFECT OF CULTURAL AND NITROGEN TREATMENT ON FRUIT SET, YIELD, FRUIT SIZE, SHOOT GROWTH, AND TRUNK-AREA INCREASE OF MATURE ANJOU PEAR TREES (BLOCK 1, 1944 THROUGH 1947)[a]

Treatment[b]	Total N applied	Fruit set	Yield[c]	Fruit size	Early[d] shoot growth	Trunk area increase 1943 to 1948
	lbs.	*no./100 bl. clus.*	*boxes*	cm^3	*cm*	cm^2
400 lbs. alfalfa mulch only	10	29.7	12.1	142	37.6	162
400 lbs. straw + 40 lbs. of $(NH_4)_2SO_4$	10	28.2	11.1	139	35.8	169
50 lbs. $(NH_4)_2SO_4$	10	32.0	10.6	136	37.2	138
Compaction + 7.5 lbs. of $(NH_4)_2SO_4$	1.5	19.7	8.7	140	37.6	131
No compaction + 7.5 lbs. of $(NH_4)_2SO_4$	1.5	26.2	10.3	......	......	146
Control (7.5 lbs. $(NH_4)_2SO_4$)	1.5	23.9	9.7	144	37.9	146
L.S.D. (.05 level)		3.3	.83	6.8	N.S.[e]	11

[a] All values are annual amounts per tree.
[b] Amounts per tree applied annually.
[c] One box = 45 pounds of fruit.
[d] Shoot growth to about July 1.
[e] Not statistically significant.

plots, but low nitrogen plots with no compaction resulted in yields statistically equal to those of two of the three high nitrogen treatments. Compaction caused a definite reduction in set, yield, and growth as compared to other treatments. Early shoot growth was similar in all treatments.

The effects of treatment on soil moisture are given in Table 3. Both mulches resulted in higher soil moisture (principally in the 0-1 foot zone) than did the other treatments. Soil in the compaction plots had significantly less moisture in the upper 3 feet than any other plots. In order to prevent compaction due to walking around the trees, those in the no-compaction plots were not sampled for soil moisture.

Soil pH at different depths was related to the amount of $(NH_4)_2SO_4$ applied (Table 4). After three years, soils under alfalfa mulch (with no $(NH_4)_2SO_4$ added) had the highest pH, while those receiving 50 pounds of the chemical per tree had the lowest. Acidity in the 0-1 foot zone was changed by the treatments much more than in the 2-3 foot zone, which was only slightly altered.

Soil nitrate was much higher in April and May when high rates of $(NH_4)_2SO_4$ were used than when a low rate was applied (Table 5). The rate of nitrate availability from mulches was less than that from $(NH_4)_2SO_4$ applied at the same rate of nitrogen.

Table 3. EFFECT OF CULTURAL AND NITROGEN TREATMENT ON THE SOIL MOISTURE AT DIFFERENT DEPTHS UNDER MATURE ANJOU PEAR TREES (BLOCK 1, 1945-1947)[a]

Treatment[b]	Total N applied	Soil moisture (dry wt. basis)			
		0-1 ft.	1-2 ft.	2-3 ft.	Avg.
	lbs.	%	%	%	%
400 lbs. alfalfa mulch only	10	27.6	26.2	25.4	26.3
400 lbs. straw + 40 lbs. of $(NH_4)_2SO_4$	10	29.0	26.5	25.6	27.0
50 lbs. $(NH_4)_2SO_4$	10	26.1	25.8	25.1	25.7
Compaction + 7.5 lbs. of $(NH_4)_2SO_4$	1.5	24.7	24.5	24.5	24.6
Control (7.5 lbs. $(NH_4)_2SO_4$)	1.5	25.2	24.8	24.4	25.0
L.S.D. (.05 level)		0.7	0.7	0.7	0.4

[a] All values are averages of samples taken 6 feet from the trunk of each record tree on several dates during the growing seasons (see appendix for details).
[b] Amounts per tree applied annually.

Table 4. EFFECT OF CULTURAL AND NITROGEN TREATMENT ON THE pH OF SOIL AT DIFFERENT DEPTHS UNDER MATURE ANJOU PEAR TREES (BLOCK 1, 1946 SEASON)

Treatment[a]	Total N applied	pH of soil			pH[b] avg.
		0-1 ft.	1-2 ft.	2-3 ft.	
	lbs.				
400 lbs. alfalfa mulch only	10	5.79	5.81	6.44	5.92
400 lbs. straw + 40 lbs. of $(NH_4)_2SO_4$	10	4.82	5.13	6.22	5.11
50 lbs. $(NH_4)_2SO_4$	10	4.42	4.70	6.10	4.71
Compaction + 7.5 lbs. of $(NH_4)_2SO_4$	1.5	5.33	5.42	6.21	5.51
Control (7.5 lbs. $(NH_4)_2SO_4$)	1.5	5.60	5.78	6.10	5.81

[a] Amounts per tree applied annually.
[b] pH values converted to H^+ concentration for averaging.

The results of Test 1 (Tables 1 to 5) indicate the superiority of alfalfa mulch and the inferiority of non-mulched compacted soil insofar as yield and growth of Anjou pear are concerned. Straw plus ammonium sulfate resulted in a higher soil moisture and pH, and in greater tree growth, than did the chemical alone. Trees in compacted soil had less growth, fruit set, and yield than those in non-compacted soil. Latham recently reported *(26)* that work done in clayey soils of the Medford area showed that in most orchards a compacted layer was found, starting just below the tillage layer. This compacted layer was not found in the less-travelled area under the trees, but was located between trees in the area where spray rigs and other heavy

Table 5. EFFECT OF CULTURAL AND NITROGEN TREATMENTS ON SOIL NITRATE CONCENTRATION AT DIFFERENT DATES UNDER MATURE ANJOU PEAR TREES (BLOCK 1, 1946—AFTER THREE YEARS TREATMENT)

Treatment[a]	Total N applied	Nitrate at three depths					
		April 16			May 7		
		0-6 in.	7-12 in.	13-24 in.	0-6 in.	7-12 in.	13-24 in.
	lbs.	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
400 lbs. alfalfa mulch only	10	5.1	4.5	6.2	8.7	4.4	3.9
400 lbs. straw + 40 lbs. of $(NH_4)_2SO_4$	10	6.0	6.1	8.4	16.9	15.0	10.1
50 lbs. $(NH_4)_2SO_4$	10	21.7	14.1	10.7	22.8	12.2	9.1
Compaction + 7.5 lbs. of $(NH_4)_2SO_4$	1.5	2.7	2.5	2.6	1.2	1.3	1.2
Control (7.5 lbs. of $(NH_4)_2SO_4$)	1.5	3.6	3.4	2.0	1.4	1.3	1.3

[a] Amounts per tree applied annually.

equipment had travelled. Latham also reported that a small amount of compaction drastically reduced water permeability. Thus the low moisture content of compacted soils (Table 3) probably was due to lack of water penetration rather than to greater extraction by tree roots. The soils under mulch had the highest moisture content in the test. This probably resulted both from less surface evaporation and from less compaction of the soil under the mulch. The increasing use of heavy orchard equipment during the past 15 years and the concomitant increase in soil compaction may be the major limiting factor to fruit production in these clayey soils.

Test 2 (pruning)

A five-year study of pruning Anjou pear showed that moderate pruning resulted in as good fruit set and yield as did heavy pruning, but nonpruning significantly reduced both set and yield (Table 6). When parts of trees were pruned, only the pruned portions were stimulated to greater set, but the increase was less than that obtained when whole trees were pruned. Thus the stimulus of pruning was not moved from pruned to unpruned portions of the tree. But leaving part of the tree unpruned seemed to reduce the set on the pruned portion. Aldrich (*3*) previously showed that a unit area of shoot leaves was more efficient for fruit growth than a unit area of spur leaves. Pruning was shown (*4*) to result in relatively more shoot leaf area than nonpruning. Previous tests with Anjou (*4, 5, 13*) also showed that pruning increased fruit set. The reduction in bearing surface from moderate pruning is more than compensated for by increased set and increased fruit growth with Anjou. Results of the present test (Table 6) show that pruning is a local influence and that unpruned leaders of trees are unaffected by pruned ones.

Test 3 (tree removal)

Removing alternate rows of mature Anjou trees in 1948 caused the remaining trees to yield much heavier than unthinned trees, but yield per acre was reduced by the tree thinning (Table 7). This effect was immediate and thus was not due entirely to an increase in tree size. At the end of the test the thinned trees were somewhat larger, but the yield increase noted at the start of the test did not further increase as the trees increased in size over the controls. Apparently the change of local environment brought about by tree removal was more

Table 6. EFFECT OF PRUNING METHOD ON FRUIT SET, YIELD, AND AMOUNT OF WOOD REMOVED FROM MATURE ANJOU PEAR TREES (BLOCK 1, 1943-1948)[a]

Pruning treatment	Fruit set	Yield	Wood removed: Old	New	Total
	no./100 bl. clus.	*boxes*	*lbs.*	*lbs.*	*lbs.*
Heavy	37.1	8.78	81	37	118
Moderate	33.6	8.98	79	26	105
None	11.3	7.31	0	0	0
¾ pruned (mod.)[b]	21.1	9.29			
¼ unpruned	6.6				
¼ pruned (mod.)[b]	17.2	7.88			
¾ unpruned	6.5				
L.S.D. (.05 level)	11.6	.87	8.0	3.7	8.6

[a] Values given are averages per tree annually.
[b] Yield shown is for entire tree, both pruned and unpruned portion.

Table 7. EFFECT OF REMOVING ALTERNATE DIAGONAL ROWS ON YIELD AND SIZE OF MATURE ANJOU PEAR TREES (BLOCK 1, 1949-1962)

Treatment[a]	Avg. annual yield per tree: Before test	1949-1950	1951-1952	1953-1957	1958-1962	Avg. annual yield per acre	Tree size, 1961: Height	Spread
	boxes	*boxes*	*boxes*	*boxes*	*boxes*	*boxes*	*feet*	*feet*
Thinned (35 trees/acre)	9.1	20.4	21.4	17.9	15.9	638	16.4	26.4
Unthinned (70 trees/acre)	9.1	15.0	16.1	13.8	10.5	931	16.0	23.5

[a] All trees received nitrogen as $(NH_4)_2SO_4$ at the rate of 140 pounds/acre annually.

important to fruiting than was tree size. Local changes in light and temperature could change the pattern and intensity of bee activity. A recent report by Westwood and Grim (*37*) indicated that, in the same orchard as the present test, Anjou trees in the border rows had greater fruit set and higher yields than did trees inside the block. Thus the original planting distance of 25 feet by 25 feet seems to cause too much shading of mature trees, resulting in a reduction of yield potential. A spacing of 28 feet by 28 feet (assuming the same yield per tree as the wide spacing) would have resulted in a yield of 1,003 boxes per acre, instead of the 638 boxes per acre obtained (Table 7). Further work should be done to test this assumption.

Test 4 (cultural plots, Block 4)

Clean cultivation resulted in the greatest total growth (as measured by prunings removed), while sod culture resulted in the least growth (Table 8). Cover cropping was intermediate in this respect. Trunk area increase did not differ significantly between different cultures and thus was not a good index of tree growth.

Clean cultivation resulted in greater fruit set and higher yield than did the other cultures (Table 9). Fruit size did not differ significantly between cultures. Based on their lower set, the trees in sod should have yielded less fruit than those in cover crop. Trees in sod were slightly larger at the start of the test than those in other cultures, and this might have resulted in higher yields. It should also be noted that fruit set was determined on only two trees per plot, while yield records were taken on five trees per plot.

The effects of culture on weight and color of leaves and on the nitrogen content of tissues are shown in Table 10. Trees in clean cultivation had greener but not heavier leaves than those in sod. Leaf nitrogen was highest in clean cultivation, and lowest in sod, while

Table 8. EFFECTS OF CULTURAL TREATMENT ON VARIOUS GROWTH FACTORS OF ANJOU PEAR GROWN IN MEYER CLAY ADOBE SOIL. (BLOCK 4, 15-YEAR TEST)

Treatment[a]	Yearly growth per shoot	Prunings removed yearly: New	Old	Total	Length new wood	Yearly trunk area increase
	cm	*lbs.*	*lbs.*	*lbs.*	*meters*	*cm*²
Clean cultivation	35	25	61	85	444	29
Cover crop	35	22	57	79	381	31
Sod	33	18	50	68	315	30
L.S.D. (.05 level)	2.0	6.1	10.4	15.6	34	N.S.

[a] Trees in all treatment plots received four pounds nitrogen as $(NH_4)_2SO_4$ annually.

Table 9. EFFECT OF CULTURAL TREATMENT ON FRUIT SET, FRUIT VOLUME, AND YIELD OF MATURE ANJOU PEAR TREES (BLOCK 4, 1945-1959)

Treatment[a]	Fruit set	Fruit volume	Yield per tree	Annual yield per acre
	no./100 bl. clus.	*cm³*	*boxes*	*boxes*
Clean cultivation	37.6	129	13.9	972
Cover crop	36.9	129	12.3	860
Sod	30.5	126	13.0	910
L.S.D. (.05 level)	6.4	N.S.	0.96	68

[a] Trees in all treatment plots received four pounds nitrogen as $(NH_4)_2SO_4$ per tree annually.

Table 10. EFFECT OF CULTURAL TREATMENT ON LEAF FRESH WEIGHT, LEAF COLOR, AND NITROGEN IN TISSUES OF MATURE ANJOU PEAR TREES (BLOCK 4, 15-YEAR TEST)

Treatment	Leaf fresh wt./50 cm² (1948)	Green leaf color[a] (1948)	Bud nitrogen (1945-1948)	Leaf nitrogen (1945-1958)
	gm.	*Klett reading minus 100*	*% dry wt.*	*% dry wt.*
Clean cultivation	.921	45	1.43	2.64
Cover crop	......	....	1.41	2.59
Sod	.928	27	1.37	2.52
L.S.D. (.05 level)	N.S.	8.4	N.S.	.03

[a] Alcohol extracts measured in a Klett colorimeter through a 660 filter.

nitrogen in buds did not differ between cultures. The lower nitrogen content and lighter green color of leaves on trees in sod was probably due to the utilization of some of the applied nitrogen (broadcasted over the entire surface) by the grass. Because of early summer sampling, the general levels of leaf nitrogen were higher than usually reported for August sampling.

Soil nitrate in the spring was higher in the surface layer than in lower layers of soil, and nitrate was slightly lower under sod than under other cultures (Table 11). Apparently the sod grass absorbed enough nitrate to account for the reduced amount in the soil.

Clean cultivation resulted in slightly lower soil pH than did the other cultures (Table 12). It should be remembered that each tree in this test received 4 pounds of nitrogen as $(NH_4)_2SO_4$ annually for 15 years, and most of the change in pH resulted from the chemical rather than from the culture. Prior to the start of the test, the pH in the upper one foot of soil was about 6.8. Acidity was increased much more in the surface foot of soil than in deeper layers.

Table 11. EFFECT OF CULTURAL TREATMENT AND TIME ON NITRATE CONTENT OF SOIL UNDER MATURE ANJOU PEAR TREES (BLOCK 4, 15-YEAR TEST)

		Soil nitrate at different times and depths						
		March	April			May		
Treatment	Year	0-6 in.	0-6 in.	7-12 in.	13-24 in.	0-6 in.	7-12 in.	13-24 in.
		ppm (dry wt. basis)						
Clean cultivation	1946	....	14.3	7.6	2.1	3.8	2.2	1.6
	1948	6.8	2.8	2.6	....	7.0	4.2	....
Cover crop	1946	....	5.9	4.3	2.2	3.0	2.8	1.5
	1948	8.1	5.8	3.0	....	8.6	4.8	....
Sod	1946	....	7.7	2.5	2.2	1.4	1.3	1.3
	1948	5.4	3.8	5.0	....	2.0	1.4	....
L.S.D. (.05 level)[a]		N.S.	5.7	....	....	5.7	....	....

[a] Statistical analyses done only on the 0-6 inch depth.

Table 12. EFFECT OF CULTURAL TREATMENT ON THE pH OF SOIL AT DIFFERENT DEPTHS UNDER MATURE ANJOU PEAR TREES (BLOCK 4: 1946, 1954, AND 1957)

	pH at different depths				
Treatment[a]	0-6 in.	7-12 in.	0-1 ft.	1-2 ft.	2-3 ft.
Clean cultivation	4.70	4.92	4.80	6.25	6.84
Cover crop	4.94	5.24	5.05	6.22	7.06
Sod	4.88	5.36	5.06	6.15	7.07

[a] Each tree received four pounds nitrogen as $(NH_4)_2SO_4$ annually.

Figure 1 shows that during the first seven years of Test 4, there was a general increase in tree yield. Since this was true of all cultures, they were averaged together into the single line on the graph. After 1951, however, yield generally declined, so that in 1961 it was as low as it was prior to the start of the test. The reason for this decline is not known, but it appears to be related to some cumulative change in the soil.

It was thought that the reduction in pH in the surface soil might have brought about chemical and biological changes that resulted in significant changes in soil fertility and tree nutrition. Soil samples submitted to the Oregon State University soil testing laboratory[3]

[3] This work was supervised by Drs. L. Alban and T. L. Jackson by the methods outlined in Methods of Soil Analysis, Ore. Agr. Expt. Sta. Misc. Paper 65. Exchange capacity and percent base saturation were determined with 1 normal ammonium acetate buffer at pH 7.

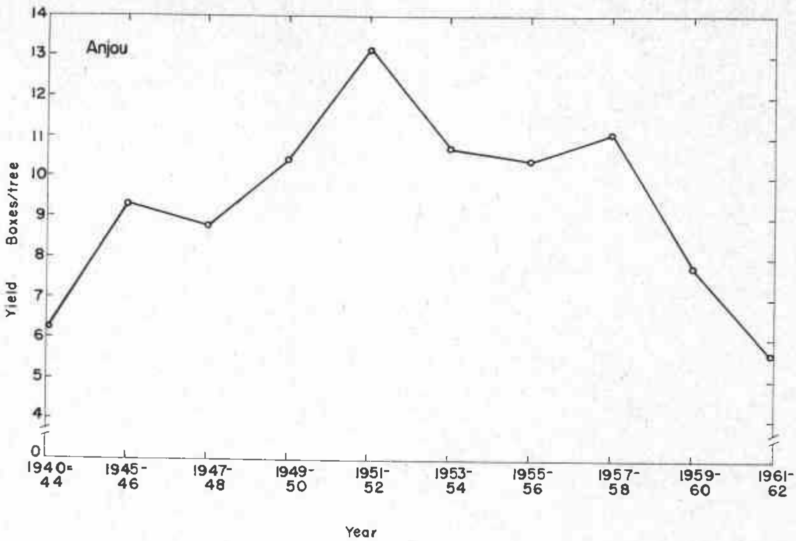

Figure 1. Effect of time on yield of Anjou pears growing in Meyer clay adobe soil to which was applied 1,400 pounds of $(NH_4)_2SO_4$ per acre annually, starting in 1945.

showed an average cation exchange capacity (CEC) of 36.5 milliequivalent (me) per 100 gm of soil, with a pH of 6.6 and 35.2 me exchangeable bases on untreated checks adjacent to Block 4. Plots that had received 4 pounds nitrogen per tree as $(NH_4)_2SO_4$ for 15 years had a pH of 4.8 and 22 me exchangeable bases.

An application of about 3 tons lime per acre was selected as a rate that would supply 6 me Ca per 100 gm of soil in the upper 6 inches of the profile. This should result in a sufficient change in soil pH to affect both biological reactions and the solubilities of some ions, such as Fe, Mn, and Al, that possibly complicated nutrition problems on the acid surface layer of soils receiving heavy rates of $(NH_4)_2SO_4$ over a long period of years.

After the culture plots were terminated in 1960 and restored to clean cultivation, several of the old plots were used to evaluate the effect of remedial treatments on restoring productiveness to the trees. Four comparable groups of fifteen trees each were selected. Two levels of nitrogen and two levels of lime were used in a split-plot design as follows:

1. Check (no nitrogen, no lime).
2. No nitrogen plus 90 pounds lime per tree.
3. Three pounds nitrogen as NH_4NO_3, no lime.
4. Three pounds nitrogen as NH_4NO_3 plus 90 pounds lime per tree.

The lime was an industrial grade of fine particle size (over 95% passed through a 100-mesh sieve), having a $CaCO_3$ equivalent of 110% and containing negligible impurities. It was spread uniformly under the trees, covering a circular area about 25 feet in diameter. Both lime and nitrogen were applied in the winter prior to the 1961 season. Since then, nitrogen has been applied each winter at the rate shown, but only the one application of lime was made.

There was very little difference in yield in 1961, even though the lime treatment raised the soil pH, but in 1962 (Table 13) the combination of lime plus nitrogen resulted in a substantial increase in yield. Lime alone did not increase yield over the untreated controls, even though the pH was raised. Nitrogen alone resulted in a moderate increase in yield over the control, although the pH remained relatively low. Applied nitrogen increased leaf nitrogen, but lime did not influence it. Thus these data indicate that the best tree performance occurred when both leaf nitrogen and soil pH were raised. Fruit set in 1963 was very poor throughout the Medford area because of adverse weather at bloom time. Even so, the nitrogen plus lime treated trees again out-yielded trees in the other treatments.

Clean cultivation resulted in higher soil moisture at all depths than other cultures (Table 14). Sod resulted in the lowest moisture at all depths, but was sharply lower in the upper foot of soil. This reflects the relatively higher use of moisture by the permanent sod. The percent available moisture (based on a P.W.P. of 17 and F.C. of 32% determined by Aldrich, *et al.* (*6*) for that soil) indicates that clean cultivated soil was nearest the optimum of 50 to 60% for clay soil (*6*), while the other cultures probably were too low for maximum fruit growth. The low moisture level in sod could also have reduced fruit set, because moisture stress during early summer can increase the amount of "June" drop. Regardless of any possible adverse

Table 13. EFFECTS OF LIME AND NITROGEN ON YIELD, LEAF NITROGEN, AND SOIL pH OF ANJOU PEARS IN OLD CULTURAL PLOTS

Treatment[a]	Yield[b] 1960 (before test)	Yield[b] 1962	Leaf nitrogen 1962	Soil pH, 1962	
				0-6 in.	7-12 in.
	boxes	*boxes*	%		
No N, no lime	9.76	8.49	1.85	5.15	5.58
Lime only (1961)	9.94	8.79	1.86	5.51	5.63
N only (each year)	9.62	9.79	2.04	5.08	5.52
N each year + lime 1961	9.84	10.74	2.06	5.43	5.62

[a] Starting in 1960, all plots were clean cultivated. N treatments received three pounds nitrogen as NH_4NO_3; lime treatments were 90 pounds per tree.

[b] Yield per tree. One box holds 45 pounds of fruit.

Table 14. EFFECT OF CULTURAL TREATMENT ON SOIL MOISTURE AT DIFFERENT DEPTHS UNDER MATURE ANJOU PEAR TREES (BLOCK 4, 15-YEAR TEST)[a]

Treatment	Depth 0-1 ft.	1-2 ft.	2-3 ft.	Avg.
	percent moisture (dry wt. basis)			
Clean cultivation	24.2	24.3	24.1	24.2
Cover crop	24.0	23.7	23.7	23.8
Sod	22.8	23.4	23.6	23.3
L.S.D. (.05 level)	0.5	0.5	0.5	0.3
	percent available moisture[b]			
Clean cultivation	48.0	48.7	47.3	48.0
Cover crop	46.7	44.7	44.7	45.4
Sod	38.7	42.7	44.0	42.0

[a] Samples were taken on several dates during the growing season in each of the 15 years of the test. (See appendix for details.)

[b] Based on permanent wilting percentage of 17 and field capacity of 32%.

influence of sod on tree root growth, as a result of poor aeration or high CO_2 as discussed by Howard (*24*), a major influence here appeared to be one of lowered soil moisture. Studies with trees in sod reported by Howard (*24*) were quite different from ours, in that his plots received 50 inches of rainfall between June 15 and October 15. That much water was probably excessive, in contrast to a somewhat deficient level in our sod plots. Our results indicate that trees in sod would need more frequent irrigation than those in clean cultivation.

PART II—BARTLETT AND BOSC

Materials and Methods

In addition to the four tests reported for Anjou, two tests were done with Bartlett and Bosc trees. These trees have Old Home x Farmingdale seedling roots and an Old Home interstock and framework. They were planted 25 feet by 25 feet apart in 1934 and were topworked with scion varieties in 1939. As with the Anjou plots, the soil is Meyer clay adobe.

Test 5 (culture and nitrogen)

Cultural plots consisted of clean cultivation, mulch, and sod. Each plot row was centered in the cultural strip, which was 50 feet wide and extended the length of the block. Each plot contained six Bosc and three Bartlett trees; one-third of the trees of each variety were treated with three levels of nitrogen as $(NH_4)_2SO_4$. Each record tree was completely surrounded with buffer trees. Each cultural plot was replicated three times and each was separated from the adjacent plot by a buffer row. Treatments were started prior to the 1952 season and terminated with the 1959 season. Details of cultures are as follows:

1. Clean cultivation consisted of discing as early in the spring as possible and between irrigations thereafter. Rye was sown each fall after harvest.

2. Mulch consisted of strips of rye sown each fall on either side of the record row. This cover crop was cut in early summer and placed as a surface mulch around the trees. The strips between rows were then disced between irrigations during the summer. This treatment did not result in a deep mulch cover under the trees as was the case in Test 1 with Anjou.

3. Sod consisted of a permanent cover of Alta fescue. No tillage was done in this treatment.

Within each cultural plot, two Bosc trees and one Bartlett were given an annual banded application of each of the following amounts of nitrogen:

1. None (control).
2. One and one-half pounds nitrogen as $(NH_4)_2SO_4$.
3. Four pounds nitrogen as $(NH_4)_2SO_4$.

Test 6 (pruning)

Treatments were started prior to the 1949 season and terminated with the 1953 season. Four degrees of pruning were done as follows:

1. None (control).
2. Light thinning out.
3. Light thinning plus removing tips of new growth.
4. Heavy thinning out.

Each variety by treatment combination was replicated three times. No fruit thinning was done during the test.

Results and Discussion

Test 5 (culture and nitrogen)

Effects of culture and nitrogen level on set, yield, fruit size, shoot growth, and leaf nitrogen are given in Tables 15 and 15a. Clean cultivation resulted in better fruit set for Bartlett than did other cultures, but this was not true for Bosc. Nitrogen level (over all cultures) did not significantly affect Bartlett set, but the medium level of nitrogen increased Bosc set over the low level. Bartlett showed a striking cul-

Table 15. EFFECT OF CULTURE AND NITROGEN LEVEL ON FRUIT SET, YIELD, FRUIT SIZE AND SHOOT GROWTH, AND LEAF NITROGEN OF BARTLETT AND BOSC PEAR TREES GROWN IN MEYER CLAY ADOBE SOIL (BLOCK 2, 1952-1959)[a]

Variety and treatment	N applied annually	Fruit set	Tree yield	Fruit size	Shoot growth	Leaf N
	pounds	*no./100 bl. clus.*	*boxes*	*cm³*	*cm*	*% dry wt.*
Bartlett:						
Clean cult.	0	53	10.6	124	27.3	2.61
	1.5	70	10.9	124	34.1	2.76
	4.0	71	9.1	128	29.6	2.93
Avg. clean cult.		65	10.2	125	30.3	2.77
Mulch	0	46	6.6	114	24.6	2.47
	1.5	50	7.2	113	25.4	2.69
	4.0	52	7.2	118	27.8	2.96
Avg. mulch		49	7.0	115	25.9	2.71
Sod	0	61	7.2	121	26.6	2.24
	1.5	54	10.1	116	24.3	2.50
	4.0	57	9.6	123	26.5	2.71
Avg. sod		56	9.0	120	25.8	2.47
Avg. effect of N	0	53	8.1	120	26.2	2.44
	1.5	58	9.4	118	27.9	2.65
	4.0	60	8.6	123	27.9	2.86
Bosc:						
Clean cult.	0	83	8.3	118	28.6	2.26
	1.5	88	8.1	119	30.5	2.42
	4.0	82	9.5	122	28.9	2.51
Avg. clean cult.		84	8.6	120	29.3	2.40
Mulch	0	75	8.6	113	25.3	2.24
	1.5	96	9.3	116	29.1	2.39
	4.0	90	10.0	111	27.6	2.54
Avg. mulch		87	9.3	113	27.4	2.39
Sod	0	74	5.6	109	24.4	1.96
	1.5	92	7.2	108	27.2	2.27
	4.0	92	9.8	115	26.6	2.55
Avg. sod		86	7.5	111	26.1	2.26
Avg. effect of N	0	77	7.5	113	26.1	2.15
	1.5	92	8.2	115	29.0	2.36
	4.0	88	9.7	116	27.7	2.53

[a] All values are annual averages per tree over an 8-year period.

Table 15a. TABULATED VALUES OF LEAST SIGNIFICANT DIFFERENCE (L.S.D. VALUES) AT THE FIVE PERCENT LEVEL FOR THE MEANS GIVEN IN TABLE 15[a]

Variety and comparison	Fruit set	Tree yield	Fruit size	Shoot growth	Leaf nitrogen
	no./100 bl. clus.	*boxes*	*cm³*	*cm*	*% dry wt.*
Bartlett:					
Culture treatments	5.3	.59	4.6	2.1	.08
Nitrogen levels	N.S.	.46	4.5	N.S.	.07
Culture at a given N level	9.2	1.02	8.0	3.6	.14
Bosc:					
Culture treatments	N.S.	.31	1.9	1.1	.06
Nitrogen levels	9.8	.52	2.5	1.2	.10
Culture at a given N level	N.S.	.53	3.2	N.S.	.10

[a] An entry of N.S. indicates that differences were not statistically significant. A standard analysis of variance was used.

ture x nitrogen interaction—the two highest nitrogen levels resulted in higher set than low nitrogen in clean cultivation, but not in other cultures. The best yields of Bartlett were obtained in clean cultivation at the two low levels of nitrogen, while mulching at the high nitrogen level was best for Bosc. The high level of nitrogen resulted in consistently higher yields than medium nitrogen for Bosc, but the medium level of nitrogen was better for Bartlett.

The effects of treatment on yield can best be seen graphically (Figures 2 to 6), where yields by treatment are plotted as a function of time. For Bartlett (Figure 2), clean cultivation was usually best and mulch was poorest. For Bosc, however, mulch was usually best and sod poorest (Figure 3). The medium level of nitrogen was consistently better than either low or high nitrogen for Bartlett (Figure 4); in contrast, the best yield for Bosc (Figure 5) was always obtained with high nitrogen. With the best culture for each variety considered (i.e., cultivation for Bartlett and mulch for Bosc), yields as related to nitrogen level are shown in Figures 6 and 7. For Bartlett (Figure 6), high nitrogen was clearly excessive. Trees in low nitrogen performed relatively poorly at the end of the test, indicating medium nitrogen was best as the trees grew larger. Bosc trees in mulch and cultivation (Figures 7 and 8) yielded consistently better with high nitrogen than with medium nitrogen. Trees in low nitrogen showed a marked tendency toward heavy yielding one year, followed by low yield the next.

Fruit was largest with both varieties in clean cultivation (Table 15). Also, the high level of nitrogen resulted in slightly larger fruits than did lower levels. In general, other factors remaining constant, fruit size is related to crop density or leaf/fruit ratio (*1, 20, 28, 31*).

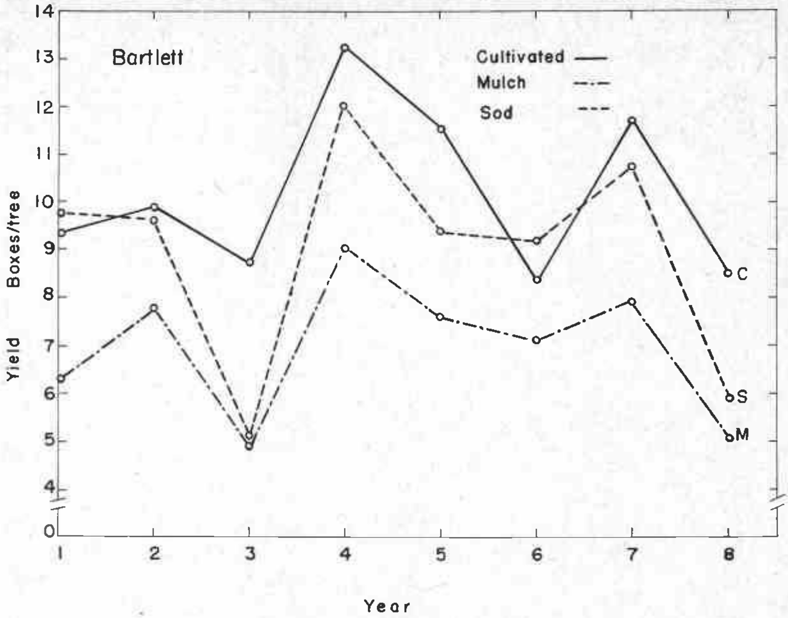

Figure 2. Effect of cultural treatment (average of all nitrogen levels) on yield of Bartlett pear growing in Meyer clay adobe soil (1952-1959).

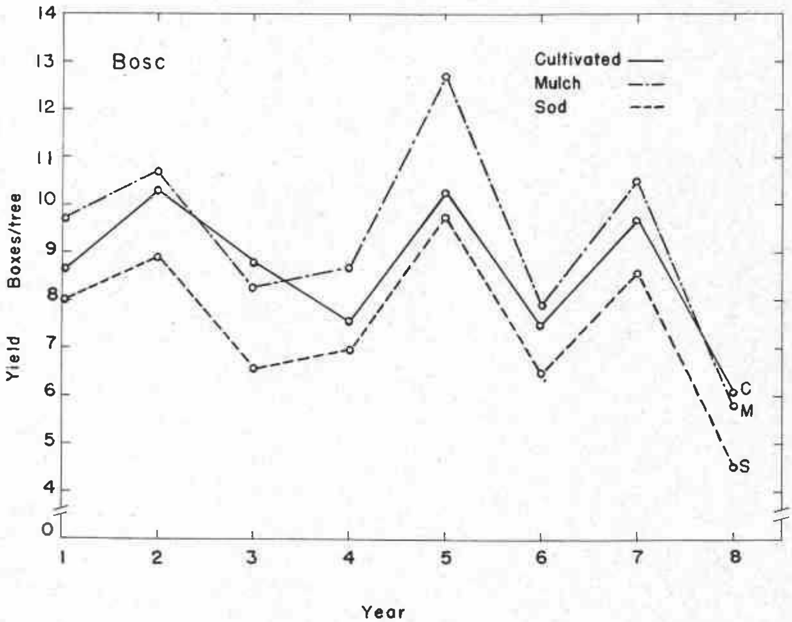

Figure 3. Effect of cultural treatment (average of all nitrogen levels) on yield of Bosc pears growing in Meyer clay adobe soil (1952-1959).

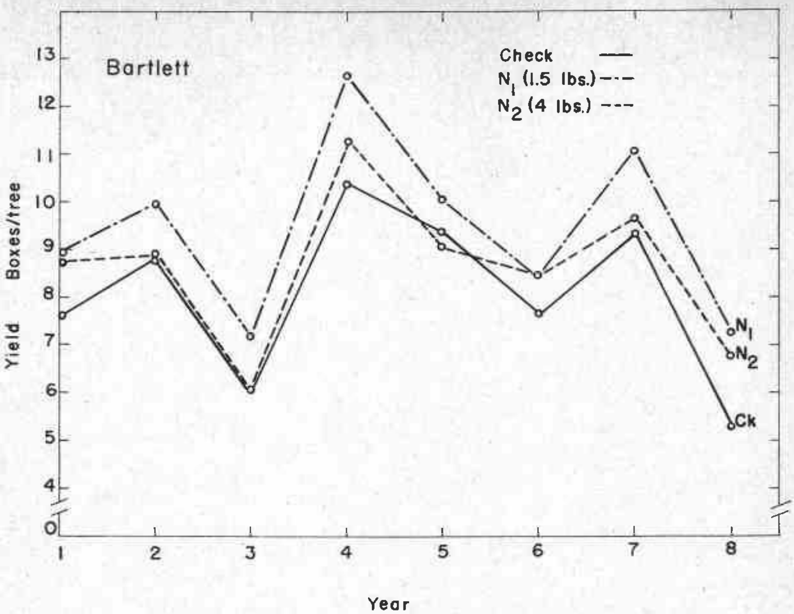

Figure 4. Effect of nitrogen level (average of all cultures) on yield of Bartlett pears growing in Meyer clay adobe soil (1952-1959).

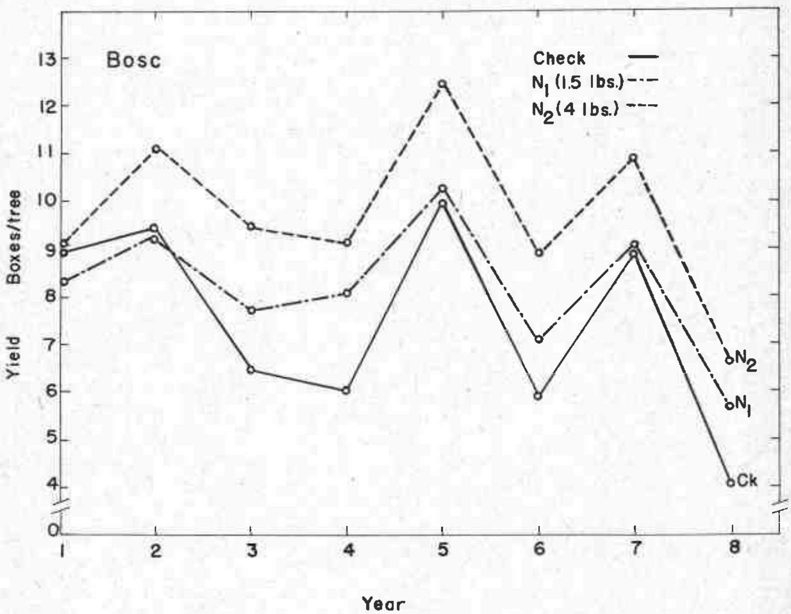

Figure 5. Effect of nitrogen level (average of all cultures) on yield of Bosc pears growing in Meyer clay adobe soil (1952-1959).

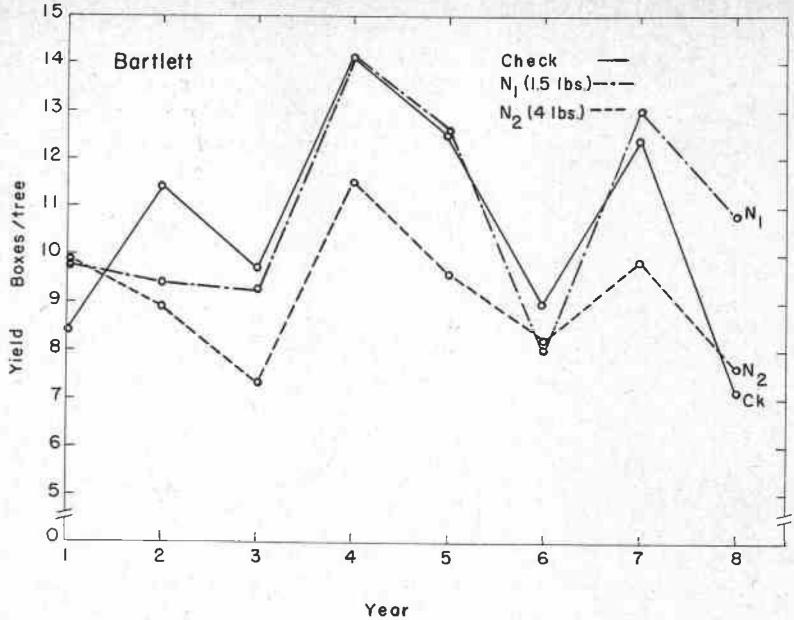

Figure 6. Effect of nitrogen level in clean cultivation on yield of Bartlett pears growing in Meyer clay adobe soil (1952-1959).

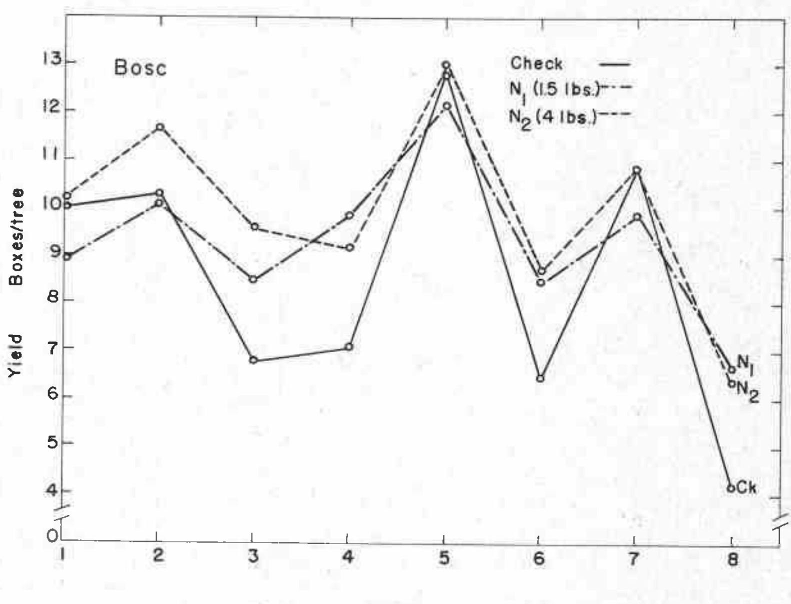

Figure 7. Effect of nitrogen level in mulch plots on yield of Bosc pears growing in Meyer clay adobe soil (1952-1959).

However, in this test, where both culture and nitrogen were varied, fruit size was related more to these factors than to crop density.

Seasonal shoot growth of both varieties was greatest in clean cultivation (Table 15). With regard to nitrogen level, maximum shoot growth occurred at the medium level for both varieties. The shorter growth of Bosc shoots in high nitrogen (as related to medium nitrogen) probably was due to the concomitantly heavier cropping of trees in high nitrogen (Figure 8).

Leaf nitrogen was significantly lower in sod for both varieties than in other cultures (Table 15). Clean cultivation and mulching resulted in similar leaf nitrogen. As expected, the amount of nitrogen in the leaves was directly related to the amount applied to the soil. But Bosc had distinctly lower leaf nitrogen than Bartlett for any given treatment. It is evident that the high level of nitrogen, resulting in more than 2.9% leaf nitrogen, is too high for optimum yields of Bartlett. But the highest leaf nitrogen for Bosc (slightly over 2.5% nitrogen) may not have been high enough for maximum yields.

Soil nitrates varied both with culture and with nitrogen applied (Table 16). The general level of nitrates on May 1 did not differ much between cultures, but on June 19, sod had less than other cultures. The surface 6 inches of soil contained markedly more nitrates

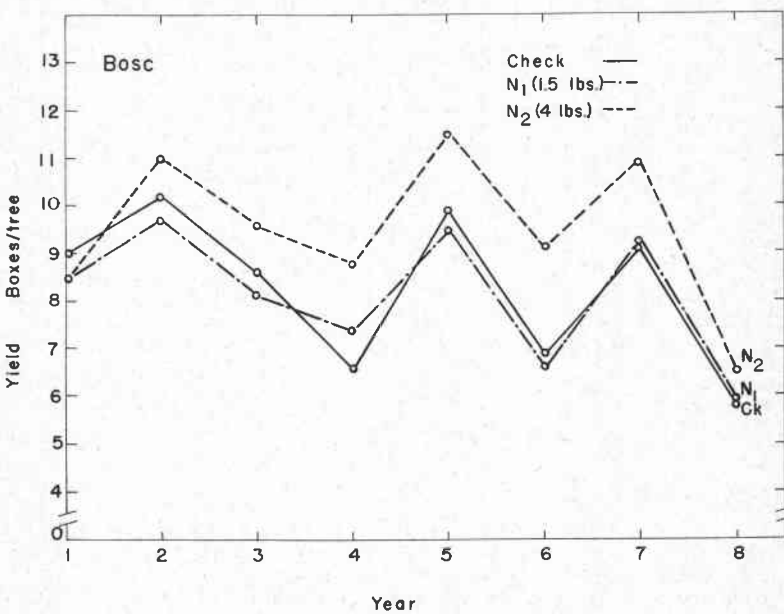

Figure 8. Effect of nitrogen level in clean cultivation on yield of Bosc pears growing in Meyer clay adobe soil (1952-1959).

Table 16. EFFECT OF CULTURE AND NITROGEN LEVEL ON SOIL NITRATE UNDER BARTLETT AND BOSC PEAR TREES (BLOCK 2, 1952)

Treatment	N applied annually	Soil nitrate, May 1			Soil nitrate, June 19		
		0-6 in.	7-12 in.	Avg.	0-6 in.	7-12 in.	Avg.
	lbs.	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*
Clean cultivation	0	6.3	3.2	4.8	13.2	3.4	8.3
	1.5	9.2	6.3	7.8	27.6	7.2	17.4
	4.0	53.7	18.1	35.9	54.4	13.7	34.0
Avg. cultivation		23.1	9.2	16.1	31.7	8.1	19.9
Mulch	0	2.5	1.9	2.2	6.7	2.7	4.7
	1.5	14.9	3.8	9.3	14.0	4.6	9.3
	4.0	36.3	5.8	21.1	72.4	10.0	41.2
Avg. mulch		18.0	3.8	10.9	31.0	5.8	18.4
Sod	0	3.4	2.7	3.0	4.3	3.0	3.6
	1.5	24.7	4.6	14.6	10.9	4.2	7.6
	4.0	50.2	6.7	28.4	24.8	9.3	17.0
Avg. sod		26.1	4.6	15.4	13.3	5.5	9.4
Avg. effect of N	0	4.1	2.6	3.4	8.1	3.0	5.5
	1.5	16.2	4.9	10.6	17.5	5.3	11.4
	4.0	46.8	10.2	28.5	50.5	11.0	30.8

than did the second 6 inches, and as expected, soil nitrates increased as the amount of applied nitrogen increased. The reduction of nitrates in sod on June 19 probably was due to nitrate removal by the grass roots.

Soil pH was only slightly affected by culture but was reduced markedly by applications of $(NH_4)_2SO_4$ (Table 17). The greatest change in pH occurred in the surface foot of soil rather than in deeper layers.

Soil moisture was slightly higher in clean cultivation than in other cultures, although none appeared limiting to tree performance (Table 18). The moisture under mulch was relatively lower, and in sod relatively higher, than was found in tests with Anjou (see Tables 3 and 14). The difference in the kind and amount of mulch in Test 1 and Test 5 might well have resulted in the differences in soil moisture. The much thicker layer of mulch in Test 1 appeared to have more effectively prevented surface evaporation. Also, the rye used for mulching in Test 5 was grown right next to the trees, which alone could account for some depletion of moisture prior to cutting. Soil moisture was lowest in sod culture in both Anjou plots (Test 4) and Bartlett and Bosc plots (Test 5). The relatively higher soil moisture in Test 5

Table 17. EFFECT OF CULTURE AND NITROGEN LEVEL ON THE pH OF SOIL UNDER BARTLETT AND BOSC PEAR TREES (BLOCK 2, 1953-1960)

Year and treatment	N applied annually	pH at different depths				
		0-6 in.	7-12 in.	0-1 ft.	1-2 ft.	2-3 ft.
	lbs.					
1953:						
Clean cultivation	0	5.65	6.17	5.84	......	......
	1.5	4.77	6.01	5.04	......	......
	4.0	4.71	6.07	4.99	......	......
Mulch	0	5.99	6.03	6.01	......	......
	1.5	5.03	5.84	5.27	......	......
	4.0	4.95	5.70	5.18	......	......
Sod	0	6.15	6.24	6.20	......	......
	1.5	5.26	6.02	5.49	......	......
	4.0	4.90	6.15	5.18	......	......
1954:						
Clean cultivation	0	......	......	5.96	6.76	7.04
	1.5	......	......	5.83	6.64	7.12
	4.0	......	......	5.44	6.72	7.10
Mulch	0	......	......	5.90	6.62	7.12
	1.5	......	......	5.88	6.57	7.11
	4.0	......	......	5.40	6.46	6.98
Sod	0	......	......	5.94	6.72	6.89
	1.5	......	......	5.58	6.80	7.27
	4.0	......	......	5.02	6.23	6.89
1960:						
Clean cultivation	0	......	......	6.47	......	......
	1.5	......	......	5.53	......	......
	4.0	......	......	4.67	......	......
Mulch	0	......	......	6.56	......	......
	1.5	......	......	5.99	......	......
	4.0	......	......	5.48	......	......
Sod	0	......	......	6.37	......	......
	1.5	......	......	5.98	......	......
	4.0	......	......	5.15	......	......

Table 18. EFFECT OF CULTURE ON THE SOIL MOISTURE AT DIFFERENT DEPTHS UNDER BARTLETT AND BOSC PEAR TREES (BLOCK 2, 1953-1958)

Treatment	Soil moisture				Available moisture			
	0-1 ft.	1-2 ft.	2-3 ft.	Avg.	0-1 ft.	1-2 ft.	2-3 ft.	Avg.
	% dry wt.				*% moisture*			
Clean cultivation	27.5	27.5	26.6	27.2	70	70	64	68
Mulch	27.0	26.8	26.0	26.6	67	65	60	64
Sod	27.0	27.0	26.3	26.7	67	67	62	65

Table 19. EFFECT OF PRUNING METHOD ON FRUIT SIZE AND YIELD OF BARTLETT AND BOSC PEAR TREES (BLOCK 2, 1949-1952)

Pruning method	Bartlett yield:[a]		Bosc yield:[a]	
	Total	Above $2\frac{3}{8}$ in. diameter	Total	Above $2\frac{3}{8}$ in. diameter
	boxes	*boxes*	*boxes*	*boxes*
None	10.8	3.7	9.3	4.2
Light	9.5	5.0	8.1	4.8
Light + tips off	8.6	5.3	7.8	4.7
Heavy	7.2	5.2	7.7	6.6
L.S.D. (.05 level)	1.1	1.0	1.1	1.0

[a] Amounts shown are per tree annually.

than in Test 4 for similar cultures was probably due to the trees in Test 5 being much smaller and thus having much less extensive root systems for extracting moisture.

Test 6 (pruning)

Total yield for both Bartlett and Bosc was inversely related to the severity of pruning, while the amount of fruit larger than $2\frac{3}{8}$ inches diameter was increased by pruning (Table 19). Maximum yield of large fruit for Bartlett was achieved with light pruning, but heavy pruning was necessary to obtain maximum yield of large fruit for Bosc. No fruit thinning was done in this test, in order to assess fully the effect of pruning on fruit size as well as total crop. It is recognized, however, that some combination of pruning and fruit thinning might be necessary to get the highest yield of well-sized fruits. Attempts to avoid fruit thinning by doing heavy pruning result in too great removal of both fruiting wood and potential leaf surface, thus reducing both tree size and yield.

GENERAL DISCUSSION

Low soil moisture appeared to be a limiting factor for fruit production in mature Anjou blocks (tests 1 to 4), but not for somewhat younger and smaller trees of Bartlett and Bosc (tests 5 and 6). Heavy mulching (Table 3) resulted in the highest soil moisture, followed by cultivation, with the lowest in compacted soil. In plots where the mulch was light and was grown in the plots (Table 18), mulched soil had less moisture than cultivated soil. Permanent grass sod (Tables 14 and 18) had less soil moisture at all depths than cultivated soil. In the mature Anjou plots, the relatively poor tree performance might have been due in some cases to low soil moisture.

Soil compaction affected very adversely both tree performance and soil moisture (Tables 1 to 3). This test and the report of Latham (*26*) indicate that the increased use of heavy equipment, particularly when the soil is wet, may be a major limiting factor in clayey soils.

The long-term use of $(NH_4)_2SO_4$ fertilizer in a mature Anjou block (Test 4) drastically lowered the pH and total bases of the upper foot of soil. The fact that liming (Table 13) increased yields in these plots indicates that low pH can lower production.

The separate adverse effects of low soil moisture, compaction, and low pH (as well as their interactions) are cumulative and appear to play major roles in lowering fruit production in tight, fine-textured soils. The cumulative effects of low pH, soil compaction, and the attendant lack of moisture penetration may well account for the reduction in Anjou yields shown in Figure 1. A small part of the yield reduction after 1957 was no doubt due to a disorder called Pear Decline. But relatively few trees in the plots developed the disorder, and all of the healthy trees in the plots produced less fruit at the end of the test than during the middle years.

Pruning response varied greatly with variety. At least moderate pruning was essential for maximum yield of Anjou (Table 6), but not for Bartlett and Bosc (Table 19). However, small-sized fruit was a problem when the latter two varieties were not pruned.

Both Anjou and Bosc appeared to require more applied nitrogen than Bartlett for maximum fruit production, although Bartlett had a higher leaf nitrogen than the other varieties under similar conditions. The form of nitrogen used is important and should be neutral or basic for soils already slightly acid. Where an acid-forming fertilizer such as $(NH_4)_2SO_4$ has been used for many years, lime may be needed to improve tree performance.

SUMMARY

Six tests of varying durations were carried out at the Southern Oregon Experiment Station between 1942 and 1963, with Anjou, Bartlett, and Bosc pear trees growing in Meyer clay adobe soil. Effects of pruning, nitrogen fertilizer, and cultural management on tree growth, fruit set and size, yield, soil moisture, and soil pH were studied. Results of the tests are summarized as follows:

Part I—Anjou

Test 1 (mulches, nitrogen, compaction)

1. Tree growth, fruit set, and yield were generally greater with high rates of nitrogen, mulches, and non-compaction than with low nitrogen, no mulching, and soil compaction.

2. Fruit size was not closely related to treatments but was inversely related to crop density.

3. Soil moisture was lowest in compacted soil, intermediate in cultivated soil, and highest under mulches.

4. Soil pH was lowered in proportion to the amount of $(NH_4)_2SO_4$ applied. The 50-pound annual rate lowered the pH to 4.4 in the upper foot of soil.

5. Soil nitrate increased as the rates of nitrogen were increased.

Test 2 (pruning)

1. Fruit set and yield were greater with moderate or heavy pruning than with nonpruning.

2. Shoot growth was greater with heavy than with moderate pruning, but yields were similar for both treatments.

3. The stimulus of pruning on fruit set was not transferred to unpruned leaders of the same tree.

Test 3 (tree thinning)

1. There was an immediate increase in yield per tree after removal of half the trees (alternate diagonal rows), originally spaced 25 by 25 feet apart, but yield per acre was decreased.

2. After 14 years, widely-spaced trees were larger than unthinned ones, but per-acre yield was still lower than on unthinned trees.

Test 4 (cultivation, cover crop, sod)

1. Tree growth was greatest with cultivation, intermediate with cover cropping (rye and vetch), and least with sod.

2. Fruit set and yield were greater with cultivation than other cultures, but fruit size was similar in all treatments.

3. Leaf nitrogen was highest with cultivation, intermediate with cover crop, and lowest with sod.

4. Soil nitrate in the spring was lower in sod than in other cultures.

5. With 20 pounds $(NH_4)_2SO_4$ per tree annually, soil pH (to a depth of 3 feet) was slightly lower in cultivation than in other cultures.

6. Both pH and yield were increased the second year after lime and nitrogen were applied to plots with low soil pH.

7. Soil moisture was highest in cultivation, intermediate in cover crop, and lowest in sod.

Part II—Barlett and Bosc

Test 5 (culture, nitrogen level)

1. Fruit set, yield, and size of Bartlett were highest with cultivation and lowest with mulch. But set and yield of Bosc were highest with mulch and lowest with sod.

2. Yield was highest for Bartlett with 1.5 pounds nitrogen (per tree annually), but 4 pounds nitrogen was best for Bosc.

3. The largest fruit for both varieties was from trees in cultivation getting 4 pounds nitrogen annually.

4. Longest shoot growth occurred for both varieties at the higher levels of nitrogen plus cultivation.

5. Leaf nitrogen varied directly with the amount of nitrogen applied, but at each level of nitrogen, Bosc leaves contained about 0.3% less nitrogen than Bartlett leaves.

6. Soil nitrate in May and June was directly related to the amount of nitrogen applied. By June 19, sod contained only half as much nitrate as other cultures.

7. Soil pH varied inversely with the amount of $(NH_4)_2SO_4$ applied and was lower in cultivation than in other cultures.

8. Soil moisture was slightly higher in cultivation than in other cultures, but all appeared to be adequate.

Test 6 (pruning)

1. Both Bartlett and Bosc yielded more fruit with no pruning than with pruning.

2. Maximum yield of fruits larger than $2\frac{3}{8}$ inches diameter was attained by light pruning of Bartlett and by heavy pruning of Bosc (with no hand thinning).

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APPENDIX

Soil Moisture Sampling and Irrigation Dates[a]

Test 1	April	May	June	July	August	Sept.	Oct.
Year							
1945	4, 19	7, (10–12)	4, 14, 25	2, 9, 24, 31	6, (8–13), 20, 27	6	4
1946	30	6, 14, 20, (24–28)	3, 10, 17	(3–8), 14, 23, 29	(1–4), 13		
1947		12, 19, 26	2, (16)	8, 14, (16–22)	(11–14)		

Test 4	March	April	May	June	July	August	Sept.
Year							
1946		30	7, 14, 20, (21-23)	4, 10, 17	(8-11), 15, 23, 29	(5-9)	
1947			12, 19, (23-24), 26	2	8, 14, (15-16)	(12-14)	
1948			25	9	2, 16, (18-22), 26	11, (20-23)	
1949		(20)	13, (17-18), 27	(11-14), 20, (24-27), 28	25	(6-13)	
1950			(16-17)	8, 15, 27	(1-8), 13	(4-5)	
1951		17, (28-30)	17	4, 19, (20-21)	11, 24, (25-30)		
1953		20	21	22	3, (6-8), 20	3, (6-9)	
1954		26	18, (24-25)	21	8, (12-13), 26	(2-9)	
1955	23, (24-25)	12	2, 16, (17-18)	3, 22	7, (15-16)	1, 15, (19-21)	7
1956		24	23	13, (25-26)	9, 23, (25-26)	13, (22-24)	
1957			6	6, (13-15), 26	(19-21)	(15-16)	
1958			22	20	2, (10-11), 16, 31	(17-20)	

Test 5	March	April	May	June	July	August	Sept.
Year							
1953		20	21	22	(10-16), 27	(7-11)	
1954		26	18, (28-31)	21	8, (16-21)	2, 10	
1955	23, (25-28)	13	3, 16, (19-22)	2, 22	7, (17-23)	1, 15, (17-25)	7
1956			3, 24	13, (26-3)	11, 23, (29-2)	(27-29)	
1957		30	6, 14, 20, 31	6, 14, (15-20), 18, 24	3, 11, 17, (21-25), 26	8, 12, (16-19), 19, 26	
1958			26	21	3, (11-14)	1,(20-24)	

[a] Numbers in parentheses are irrigation dates; all others are dates of soil sampling.