



Efficient Nitrogen Fertility and Irrigation Management in California Strawberry Production

This publication describes efficient management of nitrogen (N) fertility and irrigation in California strawberry production. Improving the efficiency of N and irrigation inputs is increasingly important, given the increased regulatory activity designed to protect groundwater resources. A number of rural communities along the coast rely exclusively on groundwater for their drinking supply. Many wells in this region are above the federal drinking water standard of 10 PPM nitrate-nitrogen ($\text{NO}_3\text{-N}$). In response to this widespread groundwater nitrate pollution problem, the Central Coast Region Water Quality Control Board has adopted a regulatory program that requires growers to track and report N inputs. This information will be used to estimate a nitrogen balance, which compares the amount of N applied to fields with the amount of N estimated to be removed from fields in harvested fruit. The greater the imbalance between applied N and N removed in harvested fruit, the greater the potential for N loss to the environment. Growers who consistently show a large imbalance between N application and harvest N removal are likely to come under increased scrutiny for their potential contribution to nitrate degradation of groundwater.

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As acreage of strawberries has steadily increased in the coastal areas, concerns have been raised regarding the impacts of berry production on water quantity and quality. Much of the water used to irrigate strawberries is pumped from aquifers adjacent to the ocean. These aquifers are susceptible to contamination with salt water if groundwater levels decline below sea level. Also, irrigation management is directly linked to $\text{NO}_3\text{-N}$ leaching. Increasingly stringent regulation will require growers to implement practices that limit both groundwater overdrafting and $\text{NO}_3\text{-N}$ leaching.

Nitrogen Management

Pattern of Strawberry Growth and Nitrogen Uptake

Intensive sampling in a total of 13 commercial strawberry fields in the Ventura, Santa Maria, and Salinas production districts from 2010 to 2015 documented the growth and N uptake dynamics in coastal strawberry production (Bottoms et al. 2013a, 2014). These fields represented both the UC cultivar Albion as well as commonly planted proprietary cultivars. In coastal production areas, transplants are typically planted in October and November. Plant sampling was conducted at approximately monthly intervals from winter until early fall to document crop N uptake. On each sampling date, the aboveground biomass of representative plants were harvested and all fruit were removed. Vegetative and fruit tissue was dried and analyzed for N content. Nitrogen removal with harvested fruit was estimated from the fruit N concentration and grower-reported yields between sampling dates.

In all production areas there was a period of slow growth as the transplants became established. This period of slow growth was longer in the Santa Maria and Salinas areas due to colder winter conditions; in all areas, a prolonged period of relatively constant growth and N uptake began at the early flowering stage and continued throughout the harvest period (fig. 1). During this period, crop N uptake averaged approximately 1 lb/ac/day in all areas, slightly higher in vigorous fields; the variability observed among fields resulted from differences in plant population, field vigor, and yield level. The 1 lb/ac/day N crop uptake rate did not include N contained in roots (about 5% of the crop total) or in cull

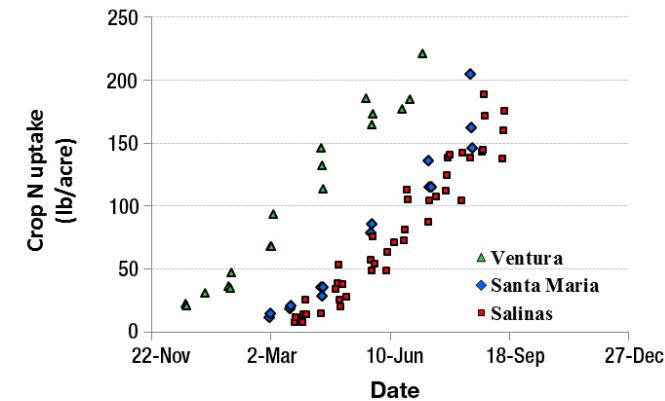


Figure 1. Pattern of strawberry N uptake in coastal California production areas.

fruit (estimated at 10 to 15% of total fruit production). Adjusting for these factors, the typical N uptake rate of high-yield fields would be 1.1 to 1.2 lb/ac/day N throughout the fruiting period, or about 7.5 to 8.5 lb/ac/week N. Estimated total crop N uptake (including N contained in roots and cull fruit) ranged from approximately 180 to 220 lb/ac N; fields kept in production beyond the monitored period monitored would undoubtedly show a reduced N uptake rate due to declining productivity.

Fruit sampling in dozens of commercial fields showed that fruit N concentration ranged from 1.0 to 2.0% on a dry weight basis, with most fields in the 1.3 to 1.5% range. Since dry weight represents about 10% of fruit fresh weight, fruit N content would average about 2.8 lb/T. Therefore, approximately 100 lb/ac N would be removed from a field at the state average yield of 35 T/ac; this represents about 50% of total crop N uptake. To estimate the approximate crop N uptake at different yield levels, use this formula:

$$\text{total seasonal crop N uptake} = \text{seasonal fruit yield (T/ac)} \times 5.6$$

To put strawberry N uptake into perspective, strawberry has a much lower N requirement than the leafy green vegetable crops commonly produced in these coastal districts. During rapid growth, leafy greens take up 4 to 6 lb/ac/day N, and summer-grown broccoli takes up more N in 3 months than strawberries do on an annual basis.

The rooting pattern of strawberry, determined by root excavation in four commercial fields in the Salinas area, is shown in figure 2. By late spring, some roots reached below 12 in, and in some fields the deepest root exceeded 24 in by the end of summer. However, the large majority of roots were found in the top half of the rooting zone, meaning that management practices should focus on keeping nitrogen in the top 6 to 12 in of soil. As soil $\text{NO}_3\text{-N}$ moves below 12-in depth it becomes increasingly less accessible to the crop.

Nitrogen Fertilizer Management

Strawberry fields currently receive on average about 200 lb/ac fertilizer N over a production season, but N fertilization rates and timing vary widely among growers (fig. 3). In the 45 fields represented in figure 3 there was no correlation between fruit yield and seasonal N rate. Preplant application of controlled release fertilizer (CRF) is a standard practice, with CRF typically accounting for about 50% of seasonal N application. Most N fertigation is applied during the fruiting season; over that period, the N fertigation rate is often quite similar to the crop N uptake rate.

The rationale for CRF use is to ensure N availability through the winter, when rain might leach soil $\text{NO}_3\text{-N}$ and growers are

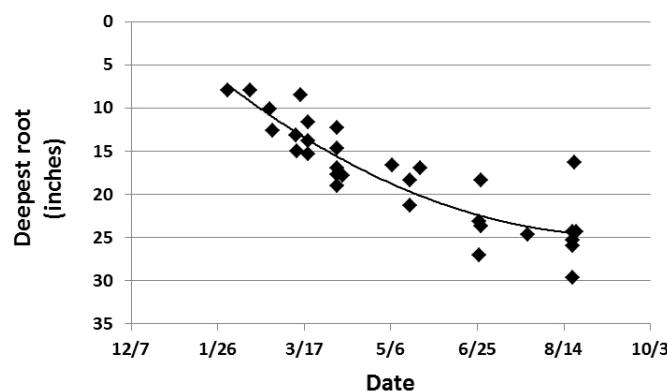


Figure 2. Pattern of strawberry root development in Salinas strawberry fields.

reluctant to fertigate N in wet soil conditions. However, the current CRF use pattern is not efficient, particularly in the Salinas and Santa Maria areas, where there is a prolonged period of slow growth and limited N uptake following transplanting. The most common CRF materials, which are applied during bed preparation in September and October, are rated for an N release period of 6 to 9 months; consequently, their N release characteristics do not match the timing of crop N uptake. Monitoring in strawberry fields in the Salinas area documented that the vast majority of N release from common CRF materials occurs before rapid plant growth in the spring (Bottoms et al. 2013a). Soil monitoring has shown that strawberry fields, particularly those in rotation with vegetable crops, tend to have high soil $\text{NO}_3\text{-N}$ at planting; with good irrigation management during transplant establishment, the soil can retain significant residual $\text{NO}_3\text{-N}$ into the winter. Due to slow crop N uptake during winter months, crop N requirements are easily satisfied during that period. Heavy preplant CRF application contributes to high winter soil $\text{NO}_3\text{-N}$ concentration and thereby increases the $\text{NO}_3\text{-N}$ leaching potential with winter rain. In-field monitoring of nitrate leaching in two strawberry fields in the

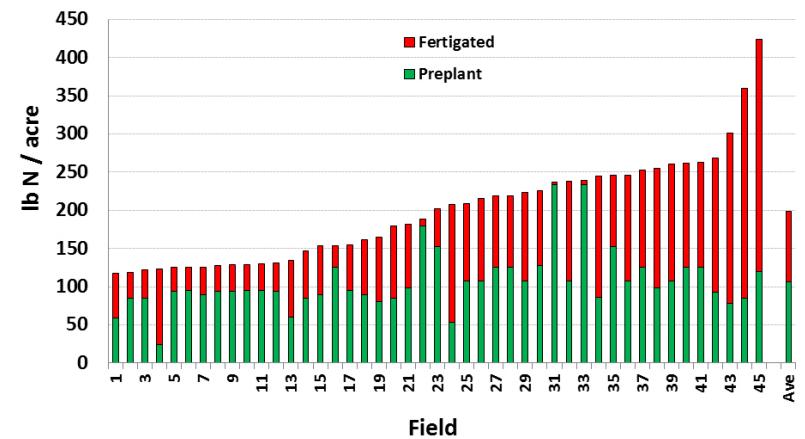


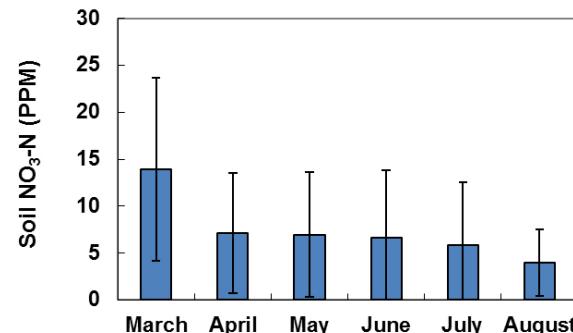
Figure 3. Seasonal N fertilizer application in coastal strawberry fields.
Source: Bottoms et al. 2013a and b.

Salinas area showed that more than 100 lb NO₃-N was lost in each field from December to April (Cahn 2013). Replicated field trials indicated that reducing preplant CRF application had minimal impact on crop productivity but did reduce potential N leaching losses (Bottoms et al. 2013a).

Improving the efficiency of CRF fertilizer requires consideration of site-specific conditions. The potential value of CRF is highest in sandy soil (which is more easily leached) and where there is minimal residual soil NO₃-N from a prior crop. Even under these conditions, CRF application rates below 100 lb/ac N should be more than adequate. Using a CRF product with an N release rate better matched to the crop N uptake pattern should also improve efficiency. Fields of heavier soil texture, particularly those coming out of vegetable rotations, would be expected to have higher residual soil NO₃-N at the beginning of the season and would be harder to leach with winter rains. Under these conditions preplant CRF may not be needed.

Current N fertigation practices appear to be reasonably efficient. At an average seasonal fertigation total of about 90 lb/ac N (see fig. 3) applied mostly from March to early fall, fertigation would not keep pace with crop N uptake over that period. This conservative approach to in-season fertilization is reflected in the pattern of soil NO₃-N observed in more than 20 fields (fig. 4). Coming out of the winter, soil NO₃-N was relatively high, but it declined in most fields as the season progressed. In the majority of fields, soil NO₃-N remained below 10 PPM for most of the fruit

Figure 4. Pattern of root zone (top 12 inches) soil NO₃-N in Santa Maria and Salinas strawberry fields; bars indicate standard deviation.
Source: Bottoms et al. 2013 a and b.



harvest season, providing limited opportunity for NO₃-N leaching. Measured summer leaching in six commercial fields averaged less than 30 lb/ac NO₃-N (Bottoms et al. 2014). The fact that high crop productivity can be maintained with such modest in-season N fertigation rates suggests that the crop is using N from other sources. Mineralization of soil organic N contributes to soil N availability, as does NO₃-N in irrigation water.

Estimating N Contribution from Irrigation Water

Nitrogen in irrigation water, typically in NO₃-N form, can make a significant contribution to crop N fertility. The NO₃-N content of irrigation water can be calculated by the formula

$$\text{PPM NO}_3\text{-N} \times 0.23 = \text{lb/ac-in NO}_3\text{-N}$$

When testing irrigation water it is important to note the units reported. Some laboratories report concentration as PPM of nitrate (NO₃); dividing PPM NO₃ by 4.4 converts the measurement to PPM NO₃-N. A number of wells in coastal production districts contain 20 PPM NO₃-N or more, which would supply in excess of 4 lb/ac-in N. The recycled municipal wastewater used for irrigation in the Castroville area contains greater than 30 PPM soluble N (a combination of NO₃-N and NH₄-N, both of which are plant-available); this water contains more than 7 lb/ac-in N. Considering that growers may apply more than 20 in of irrigation to a strawberry crop, it is clear that irrigation water N can be a significant source of crop nutrition.

Recent research conducted in the Salinas Valley documented that N in irrigation water was just as effective as fertilizer N in supplying crop N requirements. Growers may be reluctant to fully credit irrigation water N content because they recognize that irrigation efficiency is not universally high and some fraction of irrigation water N is undoubtedly lost by leaching. However, inefficient irrigation also leads to leaching of fertilizer N.

Monitoring Plant Nitrogen Status

Nitrogen monitoring in strawberry fields has traditionally been limited to tissue sampling. Recently mature trifoliolate leaves are

sampled, with either the leaf blades analyzed for total N concentration or petioles for $\text{NO}_3\text{-N}$ concentration. Bottoms et al. (2013b) collected both sample types in more than 50 Salinas and Santa Maria fields and identified 12 fields as being both high yield and nutritionally balanced. In those high-yield, nutritionally balanced fields, leaf blade N and petiole $\text{NO}_3\text{-N}$ optimal ranges were calculated (fig. 5); the vast majority of high-yield fields would be expected to have tissue concentrations within these optimal ranges. Leaf N declined from the early flowering stage until the main harvest period, then remained relatively constant through early fall. Variability in leaf N concentration was limited among high-yield fields, so the optimal ranges for all sampling stages were narrow. Leaf N concentrations of 3.1 to 3.8%, 2.7 to 3.2%, and 2.4 to 3.0% indicate N sufficiency at the early flowering, early harvest, and main harvest stages, respectively. By contrast, petiole $\text{NO}_3\text{-N}$ concentration was highly variable, particularly during the harvest season (stages 2 to 5); this phenomenon has been observed in many crops. Variability in petiole $\text{NO}_3\text{-N}$ concentration arises from the fact that environmental conditions unrelated to soil N supply can affect the rate at which plants metabolize $\text{NO}_3\text{-N}$, meaning that petiole $\text{NO}_3\text{-N}$ does not

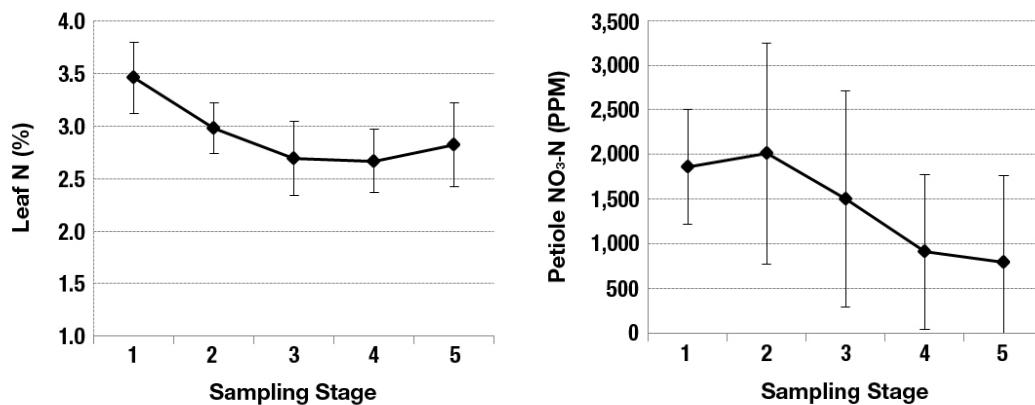


Figure 5. Leaf blade N and petiole $\text{NO}_3\text{-N}$ optimal ranges for coastal strawberries. Sampling stage 1 = early flowering, 2 = early harvest, and 3 to 5 = main harvest. Bars indicate the standard deviation of measurement.

reliably reflect a plant's overall N status or even the current soil N availability. Maintaining high petiole $\text{NO}_3\text{-N}$, particularly during the summer harvest season, often requires N fertilization in excess of the actual crop N requirement. Leaf N concentration is the more reliable tissue diagnostic.

Monitoring Soil Nitrogen

Soil $\text{NO}_3\text{-N}$ monitoring can be useful for identifying the level of residual $\text{NO}_3\text{-N}$ present at the beginning of the season and as an aid to determining when N fertigation should begin in the spring. After a vegetable crop, high residual soil $\text{NO}_3\text{-N}$ suggests that preplant N fertilization may be reduced or even eliminated. Since strawberry has a low N uptake rate, modest levels of soil $\text{NO}_3\text{-N}$ are adequate to support optimal growth. Between planting and the main harvest season, a root zone (top 12 in) soil $\text{NO}_3\text{-N}$ concentration above 10 to 15 PPM should be adequate to support crop growth and delay N fertigation. Care must be taken in soil sampling in fields where CRF application has been made, because sampling in the zone of banded CRF can yield an inaccurately high soil $\text{NO}_3\text{-N}$ estimation.

During the main harvest period, soil $\text{NO}_3\text{-N}$ concentration is often quite low, even in highly productive fields (see fig. 4); soil sampling during this period is of limited value. Provided that irrigation is managed efficiently, N fertigation at a rate to match crop N uptake (approximately 7 to 8 lb/ac/wk N) should be adequate to maintain N sufficiency. Even lower N fertigation rates may be adequate in soils with higher levels of organic matter or where irrigation water contains significant $\text{NO}_3\text{-N}$. Extremely low soil $\text{NO}_3\text{-N}$ (less than 2 to 3 PPM) may indicate that $\text{NO}_3\text{-N}$ is being leached or that the N fertigation rate is insufficient. Conversely, soil $\text{NO}_3\text{-N}$ greater than 10 PPM may indicate that N fertigation can be reduced.

Irrigation Management

Irrigation System Design and Management

Nearly all California strawberry fields are drip irrigated. The goal of irrigation is to maintain adequate soil moisture throughout a field. The less uniformly a drip system applies water, the more water must

be applied to provide adequate soil moisture in all portions of the field. From 2011 and 2013 we evaluated the distribution uniformity (DU) of drip systems in more than 30 coastal strawberry fields. A DU of 100% is perfect, and drip systems that are well designed and managed have a DU greater than 85%. The average DU in these fields was 79%; while 36% of fields had a DU less than 75%. Some of the most common factors that limited the DU of these drip systems were

- valves on submains within an irrigation block were set to different pressures
- pressure was too low in drip lines (less than 4 psi)
- pressure was not regulated on the submains
- polyethylene leads connecting the submain to the drip lines were often too narrow and varied in length, which caused pressure to vary among beds
- emitters were clogged due to insufficient filtration and infrequent flushing of drip lines

Additionally, drip systems that were located on sloping fields tended to have a lower DU due to challenges in maintaining similar pressures in all areas of the field. Elevation changes of 2.3 ft cause a change of 1 psi in a drip system. Since most strawberry drip systems are operated at pressures less than 8 psi, modest changes in elevation within a field may result in significant pressure differences. Using pressure regulators and/or pressure-compensating drip tape can help improve the DU of drip systems in sloped fields. Unfortunately, pressure-compensating drip tape is seldom used due to its high cost.

Irrigation Scheduling

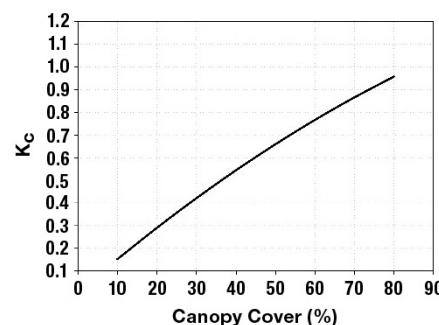
Environmental variables such as solar radiation, air temperature, relative humidity, and wind speed interact to influence the rate of water loss from plants and soil. The California Irrigation Management Information System (CIMIS) is a network of computerized weather stations that measure these environmental variables and compute a daily reference evapotranspiration (ET_o) value estimating the potential loss of water (through both plant transpiration and soil evaporation) from a well-watered grass crop that completely covers the soil surface. Daily ET_o estimates can be found on the Department of Water Resources website, <http://wwwcimis.water.ca.gov>.

Historical ET_o values are also available for many locations. Table 1 lists average daily ET_o values by month for representative coastal locations. To estimate the crop irrigation requirement, ET_o must be adjusted for field-specific conditions by using a crop coefficient (K_c). The primary force controlling crop water loss is the heating of the foliage caused by solar radiation. This provides a convenient way to account for crop vigor: simply estimate the fraction of the field surface covered by the crop canopy. This can be done visually or by using a cell phone application (see the Canopeo website, <http://www.canopeoapp.com>). Extensive monitoring in Salinas strawberry fields has shown that canopy coverage tops out at about 65% of ground cover for 2-row beds that are 48 in wide and at about 80% of ground cover for 4-row beds that are 64 in wide. The relationship between canopy cover and K_c is shown in figure 6. Multiplying ET_o by the K_c estimates the amount of water loss from the field (crop evapotranspiration, ET_c). Dividing ET_c

Table 1. Historical CIMIS reference evapotranspiration (ET_o) averages (in./day)

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Salinas	.05	.07	.09	.13	.15	.16	.16	.15	.13	.09	.06	.04
Santa Maria	.06	.08	.10	.13	.16	.17	.17	.17	.15	.11	.08	.06
Ventura	.07	.09	.10	.13	.15	.16	.18	.16	.14	.11	.08	.06

Figure 6. Relationship between strawberry canopy cover (%) and the crop coefficient (K_c). The calculation is $K_c = [(0.63 + 1.5C - 0.0039C^2) \div 100]$, where C is the percent canopy cover.



by the drip system DU estimates the irrigation requirement (the amount of water necessary to maintain adequate soil moisture in all areas of the field).

The following example illustrates calculating the irrigation requirement in a strawberry field. A field in Santa Maria in mid-June has canopy coverage of 60% and an irrigation system DU of 85%. The daily ET_o is 0.17 inches. From figure 6, the K_c is estimated to be 0.78. The daily irrigation requirement is

$$(ET_o \times K_c) \div DU, \text{ or } (0.17 \text{ in} \times 0.78) \div 0.85 = 0.16 \text{ in}$$

The appropriate irrigation frequency will be influenced by the water-holding capacity of the soil, rooting depth, and water demand of the crop. A crop grown on sandy soil with a low water-holding capacity will need more frequent irrigation than a crop grown on clay loam soil with a high water-holding capacity. In the early stages of crop development, water demand will be low; therefore, irrigations can be less frequent than during the main production period.

Monitoring soil moisture can help verify that irrigation is keeping up with the water demand of the crop and identify areas of the field that may be exceptionally dry or wet. Soil moisture sensors as well as probing the soil with a hand tool can be helpful. Tension-based soil moisture sensors such as tensiometers and resistance blocks are most often used for scheduling irrigation in strawberry production. Soil moisture tension significantly greater than 30 cb (centibars, equivalent to kilopascals, kPa) in heavy-textured soil or

20 cb in sandy soil are considered high for strawberries and may lead to reduced growth and fruit yield.

Crop Establishment

Surveys of water use in strawberry production have shown that as much as 20 to 30% of seasonal water application may occur during the establishment of transplants. Crop water use is minimal during establishment because the transplants have few leaves to transpire water. Also, ET_o is usually low during the fall, when most fields are established, so minimal irrigation is needed to maintain adequate soil moisture. However, because newly planted transplants have few roots, they are susceptible to drying out. Also, salts can accumulate near the transplants due to evaporation from the planting holes in the plastic bed mulch. To minimize these concerns growers may overirrigate during crop establishment. This is particularly problematic when strawberries are planted after vegetable crops, because the typically high level of residual soil NO_3-N is susceptible to leaching.

Irrigating frequently but for short intervals and monitoring soil moisture can help minimize overirrigation during crop establishment. Using drip or a combination of drip and sprinklers to establish a strawberry crop can reduce water application by up to 20% compared with using sprinklers alone. Microsprinklers, which are commonly used in Ventura, can also improve irrigation efficiency during establishment. Orienting the transplants so that roots are pointed down minimizes the development of shallow roots, which are susceptible to drying out. Applying preplant fertilizer bands sufficiently deep and offset from the plant rows minimizes the salinity hazard to the developing roots.

Post-Establishment

Strawberries transplanted in October-November have low irrigation requirements through the late fall and winter months. Summer plantings, which occur mostly in the Ventura area, require more-frequent irrigation and greater amounts of water, especially during periods of hot, dry winds (Santa Ana winds) that can occur during the late summer and fall. Soil moisture monitoring can be helpful in guiding irrigation management during this period.

Harvest Period

The water use of fall-planted strawberries increases in late winter and early spring when the crop canopy cover and ET_c increase as days become longer and warmer. Extra care should be taken

to assure that irrigations keep up with the increasing water demand of the crop. ET-based irrigation scheduling is particularly useful once a substantial crop canopy has been established and the likelihood of significant rainfall declines. Several years of replicated field trials demonstrated that ET-based scheduling optimized fruit yields. These trials compared applying 50%, 75%, 100%, and 150% of estimated ET_c . Marketable fruit yields were maximized with the 100% ET_c treatment (fig 7.), and no additional yield was achieved by applying more water. Limiting irrigation to 75% of ET_c caused a small but statistically significant yield loss, and a dramatic yield loss was observed when irrigation was reduced to 50% of ET_c .

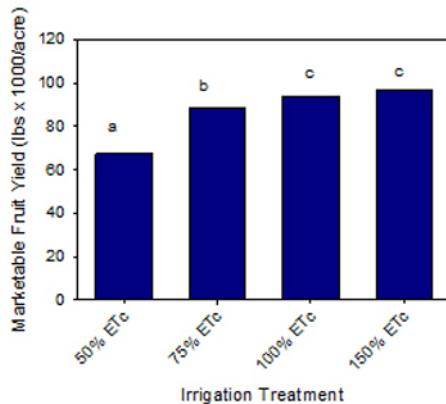


Figure 7. Marketable yield of strawberries irrigated using selected percentages of estimated crop evapotranspiration (ET_c).

Leaching Requirements

Strawberries are sensitive to the accumulation of salts in the soil, and fruit yield will be reduced as the soil salinity (EC_e , as measured in a saturated paste extract) increases above approximately 1.2 dS/m. Where calcium and sulfate are the dominate ions in the soil solution, somewhat higher EC can be tolerated without yield loss. The application of water in excess of ET_c may be needed to prevent salts from accumulating in the root zone of strawberries. For a discussion on how to calculate the leaching requirement of vegetable and row crops, see Cahn and Bali 2015. If the salinity of the irrigation water is relatively low (less than 1 dS/m), leaching requirements can be quite small. Because salt accumulation in the root zone occurs slowly over the season, a leaching fraction does not need to be applied with every irrigation; monitoring soil salinity during the season can identify when leaching is needed. Because

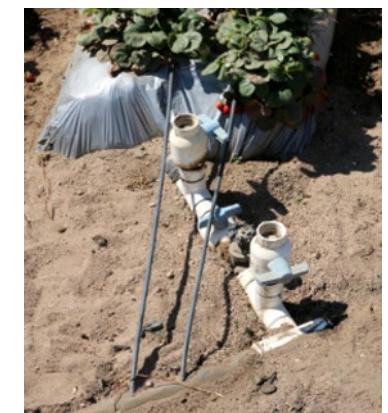
leaching for salinity control can also leach NO_3 -N, avoid leaching when soil NO_3 is high to minimize NO_3 loss.

Fertigation

Most strawberry growers inject a portion of the fertilizer applied to their crops through a drip irrigation system. Fertigation uniformity is limited by the DU of the irrigation system and the procedures used for injecting fertilizer. Drip systems that have low DU also have uneven distribution of injected fertilizer. Since fertilizer can react with salts in irrigation water to form insoluble compounds, fertilizers should be injected upstream of a filter to prevent clogging of the drip emitters. Many irrigation systems that we evaluated had high uniformity initially, but by late in the season the uniformity was much lower due to clogged emitters. Periodic flushing of the ends of the drip lines may also help reduce emitter clogging.

Assuring that injected fertilizer thoroughly mixes with irrigation water is also critical to the DU of a drip system. Because irrigation sets are often of short duration in strawberries, many irrigators prefer to inject fertilizer in the field rather than at the well so they do not need to wait for the fertilizer to travel to the field. This practice can reduce the opportunity for fertilizer mixing. For example, injecting fertilizer at a valve near where the submain branches into two directions (fig. 8) can lead to uneven DU if the fertilizer stream moves more in one direction than the other.

Figure 8. Fertilizer injected at the valve connecting the submain to the main line does not have sufficient distance to mix before the water flow splits into opposite directions.



Equally important to achieving uniform fertilizer distribution is allowing sufficient time for all of the injected fertilizer to flush from the drip tape before ending the irrigation set. Some irrigators believe that injecting fertilizer at the end of the irrigation set is the best practice to reduce leaching of fertilizer; however, because most irrigation sets in strawberries are short (often less than 2 hr), and the time required for fertilizer to travel to the farthest point in an irrigation block can be greater than 30 min, waiting too close to the end of an irrigation set to inject fertilizer can lead to poor DU.

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