Culture and Physiological Manipulation of California Strawberries

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After World War II, the California strawberry hectareage increased greatly, reaching a maximum of 8380 ha in 1957, with more fruit than the markets could absorb. As a result, within 5 years (1962) the area fell to its lowest post-war point, <2400 ha, and has since increased to 7690 ha in 1989, with increases in total fruit production and yield per unit hectare.

The success of the California strawberry industry has been due to the breeding of a succession of improved cultivars simultaneous with the development of improved planting systems and cultural practices. This paper is concerned with the planting systems, cultural practices, and the physiological manipulation of the California strawberry cultivars. For details on the cultivars, see the cover story.

California planting systems

Before the modern California planting systems were developed, most plants were transplanted early in the spring and were harvested for 3 to 4 years in southern California and for 4 to 8 years in northern California (then, as now, under the "hill system"). As the plants aged, the fruit size and quality diminished each year until the enterprise was unprofitable. The development of the summer and winter planting systems made it possible to produce and ship fruit of 'Lassen', the original California cultivar adapted to southern coastal California.

Summer planting system. Summer planting, first introduced to growers in southern California in 1955, was a major improvement over spring planting and made annual planting feasible (Voth, 1955).

For this system, plants are dug from Central Valley (near Redding, Red Bluff, and Modesto) nurseries in December or January, when they are as near to dormant as possible and the roots are filled with starch (Bringhurst et al., 1960). Leaves and petioles are removed and the plants are packed in boxes (30 × 30 × 60 cm) that are perforated to permit air exchange and lined with thin polyethylene film to prevent moisture loss. They are then stored below freezing (at -2.2°C) until planting time, about 1 Sept., depending on the cultivar and the location of the planting site. They are commonly termed "frigo" plants.

Physiologically, the frigo plants have their chilling requirement fully satisfied (Voth, 1955; Voth and Bringhurst, 1958; Bringhurst et al., 1960) and the plants first go through an abbreviated, non-fruiting first year. The "crown bud" flowers, which were initiated in the nursery in the short-day conditions of the fall, normally are removed and the runners that follow are always removed. The plants are pruned (old leaves are removed) in February and fruit production begins in March or April (≈ 7 months after planting).

This system of annual planting demonstrated that fruit produced by first-fruiting-year plants was larger, firmer, with higher dessert quality and longer shelf life compared to second- or third-year plants (Voth, 1955; Voth and Bringhurst, 1958). Thus, a commercial crop could be realized within 1 year after planting instead of the 1.5 years required for spring planting.

Winter planting system. The practices and principles that have since made winter planting the most important California strawberry

Table 1. Comparing hours of preharvest freezing and chilling (<7.2 C) temperatures at California high-elevation strawberry nurseries for 1986.

Nursery area	North lat. (°)	Altitude (m)	Hours at given temperature (°C)						Total below 7.2
			Below 0			0 to 7.2			
			September	October	Total	September	October	Total	
Irvine ^z	33.8	136	0	0	0	0	0	0	0
Susanville	40.4	1267	21	18	39	196	270	446	505
McArthur	41.2	1013	24	77	101	230	292	522	523
MacDoel	41.8	1300	78	181	258	259	507	766	1024

^zSouth Coast Field Station experimental fruiting site.

Table 2. Effect of nursery location and soil type on earliness and total 1986 yield of high-elevation 'Douglas' plants dug 15 Oct. 1985 and planted at the South Coast Field Station (Irvine) 18 Oct. 1985^z.

Nursery location	Yield (g/plant) ^y					Mean berry wt (g)
	February	March	Late	Total	SD	
MacDoel (sandy, light)	239	520	693	1452	7	20.2
MacDoel (loamy, heavy)	197	470	667	1334	41	20.1
McArthur	178	386	603	1167	28	19.5
Susanville	116	317	592	1025	29	19.1

^zFour-row, 1.7-m bed, in-row spacing 30.4 cm = 75,980 plants/ha.

^yDifferences highly significant (ANOVA, $P = 0.01$).

Table 3. Effect of various polyethylene bed mulches on bed temperatures at 7.6-cm soil depth in winter planting at the South Coast Field Station (Irvine) 1987.

Mulch	Mean bed temp (°C)			Overall mean ^z
	January-February		March	
	AM	PM	PM	
Clear	8.9	25.6	31.1	21.8 a
Brown	8.3	22.2	26.1	18.9 b
None	7.5	22.7	23.9	18.0 b
Black	6.1	21.6	22.7	16.8 c
White	5.0	17.8	20.0	14.3 d
White/Black	5.5	16.6	19.5	13.8 d

^zMean separation by Duncan's multiple range test, $P = 0.05$.

growing system (effectively 100% from Santa Maria on south and ≈ 50% in the central coast) were first studied in the late 1950s (Voth and Bringhurst, 1958; Guttridge, 1958; Bringhurst et al., 1960). Included is the use of high-elevation, high-latitude-grown nursery stock, ensuring that the plants receive early nursery chilling (Table 1). Additional cold chamber chilling at 1 to 2C is given as needed, particularly to-day-neutrals such as 'Selva' (often 3 to 4 weeks), which have a higher chilling requirement than short-day types such as 'Chandler' (usually 0 to 2 weeks; California Strawberry Advisory Board Annual reports, 1985 to 1988). Winter plantings are successful under the relatively warm winter conditions that normally prevail at south-coastal or central-coastal California growing sites only.

Thus, winter planting involves the planting of freshly dug nursery plants that cumulatively have received enough chilling to stimulate sufficient vigorous growth during the short days of winter to produce a good crop of early high quality fruit followed by repetitive fruiting for 6 months or more; hence the name "winter planting". If they lack chilling (vigor), earliness, quality, and total yield are diminished (Table 2).

Note that two plantings of the plants from the coldest nursery (Macdoel) were included in Table 2; plants from a light sandy soil and plants from a heavier (loamy) soil. The latter is more comparable to the McArthur and Susanville soils, although all are light enough to be good nursery soils. The plants from the sandy soil produced fewer plants per hectare, but the plants were about one-third larger with counts of 1000 per standard California box (30 × 30 × 60 cm), whereas plants from the heavier soil were smaller, averaging ≈ 1,500 per box. The data (Table 2) show that the plants from the colder nursery and from the sandier soil performed best

because the nursery plant density was less and, consequently, such plants had larger crowns and root systems.

Historically, after the introduction of 'Fresno' (1961) and 'Tioga' (1964), summer planting became the dominant system statewide. Later, with the introduction of 'Tufts' (1972) and of 'Douglas' (1979), winter planting became the dominant system from Santa Maria and southward to San Diego. At present, only 'Pajaro' (1979 release) and a portion of the 'Selva' (1983 release) hectareage is summer-planted. Growers changed from summer to winter planting because fruit quality is superior (larger, firmer, with better flavor and color) and production commences earlier on winter plantings. In addition, the minimum time from planting to earliest significant harvest on short-day-type cultivars is 3 months for winter plantings, compared with ≈ 7 months for summer plantings.

Overall quality has improved because the area from San Luis Obispo on south is planted annually and none is carried over for a second year. Similarly, in the Watsonville-Salinas area, only a small percentage is carried over for the second year; plants that are carried over produce the smallest size and poorest-quality fruit in the state.

Polyethylene bed mulch

Clear polyethylene bed mulch applied very snugly over the soil surface as soon as possible after planting is one of the most useful tools for enhancing the performance of winter-planted strawberries in California. It was first used in 1958, and the results of early experiments showed increases in earliness and in total yield associated with higher soil temperatures (Voth and Bringhurst, 1959, 1962). It is now standard practice.

Temperatures for six mulch treatments are shown in Table 3 for 1987-88, a fairly typical year, at Irvine (South Coast Field Station); measured in early morning and mid-afternoon, with laboratory thermometers placed 7.6 cm deep between the plants. Note that the increases in temperatures are directly associated with the amount of radiant energy penetrating the soil; highest for the clear film and lowest for the white over black. The critical temperature for growth in plants, such as strawberries, is ≈ 10C or above. Black, white, and white/black mulch reduces soil penetration by the sun's rays.

Total yield data for the six strawberry cultivars used in the above 1987-88 experiment are presented in Table 4. While there is some interaction in the response of the various cultivars to the various mulches, the clear mulch unambiguously gave the highest yield in all cases. Clear polyethylene bed mulch is more important during colder winters (Table 5), in large measure due to its effect on earliness. Note the large positive effect of the clear mulch (the warmest

Table 4. Total 1988 strawberry yield with six kinds of polyethylene bed mulch treatments in a winter planting of high-elevation-grown plants of six cultivars; dug at MacDoel 17 Oct., planted at Irvine 28 Oct. 1987^z.

Mulch	Total yield (g/plant) ^y						Mean
	Chandler	C35	Douglas	Oso	Irvine	Selva	
Clear	1850	1655	1432	1360	1238	1206	1456 a
Black	1397	1602	1181	1101	948	856	1180 b
White/Black	1397	1582	876	1161	1014	826	1133 b
Brown	1311	1489	962	1161	854	830	1101 bc
White	1383	1332	977	1091	941	839	1094 c
None	1457	1328	891	1117	885	747	1070 c

^zTwo-row 1.2-m beds, in-row spacing 41 cm = 46,131 plants/ha.

^yMean separation by Duncan's multiple range test, $P = 0.05$.

Table 5. Comparison of 1984 strawberry yield and fruit size over six bed mulch treatments in a winter planting of high-elevation 'Douglas' plants; dug at MacDoel 15 Oct., planted at Irvine, 30 Oct. 1983.^{z,y}

Mulch	Yield (g/plant)		Mean berry wt (g)
	To April	Total	
Clear	151 a	925 a	22.0 a
Reemay-clear	132 a	872 ab	20.6 b
Styrofoam	84 b	830 b	23.0 a
None	78 b	820 b	23.6 a
Black	79 b	756 bc	22.8 a
White/Black	30 c	739 c	22.4 a

^zFour-row, 1.7-m bed, in-row spacing 25 cm = 91,175 plants/ha.

^yMean separation by Duncan's multiple range test, $P = 0.05$.

Table 6. Comparison of 1988 yield and fruit size of four strawberry cultivars on two-row and four-row beds at same plant density (56,984/ha). Winter planting; dug at MacDoel 15 Oct., planted 26 Oct. 1987 at Irvine.^z

Cultivar	Type of bed						Yield increase (%)
	Two-row			Four-row			
	Total yield		Mean berry wt (g)	Total yield		Mean berry wt (g)	
	g/plant	SD		(g/plant)	SD		
Douglas	1077	117	17.6	1422	154	18.3	32
Chandler	1519	62	16.3	1827	74	18.0	20
Oso	1136	113	18.5	1651	164	20.2	45
Irvine	1088	104	16.9	1281	122	17.0	18
Mean	1205	99	17.3	1545	128	18.4	28

^zMean difference for total yield is highly significant (ANOVA).

bed) at the same site and the large negative effect of the white/black mulch (the coldest bed) on earliness. In California, growth during November through February accounts for high total yield.

Drip irrigation, bed type, and plant density

Drip irrigation is extremely important to strawberry production in California for many reasons, including the following: It places water where it is needed without waste and it has made the development of optimum bed shapes, height, and size possible.

The first experiments with drip irrigation on strawberries in California began at Torrey Pines in 1967 with 12.7-mm tubing with an orifice placed every 60 cm. These early experiments showed the benefit of good water placement on the management of salinity, enhancement of production, and reduced water usage (Voth et al., 1973)⁴. The first true drip systems were developed in 1970 and are in general use now, facilitating all cultural operations.

Drip irrigation permitted development of a new wide four-row bed system that was adopted by southern California growers by 1972 and statewide later. This system increased production per unit area on winter plantings by 30% to 50% (Voth et al., 1973).

A recent comparison of the performance of three standard cultivars ('Chandler', 'Douglas', and 'Oso Grande') and one day-neutral ('Irvine') in a winter planting on a two-row, 1.22-m-wide bed with

those on a four-row, 1.73-m-wide bed with the plant density constant (56,984 plants/ha) is presented in Table 6. The increase on the four-row-wide bed was greater (45%) for 'Oso Grande', the cultivar with the largest plants and least (18%) for 'Irvine', the cultivar with the smallest plants. In all cases there was an increase and the average was 28%.

Fertilizer placement and materials

Nitrogen fertilization of strawberries is necessary in California. Early experiments with preplant slow-release fertilizers demonstrated their effectiveness, especially as polyethylene bed mulch came into general use (Voth et al., 1963; Voth and Uriu, 1968). The only alternatives are preplant application, placement of slow-release fertilizers in the planting slot, or application of soluble materials through the drip irrigation lines. Consequently, these systems have been compared experimentally in southern California since 1978 in a soil that is particularly low in nitrogen (Table 7).

The results show that at least *double* the amount of nitrogen has to be applied through the drip system to compare somewhat favorably with the results obtained from slot applications of slow-release materials at planting.

At the same time, most of the commercially available slow-release materials were compared in a second experiment, overlapping the first in part (controls) (Table 8).

Table 7. Monthly and total 1987 yield of 'Oso' strawberries irrigated and fertilized with N through two or four driplines and/or with dry fertilizer applied before planting (slot). Winter-planted MacDoel-grown plants dug 15 Oct. and planted 30 Oct. 1986 at Irvine.

Treatment ^a	N (kg·ha ⁻¹)	Yield (g/plant)						Mean berry wt (g)
		Monthly				Total ^b		
		March	April	May	June	g	SD	
No N, control; two drip lines	0	6	28	37	40	114	11	9.3
Slot AN20; two drip lines	264	148	571	223	322	1267	174	22.9
Preplant AN20; four drip lines	264	128	704	281	252	1369	122	24.1
Slot 16-20 NS; two lines AN20	264	146	666	256	231	1300	24	23.2
Preplant drip 33.5-0-0 AN;	264	159	798	346	155	1461	191	25.8
Preplant slot; 16-20 NS	264							
Preplant drip Preplant slot; 16-20 NS	132	132	129	876	142	1494	80	26.8
	264							

^aAN = ammonium nitrate, 16-20; NS = Ammonium phosphate + the nyrpyrin "N-Serve". Four-row 1.7-m bed, in-row spacing 30 cm = 75,980 plants/ha. Split applications of fertilizers as indicated.
^bExcluding the control (no fertilizer), differences among the treatments are not significant (ANOVA).

Table 8. Monthly and total 1987 yield of 'Oso' strawberries with various slow-release fertilizers. Winter-planted MacDoel plants dug 15 Oct. and planted 30 Oct. 1986 at Irvine.

Treatment ^z	Yield (g/plant)								
	N (kg·ha ⁻¹)	Monthly (yield/plant)				Total			Berry wt (g)
		March	April	May	June	(g/plant)	SD	(t·ha ⁻¹)	
No N, control	0	6	28	37	40	114	11	8	9.3
Resin 22–7–10	336	114	653	248	221	1238	172	89	24.5
ES 26–8–8 ^y	336	164	636	221	222	1246	117	89	24.1
AP 16–20–0	336	193	640	254	179	1268	198	90	24.3
AS + NS 21–0–0	336	148	705	312	193	1361	28	97	25.6
Resin AS 18–0–0	336	182	687	285	225	1382	188	99	24.9
Resin 13–16–0	336	169	725	318	187	1403	85	100	25.2
ES AS 18–0–0	336	176	738	265	235	1418	139	101	25.3
16–20–0 NS slot	264	117	876	356	142	1494	80	107	26.8
+ drip line	132								

^aES = "Escote", AP = ammonium phosphate, AS + NS = ammonium sulfate + nyrpyrin "N-Serve". 4-row 1.7 m-bed, in-row spacing 30 cm = 65,127 plants/ha.

^bExcluding the control (no fertilizer), differences among the fertilizer treatments were not significant (ANOVA).

The general conclusion is: *Water placement determines fertilizer placement and fertilizer placement is more important than the material used.*

CONCLUSION

While the introduction of new cultivars accounts for much of the gains that have been made in California strawberry production over the post-World War II years, the improvements in cultural practices, including soil fumigation (not discussed here), have been at least of equal importance. Furthermore, they are so closely linked that one cannot have one without the other.

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