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Effects of Mechanical Pruning Regimes on Yield, Canopy Structure, and Light Interception in 'French' Prune (*Prunus domestica* L.) Orchards

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Abstract. **A 5-year field trial (2019–23) was conducted in a 9-year-old commercial 'French' prune (*Prunus domestica* L.) orchard in California to evaluate how pruning timing and canopy geometry affect yield, fruit quality, canopy development, light interception, pruning biomass, and pruning costs. Six regimes were compared: dormant hand pruning, spring and fall mechanical boxing, spring and fall mechanical hedging, and a grower-adapted mechanical system. In 2023, the grower-adapted mechanical treatment produced the greatest marketable dry yield (14 t·ha^{-1}), significantly exceeding the fall-boxed treatment (8.3 t·ha^{-1}; $P \leq 0.05$). Two-year cumulative marketable yield was also greatest in the grower-adapted mechanical treatment (23 t·ha^{-1}), whereas 5-year cumulative yield did not differ significantly among treatments with complete data (39 to 47 t·ha^{-1}). Boxed treatments, particularly fall boxing, tended to reduce marketable fruit percentage and light interception. Mechanical pruning reduced annualized pruning costs by approximately USD 929 to 1214 ha^{-1} compared with winter hand pruning, but repeated mechanical heading removed less woody biomass than hand pruning and promoted canopy crowding. These results indicate that mechanical pruning can reduce pruning costs while maintaining yield in mature prune orchards, especially when cuts are timed and positioned to avoid excessive removal of fruiting wood. However, periodic corrective hand pruning is likely required to maintain canopy porosity, spur productivity, and disease management over the long term.**

Introduction

Labor availability and escalating operational costs represent persistent economic constraints in California prune (*Prunus domestica* L.) production. Dormant hand pruning ranks among the most labor-intensive orchard operations, requiring skilled crews to execute selective thinning cuts that maintain canopy architecture, renew senescing fruiting wood, and ensure uniform light distribution throughout the canopy profile. While mechanical hedging and topping offer alternative high-throughput strategies to mitigate labor dependencies, their long-term impacts on yield, fruit size distribution, canopy microclimate, and phytopathological risks remain insufficiently quantified in mature orchards.

Research in other perennial fruit crops shows that mechanical pruning can reduce labor requirements, but responses depend strongly on canopy architecture, timing, pruning severity, and the need for follow-up hand correction. In apple, mechanical hedging can maintain narrow canopies and reduce pruning costs, particularly in high-density systems, but excessive regrowth and reduced interior light penetration may occur when cuts are too severe or when corrective hand pruning is omitted (Lewis et al. 2015; Musacchi and Serra 2018; Robinson 2003). Similar tradeoffs have been reported in citrus and stone fruits, where topping and hedging help control tree size but may reduce fruit set, fruit size, or future cropping when applied at sensitive phenological stages (İkinci 2014; Zekri 2015).

These management tradeoffs are especially relevant for 'French' prune, a cultivar grown for dehydrated fruit where total economic return depends concurrently on gross yield and fruit size distribution. Dense canopies can reduce spur light exposure, lower fruit size, increase dead wood, and exacerbate disease pressure, whereas overly aggressive pruning can remove fruiting wood and stimulate vigorous nonproductive regrowth. Previous work in dried plum suggested that moderate mechanical pruning can maintain yields comparable to hand pruning, but excessive shading and loss of interior spur productivity require periodic structural correction (Krueger et al. 2013).

Best-management guidelines for mechanical pruning in prune remain poorly defined. In particular, growers need practical information on whether pruning should be performed in spring or after harvest, whether hedging alone is preferable to full boxing, and how mechanical systems can be integrated with occasional hand pruning. The objective of this study was to evaluate six pruning regimes over 5 years in a mature 'French' prune orchard and determine their effects on marketable yield, fruit size, canopy volume, light interception, pruning biomass, and pruning costs.

Materials and Methods

Site description and experimental design. The experiment was conducted from May 2019 through Oct 2023 in a high-yielding commercial European prune (*Prunus domestica* L. 'Improved French') orchard located in southern Tehama County, CA, USA (40°08′27.88″N, 122°11′26.71″W). The orchard was established in 2010 on 'Myrobalan 29C' rootstock at a spacing of 4.6 × 5.5 m (398 trees·ha^{-1}). At study initiation in 2019, trees averaged 4.8 m in height, with a mean canopy spread of 3.4 m across the row and 3.7 m within the row. The site was managed according to standard regional commercial practices for the Sacramento Valley, including subsurface drip, irrigation fertilization

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based on annual leaf tissue analysis, and integrated pest management for key regional pests and pathogens.

Treatments were arranged in a randomized complete block design with five blocks. Each experimental unit consisted of a plot of 10 contiguous trees, and all 10 trees within each plot were sampled for evaluations. Blocks were positioned to account for localized spatial gradients in soil texture and tree vigor.

Pruning treatments. Six pruning regimes were evaluated. The hand-pruned control represented the grower standard, whereas the mechanical treatments contrasted pruning timing, pruning severity, and canopy geometry:

- Grower standard hand pruning (GS): winter dormant selective hand pruning with loppers and ladders in January, using thinning and structural cuts typical of commercial prune orchards in the region.
- Boxed spring pruning (BSP): mechanical topping to ~4.0 m and hedging on both sides of the row and across the row at approximately 1.5 m from the trunk, applied in May to create a box-shaped canopy.
- Boxed fall pruning (BFP): the same geometry as BSP, applied after harvest in September or October.
- Hedged spring pruning (HSP): mechanical hedging on both sides of the tree row at approximately 1.5 m from the trunk, without topping or cross-row hedging, applied in May.
- Hedged fall pruning (HFP): the same geometry as HSP, applied after harvest.
- Grower mechanical pruning (GMP): a grower-adapted system applied in mid-May in which trees were skirted at ~30° and topped at ~20° on both sides, producing a diamond-shaped canopy; cross-hedging was performed every other year. The GMP treatment was added in 2022; therefore, data for this treatment were available only for 2022 and 2023, and it was excluded from 5-year cumulative comparisons.

Mechanical pruning was performed with a single-bar topper-hedger (Erick Nielsen Enterprises, Orland, CA, USA). Mechanical operations removed ~50% of current-season shoot growth based on visual estimates. Prunings from two to six representative trees per plot were weighed immediately after cutting, with the number of sampled trees adjusted according to the amount of pruning material produced. Approximately 500-g subsamples were oven-dried at 68 °C to constant mass, and total dry pruning biomass per replicate was estimated from the dry mass.

Crop thinning, harvest, and fruit quality. Crop load was evaluated annually, and mechanical thinning was applied only in 2023 when crop load exceeded commercial targets. Thinning decisions followed commercial California prune crop-load management practices based on the reference date. At or near this date, ~7 to 10 d after pit hardening, crop load was evaluated to determine whether thinning was needed and to estimate the amount of fruit to remove. When thinning was applied, shaker duration and intensity were adjusted by the grower and equipment operator to achieve the desired level of fruit removal. At harvest, the 10 measurement trees in each plot were shaken with commercial harvest equipment equipped with load-cell scales. Fresh yield was recorded for each plot, divided by the number of harvested trees to obtain mean yield per tree, and then converted to metric tonnes per hectare using the orchard planting density of 398 trees·ha^{-1}.

A 1.8-kg fruit subsample was collected at harvest from each plot replicate. Each subsample was taken from the harvested fruit of the central 10 measurement trees in that plot. Fruit subsamples were dehydrated in a commercial prune dryer using standard industry tunnel-drying conditions, with maximum drying air temperatures of ~85 °C and a drying duration of ~2 d. Plot dry yield was calculated by multiplying plot fresh yield by the dry-matter conversion factor determined from the 1.8-kg fruit subsample. Fruit size distribution was determined using nested sieve screens (A, B, C, D, and undersized) following procedures used for prune grading (James et al. 2000). For this study, marketable yield was defined as the dry yield represented by A and B screen-size fruit because C, D, and undersized fruit currently have little or no commercial value in the California prune market.

Tree canopy measurements and light interception. Canopy dimensions were measured annually just before harvest, after the spring-pruned treatments had completed seasonal regrowth and before any fall pruning was imposed. Five trees were measured per treatment replicate. Tree height, cross-row canopy width, and in-row canopy length were measured with a tape. Canopy volume was calculated as height × width × length to provide a consistent relative index of canopy size across treatments.

Canopy light interception was measured during the 2021–23 seasons using a manual transect approach adapted from the midday photosynthetically active radiation (PAR) light-interception methods developed by Lampinen and colleagues (n.d.) for orchard systems. Measurements were collected under clear-sky conditions near solar noon. For each plot replicate, four to five representative trees were sampled along perpendicular transects across the tree row. Approximately 100 below-canopy PAR measurements were collected per replicate, with measurements distributed beneath and between the sampled trees to characterize the light environment across the plot. Ten full-sun PAR measurements were collected in an unobstructed area and averaged to represent incident radiation. Percent light interception was calculated as $100 \times [1 - (\text{mean below-canopy light}/\text{mean full-sun light})]$.

Statistical analysis. Treatment effects were analyzed by analysis of variance for a randomized complete block design. Annual responses were analyzed separately by year, and cumulative yield variables were analyzed separately for the 2022–23 and 2019–23 periods. Percentage data were arcsine square-root transformed before analysis when required to improve normality and homogeneity of variance; untransformed percentages are presented for interpretability. Mean separation was performed with Tukey's honestly significant difference test at $P \leq 0.05$. Analyses were conducted with Statistix 10.0 (Analytical Software, Tallahassee, FL, USA).

Results

Marketable yield. Marketable dry yield varied among years and pruning regimes (Table 1; Fig. 1). The categorical dot plot illustrates the year-specific nature of yield responses, with higher marketable yields generally observed in 2019 and 2023 and lower yields from 2020 through 2022. The hand-pruned control followed a similar year-to-year pattern, indicating that annual yield variation was not limited to mechanically pruned treatments. Treatment rankings were not consistent among years, suggesting that pruning effects on marketable yield varied by harvest year. In 2022, the first year in which the grower-adapted mechanical treatment was included, no significant differences in marketable yield were detected among pruning regimes. In 2023, the grower-adapted mechanical treatment produced the greatest marketable yield (14 t·ha^{-1}), but this value was significantly greater only than the fall-boxed treatment (8.3 t·ha^{-1}); all other treatments were intermediate and did not differ significantly from either treatment.

Cumulative yield over 2022–23 ranged from 16 to 23 t·ha^{-1} and was numerically greatest in the grower-adapted mechanical treatment, followed by hedging in spring and

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Author contributions: R.R. conceived the study, coordinated the field trial, analyzed the data, and drafted the manuscript. B.W.-D., L.M., F.N., K.C., C.R., and N.O. contributed to field implementation, data collection, interpretation of results, and manuscript review and editing.
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Table 1. Marketable dry fruit yield (A + B screen sizes) of 'French' prune under six pruning treatments from 2019 through 2023. Yields are dry tonnes per hectare (t·ha^{-1}). Within a column, values followed by different letters differ by Tukey's honestly significant difference test ($P \leq 0.05$).

Treatment	2019	2020	2021	2022	2023	Cumulative 2022–23	Cumulative 2019–23
Hand-pruned control	12.0	7.2	7.8	6.7	13.3 ab	20 ab	47
Boxed spring	8.7	6.3	6.7	8.3	9.4 ab	18 ab	39
Boxed fall	9.9	6.5	7.2	7.6	8.3 b	16 b	39
Hedged spring	9.0	6.7	8.3	8.3	12 ab	21 ab	45
Hedged fall	9.9	6.5	9.6	9.0	9.6 ab	19 ab	45
Grower mechanical	—	—	—	9.2	14 a	23 a	—

the hand-pruned control. Across the full 2019–23 period, treatments with complete 5-year records produced 39 to 47 t·ha^{-1}, and cumulative yield did not differ significantly among treatments. Thus, mechanical pruning did not reduce long-term marketable yield in this mature orchard compared with conventional hand pruning, although the full boxed treatments tended to produce lower cumulative yields than hand pruning and hedging.

Marketable fruit percentage. The percentage of marketable fruit generally remained high, but treatment differences emerged in 2022 (Table 2). Hand pruning and grower-adapted mechanical pruning maintained high marketability, whereas fall boxing produced the lowest percentage of marketable fruit (68%) and was significantly lower than the hand-pruned and grower-adapted mechanical treatments. By 2023, marketable fruit percentages recovered across treatments, and no significant differences were detected.

Pruning costs. Mechanical pruning substantially reduced pruning-related costs compared with dormant hand pruning (Table 3). After accounting for periodic corrective hand pruning in mechanically pruned trees, projected annualized savings ranged from approximately USD 929·ha^{-1} for boxing to USD 1214·ha^{-1} for hedging. Hedging was less expensive than boxing because it required fewer mechanical passes and did not include topping or cross-row cuts.

Pruning biomass. Hand pruning removed substantially more dry biomass than any mechanical treatment over 2019–22 (Fig. 2). This difference reflects the type of cut. Hand pruning relied primarily on thinning cuts that removed entire branches back to a scaffold or trunk, whereas mechanical hedging and topping used heading cuts that shortened terminal growth. Consequently, mechanical pruning removed less woody material and retained more canopy volume, but it also left interior branches that would normally be removed during selective pruning.

Canopy volume and light interception. Pruning regime altered canopy architecture (Fig. 3). Hand-pruned trees had the greatest cumulative canopy volume, although they were not significantly different from the boxed-fall, hedged-spring, or hedged-fall treatments. Boxed-spring pruning produced the smallest canopy volume and was significantly lower than the hand-pruned control. These results indicate that the most restrictive mechanical pruning geometry, particularly spring boxing, reduced canopy size, whereas hedging and fall boxing maintained canopy volumes more similar to hand pruning. Smaller canopy volume can improve machinery access and canopy containment, but excessive canopy reduction may reduce total leaf area and light capture.

Light interception differed among pruning regimes during 2021–23 (Fig. 4). Boxed spring pruning consistently had the lowest light interception, whereas hedged fall and hand-pruned trees generally intercepted more light. Observed light interception values ranged from ~39% to 54%.

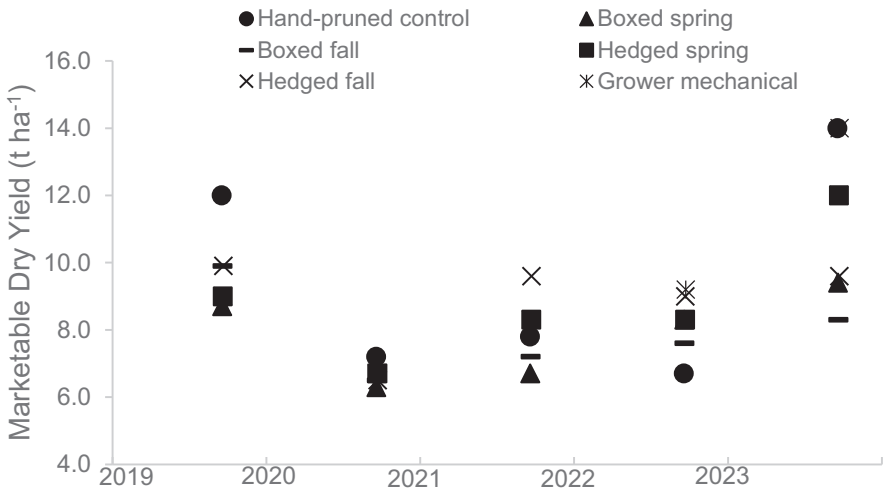

Fig. 1. Marketable dry yield of 'Improved French' prune trees under six pruning treatments from 2019 through 2023. Each point represents the treatment mean for a discrete annual harvest. Points are horizontally offset within each year to improve visibility. The grower-adapted mechanical treatment was added in 2022; therefore, data for this treatment are shown only for 2022 and 2023.

Cytospora incidence. *Cytospora* canker incidence was measured during the study, but no significant treatment differences were detected among pruning regimes. Overall disease incidence remained low across the experimental orchard, likely reflecting the cooperating grower's active disease-management program. These results indicate that pruning regime did not measurably affect *Cytospora* incidence under the disease-pressure conditions present in this orchard.

Discussion

Yield and fruit quality responses. Annual yield trends in the experimental orchard generally followed California prune production patterns from 2019 to 2023, with relatively high yields in 2019, reduced yields in 2020, and high yields again in 2023. However, the orchard did not fully mirror statewide trends in 2022, when several pruning treatments produced yields similar to or greater than those in 2021. This indicates that local orchard conditions, crop load history, thinning, and pruning treatments also influenced annual yield. The hand-pruned control followed the broader year-to-year pattern of high yield in 2019 and 2023 and lower yield in 2020–22, suggesting that annual yield variation was not limited to mechanically pruned trees.

Treatment rankings were not consistent among years, indicating that pruning effects on marketable yield varied by harvest year. Bloom-period heat did not appear to be the primary driver of annual yield variation in this study. Although high temperatures during or shortly after bloom can shorten the effective pollination period and reduce fruit set in prune (Castro and DeJong 2021), the lowest-yielding years were not consistently associated with unusually high bloom-period temperatures. Annual yield variation was therefore more likely driven by interacting effects of bloom weather, crop load, fruit thinning, pruning treatment, and seasonal growing conditions, rather than by bloom-period heat alone or by a simple alternate-bearing pattern.

The higher marketable yield of the grower-adapted mechanical treatment in 2023 should be interpreted cautiously because this treatment was added in 2022, whereas the other pruning regimes had been imposed since 2019. No significant differences in marketable yield were detected in 2022, the first year in which the grower-adapted treatment was included. The 2023 difference may therefore reflect both the less disruptive canopy geometry of the grower-adapted system and its shorter treatment history. By creating a diamond-shaped

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Table 2. Marketable fruit percentage (A + B screen sizes) from 2019 through 2023 under six pruning treatments. Values represent percentage of dry yield by weight. Within the 2022 column, values followed by different letters differ by Tukey's honestly significant difference test ($P \leq 0.05$).

Treatment	2019	2020	2021	2022	2023
Hand-pruned control	94	95	100	92 a	93
Boxed spring	86	91	98	82 ab	83
Boxed fall	89	86	99	68 b	92
Hedged spring	89	85	92	77 ab	87
Hedged fall	89	84	99	75 ab	89
Grower mechanical	—	—	—	91 a	93

Table 3. Estimated pruning costs and projected savings from mechanical pruning in a mature 'French' prune orchard. Costs are presented as USD·ha^{-1}. Projected savings for mechanical treatments include one-quarter of the estimated corrective hand-pruning cost applied every fourth year.

Cultural operation	Pruning cost (USD·ha^{-1})	Projected savings (USD·ha^{-1})
Hand pruning	2,590	—
Hedging both sides	285	1,214
Boxing	570	929
Corrective hand pruning in mechanically pruned trees	4,365	—

Hand-pruning cost is based on USD 6.50·tree^{-1}. Hedging and topping costs are based on commercial mechanized hedging service rates. Boxing includes hedging on four sides plus mechanical topping. Corrective hand pruning in mechanically pruned trees is estimated at USD 9.75·tree^{-1} every fourth year; one-quarter of this cost is included in the projected savings for mechanical pruning.

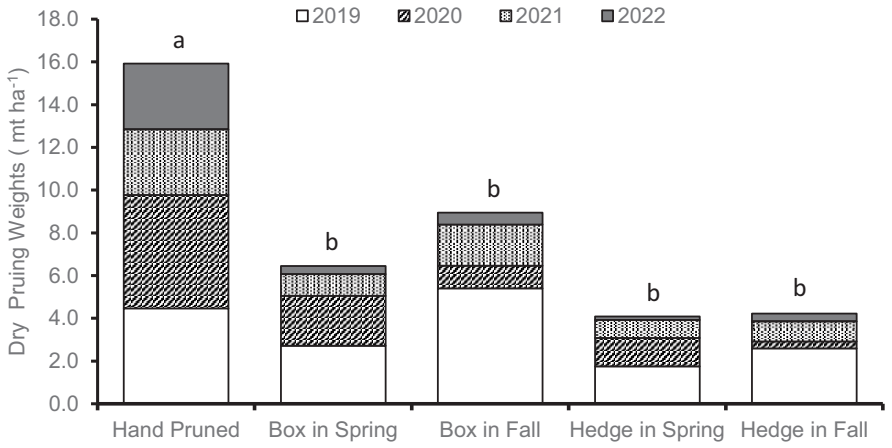

Fig. 2. Cumulative dry pruning biomass removed by hand and mechanical pruning treatments from 2019 through 2022. Pruning weights were not collected in 2023. Columns with the same letter are not significantly different ($P \leq 0.05$).

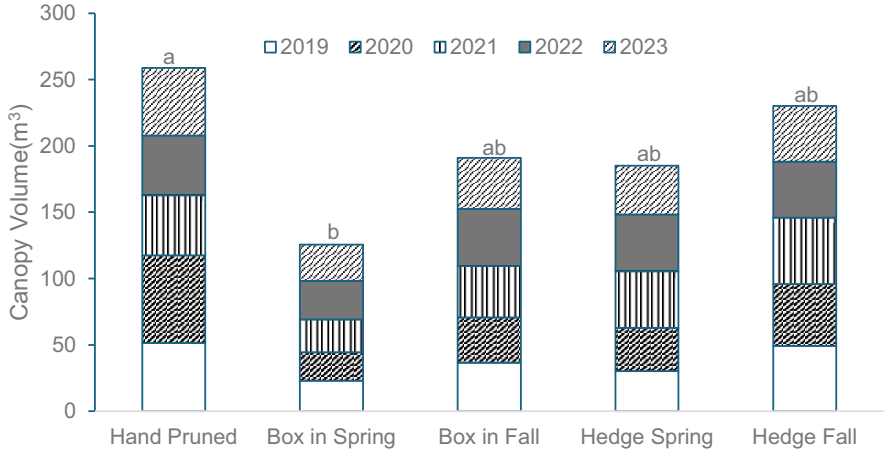

Fig. 3. Cumulative canopy volume of 'French' prune trees under hand and mechanical pruning treatments from 2019 through 2023. Columns with the same letter are not significantly different by Tukey's honestly significant difference test ($P \leq 0.05$).

canopy and limiting removal of large structural limbs, this approach likely preserved more fruiting wood and reduced the vigorous vegetative regrowth commonly associated with large heading cuts. Such regrowth can remain nonproductive for multiple seasons and may compete with fruiting spurs for light and carbohydrates (Guimond et al. 1998). In contrast, the other mechanical regimes had experienced repeated heading, topping, or boxing for five seasons, which may have cumulatively altered scaffold structure, canopy density, and the amount or distribution of fruiting wood.

Across years, hedged treatments tended to produce greater and more consistent marketable yields than boxed treatments, suggesting that hedging maintained more productive canopy while still providing canopy containment. Field observations indicated that hedged trees retained substantial fruiting wood between adjacent trees, forming a more continuous fruiting hedge within the row. In contrast, boxed treatments removed more limbs from the inter-tree space, reducing canopy volume and likely decreasing bearing surface. This difference in canopy geometry may help explain why boxed treatments, particularly fall boxing, tended to have lower cumulative marketable yield and lower marketable fruit percentage than hedged treatments.

The 2022 reduction in fall-boxed trees may have resulted from the combination of aggressive postharvest pruning and reduced carbohydrate replenishment after harvest. Pruning timing may also affect subsequent yield because flower buds for the following season in *Prunus* species are initiated and differentiated during the current growing season, generally from late spring through summer and early fall (Faust 1989). Therefore, postharvest pruning can remove photosynthetic leaf area during reserve replenishment and flower-bud development, potentially reducing return bloom, fruiting wood quality, or subsequent crop performance. Although flower-bud development was not measured in this study, this mechanism may help explain why more aggressive postharvest canopy removal was less favorable than hedging or the grower-adapted spring mechanical system. Similar reductions in growth, carbohydrate status, or fruit quality after poorly timed summer pruning have been reported in peach trees (İkinci 2014).

A central concern was that mechanical pruning would reduce fruit quality by altering canopy structure and fruiting wood distribution. The data only partially supported this concern. Boxed treatments, especially fall boxing, were more likely to reduce marketable fruit percentage and light interception, but the grower-adapted mechanical system maintained marketable fruit percentages equivalent to the hand-pruned control in 2022 and 2023. These results suggest that mechanical pruning can preserve fruit quality when it avoids excessive canopy compression and when pruning timing is matched to crop load and tree phenology.

In practice, pruning timing should account for expected crop load and tree vigor. In high-crop years, spring mechanical pruning

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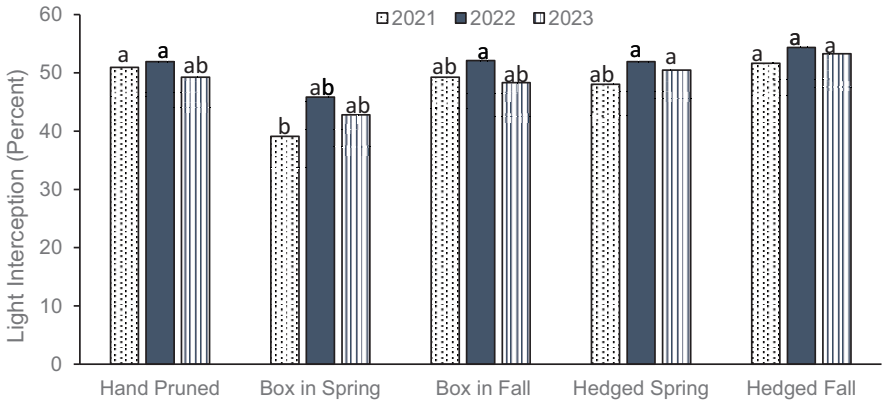

Fig. 4. Midday canopy light interception (%) in 'French' prune trees under selected pruning treatments from 2021 through 2023. Measurements were collected using manual perpendicular transects across adjacent tree rows. Columns with the same letter are not significantly different by Tukey's honestly significant difference test ($P \leq 0.05$).

can reduce crop load and may reduce the need for fruit thinning. In low-crop years, delaying mechanical pruning until after harvest may avoid unnecessary fruit removal. Regardless of timing, cuts into large-diameter wood should be minimized because they can stimulate vigorous regrowth for multiple seasons and reduce productive canopy volume.

Pruning economics and biomass removal. These savings are economically important because pruning is a recurring expense and skilled labor availability is uncertain. However, mechanical pruning should not be viewed as a complete replacement for structural hand pruning. Repeated mechanical heading can retain excessive interior wood, reduce canopy porosity, and increase dead or shaded spurs. A rotational strategy in which mechanical pruning is combined with periodic hand correction every 4 to 5 years appears more appropriate for sustaining canopy structure while capturing most of the labor savings.

Mechanical pruning was applied annually in this trial to maintain consistent treatment structure, but pruning biomass generally declined over successive years. This suggests that in commercial orchards, alternate-year or as-needed mechanical pruning may be sufficient in some years, provided that canopy structure, light penetration, and fruiting wood renewal are maintained.

Greater pruning biomass removal was negatively correlated with yield ($r = -0.47$, $P \leq 0.05$), suggesting that excessive removal of woody and fruiting structures can reduce yield potential. This relationship should be interpreted cautiously because pruning weight is both a treatment response and an indicator of canopy vigor, but it supports the practical recommendation to avoid large, aggressive cuts unless structural correction is necessary.

Canopy architecture, light interception, and corrective pruning. Prune-specific target values for midday PAR interception have not been well established. However, limited California prune data suggest that denser plantings can intercept ~60% to 80% of midday light, whereas wider-spaced plantings commonly intercept ~30% to 45% (Milliron et al. 2019). In the present study, light interception ranged from ~39% to 54%. These values suggest that some pruning regimes, especially full boxing, may have removed too much canopy to maximize light capture. Recent work in European plum also showed that tree architecture can strongly influence canopy light interception: upright, pillar-type trees intercepted about twice as much light as unpruned, standard-shaped control trees and produced fruit with more uniform red skin overcolor, although fruit size and soluble solids were not increased (Tang et al. 2025). The absence of a significant correlation between yield and light interception in this study may reflect crop thinning, treatment effects on fruiting wood, or species-specific differences in how prune canopies translate light capture into dry fruit yield.

Canopy volume differed more clearly among pruning treatments than midday light interception (compare Figs. 3 and 4), indicating that canopy size alone did not fully determine light capture. Canopy volume was calculated from external canopy dimensions and therefore reflected treatment effects on tree height, width, and row length. In contrast, light interception depended on the spatial distribution and density of foliage within that volume. Mechanically boxed trees occupied less canopy space, but the remaining canopy may have contained dense peripheral foliage that intercepted incoming radiation. Similarly, larger hand-pruned

Fig. 5. Dense canopy structure in a 'French' prune tree following five consecutive years of mechanical pruning by boxing.

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Table 4. Conceptual summary of expected seasonal effects of mechanical pruning on regrowth dynamics and Cytospora risk in mature 'French' prune trees.

Time of year	Regrowth response	Regrowth notes	*Cytospora* infection risk (rain splash)	Latent *Cytospora* symptom expression	Disease-risk notes
Dormancy (late December–mid March)	High	Pruning before budbreak removes apical dominance without immediately limiting photosynthesis; stored reserves support vigorous regrowth from latent buds.	Moderate to high	Low	Winter storms can spread inoculum to pruning wounds; cool temperatures may suppress symptom expression.
Flowering (early spring)	High	Reserves remain high, but pruning can disrupt bloom and fruit set.	High if rain occurs	Low to moderate	Rainy periods may coincide with fresh pruning wounds.
Pit hardening (4–6 weeks after full bloom)	Low to moderate	Pruning removes active leaf area while resources are being allocated to fruit.	Low to moderate	Low	Infection risk declines as rainfall decreases.
Midsummer heat stress	Low	Heat and crop demand limit regrowth; sunburn risk may increase and wounds may heal slowly.	Low	High	Dry conditions limit new infection, but heat or water stress can activate latent infections.
Postharvest (late summer–early fall)	Low	Late pruning removes leaf area during reserve replenishment and may increase frost susceptibility.	Low if dry	High	Harvest stress and depleted reserves can trigger canker expression and spread.

or hedged trees may have included more open space, gaps, or shaded interior wood that contributed to canopy volume without proportionally increasing light capture. These results suggest that mechanical pruning altered external canopy geometry more than the amount of functional leaf area exposed to midday sunlight.

Repeated mechanical pruning, particularly annual boxing without selective hand pruning, can promote dense peripheral canopy growth that restricts interior light penetration (Fig. 5). Reduced interior light can suppress flowering and fruiting in shaded canopy zones, accelerate spur decline and wood dieback, and potentially increase disease pressure by limiting airflow. However, these results indicate that the primary limitation is not mechanical pruning per se but rather the timing and geometry of biomass removal. Hedging offered a superior compromise to full boxing by maintaining a continuous fruiting wall within the row while avoiding excessive structural limb removal. In contrast, full boxing reduced canopy volume too aggressively, likely excising productive framework branches between adjacent trees. Pruning phenology is equally critical; spring mechanical pruning is advantageous when moderate crop adjustment and vegetative containment are desired, whereas postharvest pruning should be approached cautiously, as it depletes active leaf area during critical carbohydrate reserve accumulation. Consequently, mechanical pruning in mature prune orchards should be deployed as an integrated canopy management strategy, pairing strategically timed mechanical cuts with periodic hand thinning to optimize yield, canopy porosity, and long-term spur productivity.

Pruning timing, regrowth, and Cytospora risk. Although pruning regime did not significantly affect *Cytospora* incidence in this trial, disease risk remains an important consideration for mechanical pruning in commercial prune orchards. Disease pressure was low in the experimental orchard, likely because of an active fungicide program, but observations from other prune orchards indicate that *Cytospora* canker can become a major problem when pruning wounds, susceptible tissue, inoculum, and favorable weather conditions coincide.

The physiological and disease consequences of pruning depend strongly on timing (Table 4). *Cytospora* canker is an important disease of California prune, and recent work has shown that pruning wounds can contribute to canker development and that latent infections may occur in prune nursery and orchard systems (Luo et al. 2024; Michailides et al. 2024). Dormant and early spring pruning can stimulate strong regrowth because stored reserves are high and shoot growth has not yet depleted carbohydrate pools. However, these timings also coincide with periods when rain splash can spread *Cytospora* inoculum to pruning wounds. In contrast, midsummer and postharvest pruning generally produce less regrowth because trees are under heat, water, or harvest-related stress, but latent *Cytospora* infections may become more visible during these stressful periods.

These timing effects reinforce the need to select pruning windows according to both crop management objectives and disease risk. Spring mechanical pruning may be useful in heavy-crop years when modest crop removal and regrowth are acceptable. Postharvest pruning may limit regrowth but should be applied cautiously because it removes leaf area during reserve replenishment and may increase stress-related expression of latent cankers.

Conclusions

Mechanical pruning maintained marketable yield over 5 years in a mature 'French' prune orchard while substantially reducing pruning costs relative to conventional dormant hand pruning. The best-performing mechanical approach was a grower-adapted spring system that produced a diamond-shaped canopy and avoided excessive removal of large limbs. Full boxing, particularly after harvest, was less favorable because it tended to reduce light interception and marketable fruit percentage.

Mechanical pruning should be implemented as part of an integrated canopy-management program rather than as a complete substitute for hand pruning. Periodic structural hand pruning every 4 to 5 years is recommended to remove dead, crossing, and shaded wood; restore interior light channels; reduce disease risk; and maintain spur productivity. Because this study was conducted in one mature commercial orchard, responses may differ in younger orchards, different spacings, other rootstocks, or sites with different vigor and disease pressure. Future research should refine pruning intervals, quantify *Cytospora* development under different pruning windows, and determine prune-specific light interception targets that balance yield, fruit size, canopy health, and economic return.

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