SHAKER-CLAMP INJURY TO FRUIT AND NUT TREES

. . . a research program aimed at causes and control

P. A. ADRIAN · R. B. FRIDLEY · D. H. CHANEY · K. URIU

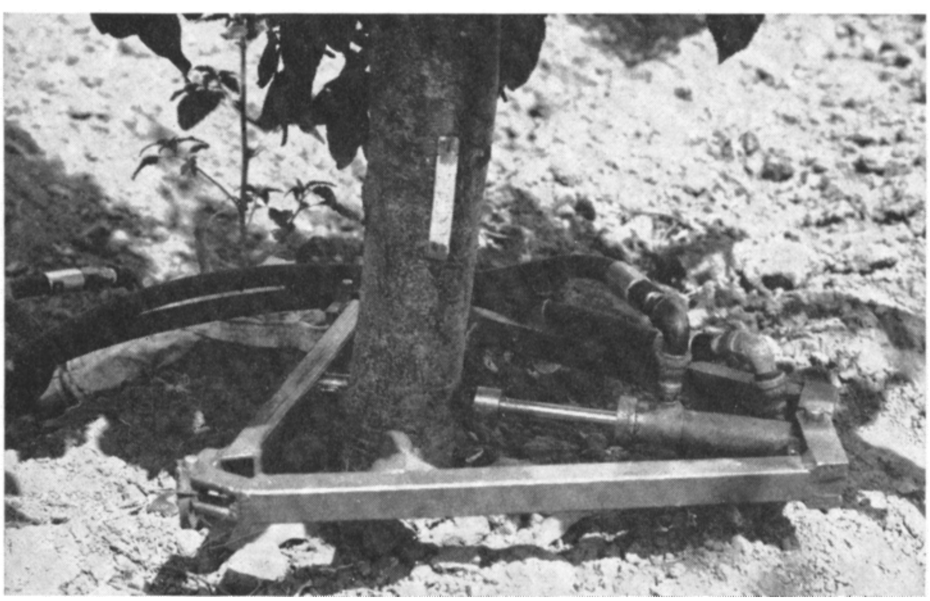
Shaker-clamp stresses on fruit and nut trees during mechanical harvesting, which can result in bark injury and susceptibility to disease, were measured under a variety of conditions in these continuing studies. Some of the variables found to affect bark injuries include moisture in both soil and bark, varietal differences, and tree age.

BEFORE 1962, injury to tree bark was observed to occur not only while shaking, but also while clamping onto limbs. In some instances, the injury was caused by tangential (shear) stresses arising from poor design or operation of the clamp, or by clamping limbs too firmly, which resulted in excessive radial (compression) stresses. Injuries were also caused by longitudinal stresses occurring when the shaking force was not directed perpendicular to the limbs. The problem first was approached by determining the allowable stresses that could be applied to limbs before injury or infection occurred —and consideration of possible methods for attaching and shaking limbs without exceeding these allowable stresses.

In 1962 a bark-strength testing unit was designed to apply either radial or tangential forces on the bark of both young and old French prune trees by hydraulic cylinders. The stresses applied to the tree were determined from the hydraulic pressure. In the radial tests, injury to the bark and cambium was evaluated by observation and by inoculation of the test areas with a solution containing *Ceratocystis* fungi. Additional radial tests were conducted on peaches, almonds, olives, and apricots.

Tangential tests were conducted for comparison with the radial tests, and since trees were found to be most susceptible to tangential failure, this type test was used during 1964 to evaluate the effects of irrigation, tree age, and tree variety and species.

Bark strength tester used in shaker tests.



Most tangential tests were designed to determine the total ability of bark to resist tension, compression, and shear reactions within—as well as shear at the cambium. Limited tangential tests were also conducted to determine the shear strength of the cambium only by cutting through the bark around the test area and removing adjacent bark.

Following the radial force tests, it was discovered that when the stress exceeded a given amount, the inner bark became discolored. As stress was increased, the discoloration extended to the cambium. Apparently, when the stress caused any hairline cracks in the bark, air entered and caused oxidation which was visible as browning. In the tangential shear tests, injury occurred only when the bark failed completely. This bark failure, occurred at a significantly lower stress than that which caused darkening in the compression tests.

The radial stresses causing browning at the cambium and tangential stresses causing bark failure are given for several species in table 1. With the exception of the Dixon peaches all trees were in U.C. orchards at Davis. Tests comparing static (clamping)and dynamic (clamping plus shaking) stresses were very limited. However, the dynamic stress which caused browning was at least 75% of the static stress which caused browning.

To determine the correlation between visible injury and fungus infection, thirteen trees were subjected to different compression pressures on each of two limbs. Test areas on one limb were cut open to determine when darkening occurred; test areas on the second limb were inoculated with fungus spores and wrapped with masking tape.

TABLE 1. COMPARISON OF RADIAL STRESS CAUSING BROWNING AT CAMBIUM AND TANGENTIAL STRESS CAUSING FAILURE FOR TREE SPECIES

Species	Radial (psi)	Tangential (psi)
Tilton Apricots*	800–900	250–265
Blenheim Apricots*	800–900	215–245
Dixon Peaches	700–800	200–230
Nonpareil Almonds	550–600	
Peerless Almonds	550–600	
French Prunes*	600–650	145–155
French Prunes	700–800	200–225
Olives	500–600	140–160

*Trees approximately 6 years old, other trees tested were mature.

TABLE 2. AVERAGE TANGENTIAL STRENGTH OF BARK AS RELATED TO TREE AGE 1964

Planting date	Ave. tangential strength (psi)		
	Yuba City		Oroville
	8/17	9/3	9/4
1941	...	...	368
1947	258	255	...
1951	263	267	...
1953	...	252	...
1955	...	...	363
1956	234	...	...
1957	234	245	...
1958	223	222	332
1960	...	...	284

Among the inoculated trees, *Ceratocystis* canker infection occurred on mature prune trees when the radial stress exceeded 1,000 psi (pounds per square inch). On young trees, the critical stresses were about 75% of this value. This correlated very closely to the magnitude of stress which visibly cracked the bark from the surface to the cambium. Thus, to combat *Ceratocystis* infection, a pad designed to allow a maximum radial stress of 500 psi and a maximum tangential stress of 100 psi to be developed on the limb would give a safety factor allowing for tree variability. However, in a few instances a radial stress of 500 psi resulted in visible discoloration of the inner bark and cambium, indicating some tissue injury and the possibility of future problems; therefore, a conservative radial design stress would be 250 psi. A total clamping and shaking force of 2,500 lbs would then require 10 square inches of contact on each side of the limb.

The effect of soil and bark moisture on the tangential strength of the bark was studied in 1964. Three plots (I, II, and III) containing 12 trees each were irrigated. The range of irrigation schedules used was greater than the normal grower practice to assure that extreme soil moisture conditions would be obtained. These three plots were compared to a test plot (IV) which was not irrigated after June 15. All plots were in adjacent areas and all trees were of the same age.

Analysis of the bark strength showed that for all irrigated plots a reduction of strength occurred around the end of July (see line graph). It then increased and in a period of about a week, was up to original bark strength. In general, the bark strength then gradually increased until the end of the test on September 16. In contrast, the nonirrigated plot did not show this reduction in bark strength but remained about constant until the last test date, when it increased slightly. The reduction in bark strength in irrigated plots and not in nonirrigated plots suggests that bark strength is susceptible to a change in soil moisture early in the season during the period of tree growth. After this period, no matter what the irrigation treatment, there seems to be little difference. A physiological change in the tree at cessation of growth which causes the bark fibers to strengthen, suggests that strength is no longer affected by soil moisture conditions during this period.

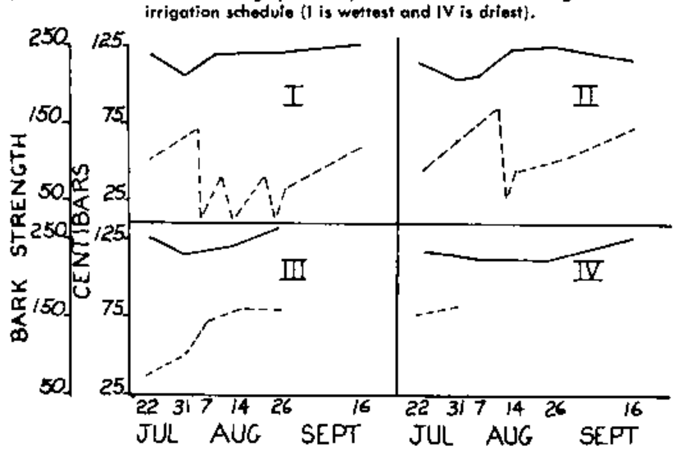
The absence of a correlation between soil moisture and bark strength late in the season may also be caused, in part, by the low normal stress applied by the shear pads. Studies have shown that for longitudinal shear at the cambium, the effect of bark moisture is most pronounced when the normal stress is high. It should also be pointed out that although the range in soil moisture was wide, the range in bark moisture was relatively narrow. The cambium strength followed the same trends as the total strength and was in the range of 60 to 80% of the total strength.

Shear tests were conducted in two grower orchards to correlate tree age and strength. One orchard was in the Yuba City area and the other was in the Oroville area. Table 2 shows the variation in average strength in terms of tree age. In the Yuba City orchard, both total and cambium strength were lowest for the 6-year-old trees, increased for the 7-, 11-, and 13-year-olds, but decreased slightly for the 17-year-olds. The reduction in strength for the 17-year-olds can probably

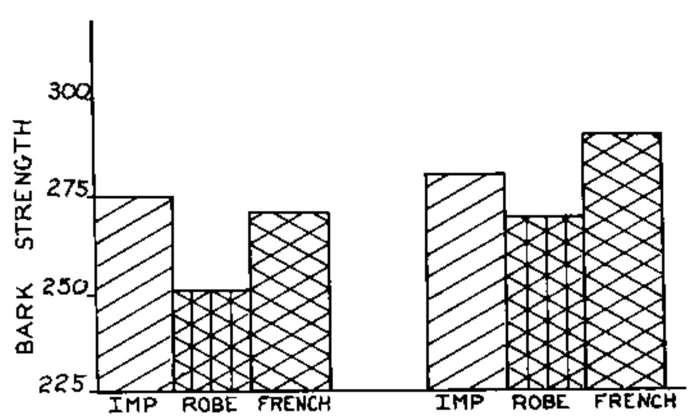
FUTURE RESEARCH

Although the combination of research results and commercial developments has reduced greatly the problem of injury to the bark of trees, the following aspects require further study: (1) the effect of tree vitality and seasonal variation on bark strength; (2) construction and field testing of remote-control limb-shaker for perpendicular attachment; (3) field testing the belt-type pads with modified rollers; (4) modification of trunk shaker pads to give radial force on bark; (5) the use of bolts for shaking the trunk in more than one direction; (6) the use of bolts in tree limbs on a commercial trial basis; and (7) improved pad construction. Tests to date with shaker clamp modification and permanent fasteners are described in a following article in this issue of *California Agriculture*.

RELATIONSHIP OF BARK STRENGTH AND SOIL MOISTURE
Solid line indicates bark strength; broken line is tensiometer reading and reflects irrigation schedule (I is wettest and IV is driest).



BARK STRENGTH RELATIONSHIP OF THREE PRUNE VARIETIES IN TWO TESTS



be attributed to past growing conditions or soil variability in the test area.

In the Oroville area, the total strength increased about 25% for 4- to 9-year-old trees (284 to 363 psi) but only slightly for trees from 9 to 23 years old. Cambium strength showed the same trends as total strength and was found to be about 60 to 70% of the total strength.

An interesting result of this test was the large difference in bark strength for the same age trees in two different areas. The Oroville trees were approximately 100 psi stronger than those in the Yuba City area. A considerably drier bark moisture condition was present in the Oroville orchard, which could account for part of this difference.

Measurements of shear strength were made on French, Imperial and Robe prunes on August 17 and September 3 in one orchard and on September 4 in a second orchard. Results show that Robes consistently were lowest in total strength, but that little difference existed between Imperial and French. The results from the Yuba City orchard indicate a general increase in strength of about 10% from August 17 to September 3. It was also noted that shear strength at the cambium was about 60% of the total shear.

The comparative bark strengths for four species, Texas almond, Blenheim apricots, Red Haven peaches, and French prunes, were also measured — under "wet" and "dry" conditions. Almond, apricots, and peaches all had the same strength (270 psi), while French prunes were slightly lower (245 psi) in the dry plot. The bark strengths (both wet and dry) were about the same except for the Red Haven peach, which maintained about 55 psi greater strength in the dry plot than in the wet plot.

P. A. Adrian is Agricultural Engineer, USDA; and R. B. Fridley is Assistant Professor, Department of Agricultural Engineering, University of California, Davis. David H. Chaney is Agricultural Extension Service Farm Advisor, Sutter County; and K. Uriu is Associate Pomologist, Department of Pomology, U. C., Davis. *These tests were conducted by the University of California in cooperation with USDA at the request of the California Prune Advisory Board. The California Prune Advisory Board, the Cling Peach Advisory Board, and the Almond Industry provided financial assistance; Delbert Henderson and James De Vay contributed technical assistance; and Jim Rumsey and Clarence Wong, U. C., Davis, aided in collection of data.*

TESTING PERMANENT FASTENERS

for shaker attachment to reduce limb injury in fruit and nut tree harvesting

P. A. ADRIAN · R. B. FRIDLEY · DAVID CHANEY

TO REDUCE SHAKER-CLAMP INJURIES on fruit and nut trees as described in a companion article in this issue of *California Agriculture*, tests were made to check the feasibility of using permanently installed fasteners for shaker attachments. This has the advantage of transmitting the shaking force through the fastener to the structural wood rather than through the vulnerable bark and growing tissue.

Threaded rods

The project was initiated in 1962 when threaded rods were installed in trunks of a number of prune and peach trees early in the spring. Three-fourths-inch and 1-inch rods were placed in both clearance and undersize holes. First, the bolt hole was drilled completely through the trunk; then a spur drill was used to make a flat surface into the hard wood for a flat washer to bear against. For the shaker attachment, a trailer hitch ball was placed on one end and the shaking force was directed approximately in line with the rod.

By harvest time, a thin layer of callus had formed over the edge of many washers. This layer was not disturbed during shaking. The ¾-inch bolt had sufficient strength for all shaking forces, provided the attachment was no greater than 2 to 3 inches from the tree. It was also found that clearance holes were adequate. The only problem encountered was the collapse of very old trees which had decayed internally.

TABLE 1. MEASURED WITHDRAWAL RESISTANCE FOR LAG SCREWS AND NAILS INSTALLED AND TESTED IN GREEN ALMOND WOOD

Type of Fastener	Hole diameter (in)	Withdrawal resistance*	
		Yield Force (lbs)	Ultimate Force (lbs)
1/2" Lag screw	5/16	3250	3400
	3/8	3550	3950
	7/16	3350	3570
5/8" Lag screw	7/16	5450	5720
	1/2	5770	6250
	9/16	5200	5600
3/4" Lag screw	5/8	6000	6500
1/2" Screw nail	1/2	2500	2700
5/8" Screw nail	5/8	2800	3020
3/4" Screw nail	3/4	—	3450

* Results given are averages of two measurements except for 3/4-inch fasteners which are one measurement.