Why Soil Fumigation Changed the Strawberry Industry

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We assess the U.S. strawberry industry and its transition from land to capital intensity, with emphasis on the role of methyl bromide, a broad-spectrum soil fumigant, and its impact on the supply chain. Historical analysis suggests strawberries' unique characteristics made them particularly well-suited for monoculture, and that disease control was the means—not the cause—for adopting this system. We also argue that the geographic concentration and the stability it permitted are the root causes of the immense productivity gains in strawberry production from the mid-20th century onward.

Early strawberry cultivation consisted of cottage industries located within short distances of eastern urban centers. Strawberries are both perishable and easily damaged, limiting the distance they can be shipped without spoiling. However, by the mid-20th century, California had become the single largest strawberry producer nationally; by the 1970s, the state had almost completely dominated the market. Today, strawberries are a high-value, capital-intensive crop grown primarily along the California coast; just five counties are responsible for over 80% of U.S. output.

As suggested by Figure 1, this transition was characterized by simultaneously increasing total output while decreasing total acreage. While several factors contributed to this transition, its continuation is inextricably linked to the introduction of methyl bromide soil fumigation in the 1960s.

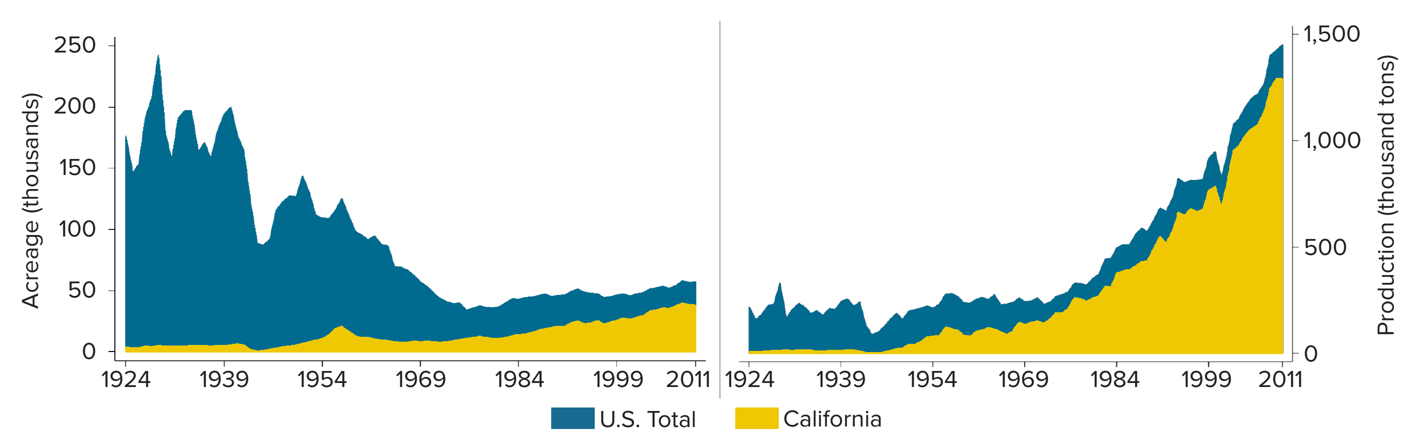
Early Commercial Production

Small pockets of commercial production first emerged at the beginning of the 19th century. They accounted for less than 1,500 acres nationally until the 1850s, when the railroad boom fundamentally altered the geographic distribution of production. While constraints were still comparatively strict, growers could feasibly supply markets within a few hundred miles. As a result, "strawberry fever" erupted in the late 19th century, and cultivation increased from 1,500 to 150,000 acres nationally by the 1880s.

The "shipping system," or long-distance strawberry marketing, required new physical and institutional infrastructure. Marketing over such distances was impossible for individual farmers, who now relied on commission agents and auction houses. Shipping demanded adequate facilities and available labor, while keeping freight costs low required cooperative agricultural associations. Perishability was mitigated by railcar innovations—first ventilated cars, then cars that could carry ice. Strawberry breeding, a private enterprise, was critical to developing firmer, more climate-tolerant berries.

This system could be extremely lucrative for strawberry growers given the right conditions. In particular, warmer climates in the South permitted earlier marketing, and early-season prices—sometimes an order of magnitude higher than normal—could generate astronomical profits. This caused the locus of production to shift further and further south throughout the late 19th and early 20th centuries. However, to justify investing in the necessary infrastructure, a district also needed sufficiently concentrated production;

Figure 1. National Acreage and Production, 1924–2011



Source: Author calculations based on data from Bain and Hoos, NASS, *California Vegetables*, and the Census of Agriculture.

one rule of thumb was a minimum of 100 acres within a few of miles from a shipping facility.

By the early 1920s, Tennessee, Missouri, and Arkansas had the lion's share of strawberry acreage. Establishment costs in these regions were relatively low (roughly $100–$110 per acre, in nominal dollars). Producers in these states focused on expanding strawberry acreage rather than investing in inputs and capital to sustain soil fertility, leading growers to relocate to previously unused land for each new planting. By the 1930s, land was starting to become scarce near shipping facilities.

California

California's strawberry industry emerged during the mass migration of the Gold Rush era and came to be characterized by intensive, costly cultivation practices. This was in large part due to irrigation requirements; after accounting for land leveling, flumes, and water, it could cost growers up to $200 an acre. Weeding, fertilizer, and soil cultivation—optional in the South—were also standard practices. As harvests were too large for household labor alone, it was also frequently necessary to supply workers with room and board. On the Central Coast, these costs could reach $700 an acre, or higher if a new building or well was required. In exchange, the fertile soil and favorable local climate led to yields that were three to four times higher than the national average. California's bearing season was also significantly longer: 4 to 5 months, rather than weeks.

Despite substantial differences between the regions, California growers also noticed declining yields when replanting on old strawberry land, and growers began to avoid old ground even after crop rotation. In combination with the high cost of establishment, this resulted in the widespread adoption of intercropping; growers cultivated strawberries between rows of new orchards, providing early income for the landlord while allowing them to split investment costs. However, intercropping appears to have fallen out of practice by the late 1930s, likely as new orchard acreage declined; this left strawberry growers to seek out previously untouched soil or old pastures for new plantings.

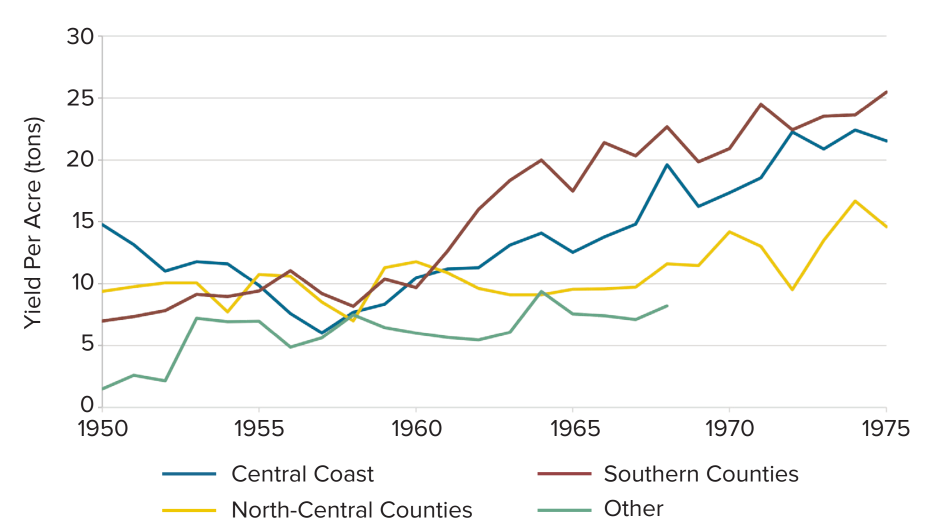
Post-war Transition

Prior to the mid-20th century, California's participation in the wider shipping system was restricted due to technological limitations; consumption either occurred locally or in adjacent states. This began to change in the 1920s, as innovations in transportation—pre-cooling and rudimentary refrigeration—made longer distances physically feasible, if not economically sound. After WWII, California producers began to market to East Coast consumers in earnest. The University of California's breeding program had recently introduced five high-yielding varieties, and this coincided with new demand for frozen berries and a series of weather shocks back east that impeded the slow post-war recovery in their own strawberry industries. By 1956, California had become responsible for nearly half of all strawberry production in the United States.

It is important to note that the relative costs of production had not materially changed; the Central Coast remained perhaps the most expensive district to cultivate strawberries in nationally. The overall cost per acre was 50% to 100% higher than in the Pacific Northwest or Michigan—now major producers in the post-war era—and several times greater than most southern districts. Depending on the market, California growers also faced an additional shipping premium of 0.4 to 1.2 cents per pound—an increase of 25% to more than 100% in transportation costs. Extended time in transit also magnified the impact of any pre-shipping damage or spoilage. Therefore, shipping over long distances depended on high yields and efficient capital to keep unit costs low, minimizing time spent between harvesting and cooling.

The transition from local to national supplier was in large part facilitated by the University varieties, which nearly doubled pre-war yields. Critically, this increase was limited to California's climate and declined substantially if cultivated elsewhere. Compared to other regions, the extended

Figure 2. California Strawberry Productivity by Region; 1950–1975



Source: Data from the California Agricultural Commissioners Crop Reports, 1950–1975. Available at: https://ageconsearch.umn.edu/?ln=en.

bearing season also enabled processing facilities to devote 5 to 6 times the number of annual operating hours to strawberries. In turn, this permitted greater capital specialization, keeping average total costs below other regions despite higher local wage rates.

Systemic Disruption

While agricultural innovation and California's natural advantages compensated for transportation costs, average productivity was also beginning to decline, falling from 7–8 tons per acre in the early 1950s to 5–6 tons in the second half of the decade. This was attributed to several factors, including disease pressure and limited availability of new land; both of these resulted from an expansion of acreage in an increasingly concentrated geographic area.

Some degree of land scarcity was an inevitable result of post-WWII urban expansion. However, it was exacerbated by increasingly virulent outbreaks of Verticillium wilt, a disease caused by a pathogenic soil-borne fungus, *Verticillium dahliae*. Although wilt affects numerous crops, strawberries are particularly vulnerable; plant loss could be catastrophically high, on the order of 75%. In addition, any soil inoculum (pathogen remaining in the soil) becomes a pervasive issue, as *V. dahliae* can remain viable in soil for up to 25 years.

Given the importance of location and capital, the combination of land and disease pressure posed an existential threat to California's dominant market position. At the beginning of the 1930s, wilt was considered to be a growing threat to strawberry plantings; incidence was particularly concentrated around the Central Coast, possibly due to the heavy cultivation of other host crops. For strawberries, plant loss was most severe in plantings that followed tomato, cotton, or potato crop rotations, leading growers to avoid any land previously used to grow those crops. In addition, just two of the five University varieties—Shasta and Lassen—comprised the large majority of acreage in California. While Shasta demonstrated slight resistance to *Verticillium*, it was more susceptible than Marshall, its predecessor. Lassen possessed no resistance at all.

Fumigation

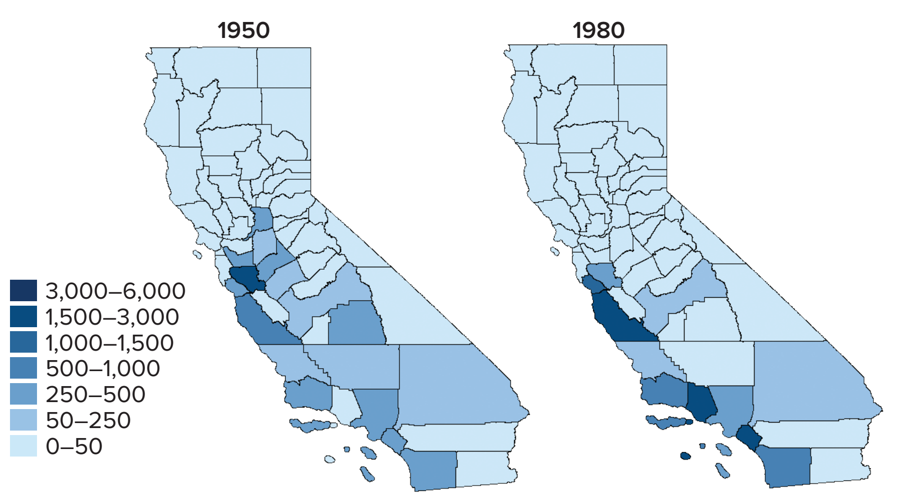
The threat posed by Verticillium wilt drove a significant amount of phytopathological (plant disease) research during the mid-20th century, and featured prominently in the numerous trials of soil fumigants throughout the 1950s. A mixture of two chemicals—methyl bromide (MB) and chloropicrin (Pic)—was soon discovered to be a "silver bullet" against *Verticillium*. MB-Pic treatment was expensive at $300–$400 per acre—increasing establishment cost by 20% to 30%—but was associated with a 94% to 97% reduction in plant loss. As an herbicide, methyl bromide also mitigated some of this cost through a sizable reduction in weeding labor, which comprised roughly half of pre-plant labor expenses.

Impact

Fumigation with MB-Pic was introduced in 1960. While quantitative data on its early usage is sparse, some authors suggest it reached 100% adoption on new strawberry land by 1965. As shown in Figure 2, there is indeed evidence of a sharp, localized increase in productivity post-1960, first in southern districts and then the Central Coast. California strawberry acreage was increasingly concentrated within these two regions (Figure 3), even as total acreage declined by a third from 1960 to 1966. Output, however, remained nearly constant, as yield per acre rose by almost 50% over the same period. Crop budgets for Orange and Los Angeles counties as well as Santa Cruz and Monterey counties indicate owned capital per acre increased roughly 200% between 1959 and 1976.

Aside from *Verticillium* control, the adoption of MB-Pic permitted technologies and production practices that would have either been economically difficult or physically impossible otherwise. Plasticulture adoption, for example, was directly related to the use of MB-Pic, and in particular, with methyl bromide. The use of clear plastic sheets as an early-season soil covering generated significant positive responses in both plant growth and yields, but interference with hand-weeding made herbicidal fumigation virtually mandatory.

Figure 3. Changes in California Strawberry Acreage, 1950 vs. 1980



Source: Data from the California Agricultural Commissioners Crop Reports, 1950 and 1980. Available at: https://ageconsearch.umn.edu/?ln=en.

Yield and quality gains from new varieties have been almost entirely predicated on MB-Pic, as the vast majority of cultivars adopted post-1960 are highly susceptible to disease and rely on fumigated soil. While not directly reliant on MB-Pic, existing transplant propagation systems are also tied to improved cultivars and the use of plastic to accelerate plant growth. These systems also require chilling hours in high-elevation nurseries at considerable distances from production districts, requiring phytosanitary control; MB-Pic is a preventative measure against cross-site contamination.

Drip irrigation was introduced in the 1970s and complemented the new production system; the improved weed control and use of plastic mulch improved the profitability of drip systems by reducing the labor required to maintain them. Drip systems also require significant capital investment, which would have been difficult to justify under migratory practices. More generally, any technological adoption or capital investment was arguably made more economically feasible by the overall reduction in risk provided by fumigation.

It is also worth noting that early yield gains from MB-Pic were essentially confined to California and, to a lesser extent, Florida. Outside of California, extension services generally discouraged the use of MB-Pic as it was prohibitively expensive, and returns were unlikely to justify expenditures. This served to widen the yield gap between California and the rest of the country.

Phaseout of Methyl Bromide

MB-Pic fumigation became a staple of California strawberry production and remained so for the next 30 years. Unfortunately, however, methyl bromide was later identified as a Class-1 ozone-depleting agent. Under the Montreal Protocol, methyl bromide soil fumigation was progressively restricted from 1994 onward until it was completely banned in 2005. Many agricultural stakeholders lobbied against the phaseout; some were granted temporary reprieves in the form of critical-use exemptions (CUEs), but these came to an end in 2017.

Methyl bromide's phaseout has had significant implications for the strawberry industry, particularly as the incidence of both new and previously controlled diseases continues to increase. Alternative fumigants, as well as tighter management practices, have thus far preserved the existing system. However, the loss of methyl bromide is not the only issue the industry currently faces. The increasing cost of labor and, for certain regions in California, greater import volume from Mexico, pose further challenges.

Lessons

The relationship between methyl bromide and the strawberry industry is in large part a story about the evolution of its supply chain. Improved transportation has shifted the locus of production over time, first to the southern United States, then to California. Disease control then allowed acreage to concentrate on California's coast, where production depended on economies of scale to mitigate high relative costs. MB-Pic provided a means to remain in one place in order to utilize capital more efficiently.

Despite the economic benefits of this system, there are obvious vulnerabilities. The long search for a suitable alternative to methyl bromide emphasizes the value of ongoing, continuous research as well as the distinct possibility that the strawberry industry of today, almost unrecognizable compared to the one from 50 or 100 years ago, may appear fundamentally different from the one that will exist 50 years in the future.

Looking Forward

We feel it is unlikely that the existing system will change drastically in the immediate future, although incremental improvements to existing techniques and cultivars will continue to accrue. In the medium-term, however, we may also see different modes of production become mainstream. Enclosed environments—vertical farms, greenhouses, scaled-up container farming—provide greater control over growing conditions and allow farmers to substitute capital investment for land quality. We would expect this to lower reliance on chemicals.

For strawberries in particular, elevated systems of cultivation may also make harvesting easier, improving speed and lowering costs. If yields increase, we would also expect this shift to be land-sparing and potentially reduce emissions. If these types of technologies become sufficiently inexpensive, they may lead to more decentralized production, as transportation becomes a larger component of total costs.

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