Irrigating Corn with Limited Water Supplies

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Introduction

Field corn acreage in California from 2006 – 2008 ranged from 515,000 to 665,000 acres with approximately 75% harvested for silage (8). The Central Valley accounts for 98% of the state's corn acreage. The Sacramento Valley contains 12% of the acreage, of which roughly two thirds is for grain. (In the past 3 years the percent of the acreage going to grain in the Sacramento Valley ranged from 54% in 2008 to 83% in 2007). The San Joaquin Valley has 86% of the corn acreage, of which 80% is for dairy silage. Some corn varieties are designed specifically for grain production while others are promoted for silage. However, many growers in the state choose "dual purpose" varieties that can be grown for either, enabling the farmer to evaluate the market and decide at the last minute whether to go for grain or silage. The state's average yield of grain corn for 2006-2008 was just over 5 tons per acre. For that same period the average for silage corn was 26.7 tons per acre (70% moisture). While the emphasis of this paper is on field corn, the information provided should also apply to sweet corn.

Corn and Corn Growth

Corn is a monocot with the C4 photosynthetic pathway which is more efficient than the more common C3 pathway. C4 plants have higher water use efficiency than C3 plants and are better adapted to hot climates with intense sunlight than C3 plants. Other C4 plants include sorghum, sugarcane, and amaranths. Corn has a relatively small root system compared to sorghum. The majority of the water used by corn will be in the top 2-3 feet of soil.

Depending on variety, a corn crop can go from planted seed to grain maturity in as short as 80 days (or less) or as long as 125 (or more) days. Varieties taking longer to mature usually have higher yields. In the southern San Joaquin Valley varieties are usually chosen that take 105 to 120 days to maturity. The longer season varieties would be for single crop grain production planted in March. Silage crops usually follow winter forage and are planted from late April through June and sometimes later.

Visually, corn development is divided into the vegetative stage that lasts through tassel and the reproduction stages that include silking, pollination, and grain filling (5). Stress during the vegetative stage (any stress prior to 2 weeks before silking) can slow the appearance of new leaves, reduce leaf area expansion, reduce plant height, and delay crop maturity (9, 15). Stress during reproduction will hasten maturity and reduce yields.

Crop Water Use

Corn evapotranspiration (ET) estimates for the Central Valley range from 25 to 29 inches, depending on location within the Central Valley, time of planting, and season length for the variety chosen (11). At full canopy, ET is around 0.3 inches/day.

General strategies for coping with limited water include deficit irrigation of crops which can be stressed without significant loss of yield or quality, improving irrigation efficiency and/or uniformity, improving crop genetics to develop varieties more tolerant to water stress, or planting other crops.

Deficit Irrigation of Corn

Deficit irrigation can be defined as the application of water below the (ET) requirements of the crop (3). Deficit irrigation of tree and vine crops has been more successful than on annual crops. Reasons for this include yield determining processes in many fruit trees are not sensitive to water shortage at some stage of development, economic return is often due to quality and not as directly related to ET and biomass production as in many annual crops, and higher value crops often have micro-irrigation systems that enable application of small amounts of water with fine-tuned scheduling (3). What is the impact of irrigating corn below what is needed for maximum ET and does it matter if the stress is throughout the season or at specific times?

Considering first season-long deficit irrigation, recognize that biomass production is tightly associated with ET. When ET is reduced from the optimum for a crop, biomass is reduced. From the silage point of view, any loss of biomass reduces yield. In addition silage quality is a concern. Fiber digestibility is a major component of silage quality. Papers reviewed for this presentation did not address if, or how much, water stress affects silage quality. However because the grain is a major component of silage quality, both grain and silage producers have a similar concern: what is the impact of limited water on grain production?

Besides biomass reduction, water stress can affect the Harvest Index (HI) which is the fraction of the above-ground biomass that is harvested. To a point, corn can be stressed through the season so that the fraction of grain compared to the total above ground biomass does not decline. However, there is a reduction in yield because total biomass declines even though the percent of the biomass that is grain remains constant (3). Under this scenario, stress gradually increases during the season as the soil water reserve declines and the irrigation water applied is less than optimum ET. If too much stress occurs, then the HI declines. The amount of stress corn can withstand before the HI is impacted depends on soil type and ET demand. Realistically, it would be hard to manage even is a grower was willing to accept the yield decrease.

If simply under-irrigating through the season is not a reasonable strategy, is there a time in corn development when water stress can be applied without impacting grain yield? Can an irrigation be skipped or the irrigation interval be extended significantly at a particular growth stage without impacting yield? Most studies demonstrate, and experience has shown, that there is no good time to stress corn. But if water stress is unavoidable, then it is best during the vegetative period up to 2 weeks prior to silk emergence. Stress during this vegetative period has the least impact on grain yield. It can result in shorter corn and may delay the appearance of new leaves and tassels. If water stress is severe, it may negatively impact nodal root development and a dry hard soil surface when brace roots start to grow may impede their development. These smaller root systems may lead to mature plants falling over when the field is irrigated (9).

The second least damaging time for water stress is late season during grain fill when it can reduce photosynthesis and reduce movement of carbohydrates into the kernels. The number of kernels is not reduced but kernels are smaller than they would be if plants were well watered. If stress is extreme, kernels can be shriveled. Additionally late season water stress can increase stalk rot leading to higher risk of lodging with subsequent harvest losses.

The most important time to avoid water stress is the 2 weeks prior to silking through the 2 weeks following silking. Stress before silk emergence can delay silking relative to pollen resulting in insufficient pollen available for good fertilization. If the stress occurs during pollination, silks may desiccate, preventing pollen germination or the pollen tube from extending down the silk to fertilize each kernel. Kernel abortion can also occur. The result is an ear with reduced number of developing kernels. It has been estimated that severe stress 2 weeks prior to silking can reduce grain yield by 3-5% per day; at silking 3-8% per day; and during the 2 weeks following silking, 3-6% per day (9).

Regulated deficit irrigation is not a strategy that is promising for corn as there is no really good time to impose stress. It is also a strategy that would be difficult to implement with furrow or flood irrigation, the most common types of irrigation for corn in the state, because it is hard to regulate the amount of water applied with these systems.

Variety Selection

Growers can choose from a wide selection of varieties. One characteristic of a variety is the relative days to maturity. Corn varieties grown for silage and planted in May are often “105 day” varieties. Corn planted in March for grain might be 125-day varieties. Generally a grower wants to have a variety that is a long as the climate allows because in general the more days to maturity, the higher the yield. Growers facing a shortage of water, however, may want to consider planting shorter season varieties. In the end, it may be better to have an adequately watered short season corn than a stressed longer season variety.

Irrigation systems

Because opportunities for reducing the amount of water available for ET are limited without yield loss in corn, improvement in utilizing the water applied is another strategy. Specifically, losses due to deep percolation or runoff must be reduced. Some water needs to drain below the root zone to remove salts but excessive drainage needs to be avoided. Fields and irrigation systems vary due to numerous factors, including soil types, slope, flow rate, and irrigation management. For the purpose of this paper, generalizations have to be made but it is important to realize that the alternatives mentioned need to be evaluated on a specific field with consideration of the performance of the irrigation system currently in use. Finally, the economics of significant changes in irrigation systems and management must be considered but are beyond the scope of this paper.

Currently almost all of corn grown in the California is irrigated by surface irrigation, mostly furrow but some flood irrigation is also used. Depending on soil type and system design, these methods can be quite efficient, but often there is room for improvement. Corn roots are not particularly deep or well developed. Most water is taken up from the top 2 feet. Growers are often on a 7 – 10 day schedule. At maximum canopy, ET for corn is about a third of an inch per day. In 10 days, about 3 inches would be needed to refill the profile but many furrow systems would apply 4-6 inches just to get water to the end of the field. With pre-irrigation and irrigations following cultivation, application rates are commonly even higher.

For furrow irrigation the management strategy that most improves irrigation efficiency and uniformity is to shorten the irrigation run. If the on-field flow rate remains the same, halving the field length reduces the time needed for water to reach the end of the field by at least 30-40%, usually improves distribution uniformity by 10 – 15%, and often reduces deep percolation by more than half (4). With less time to reach the end of the field, less water is applied. However shortening the field will result in more surface runoff so a way to re-use this runoff water, such as a tail water recovery system, is needed. An example of the impact of shortening a field is found in Table 1.

Alternate furrow irrigation can reduce subsurface drainage and runoff. In one study comparing alternate and every-row furrow irrigation in corn on different soil types, yields were equivalent for the two methods (4). With alternate furrow irrigation, 29% less water was applied than was applied with every-row irrigation. Alternate row irrigation has the added benefit of moving salts from the wet furrow across the bed and out of the seed row, which may be of benefit in some situations. However, some studies in different crops have shown a yield reduction with alternate furrow irrigation. Some soils, in particular those that crack across the bed are not very adaptable to alternate furrow irrigation. As always, care must be taken when trying new irrigation methods on a particular field.

For many soils, strategies to reduce the amount of applied water would only need to be used on those irrigations following cultivation when infiltration is high. It is common that 6-9 inches (or more) can be applied in a pre-irrigation. In a soil that holds 1 inch of water per foot, this would wet the soil to 6-9 feet, much deeper than corn roots will effectively take up water. Irrigations that follow cultivation can also result in heavy applications of water. Plants are usually small at this stage and their root development limited resulting in much of the water applied not being available to the plants. A major challenge is how to limit the amount of water applied when irrigation occurs after the ground has been cultivated prior to planting or when plants are small.

Torpedoes are heavy tube-sahped blocks pulled through furrows to smooth the floor of the furrow, allowing the water to run more quickly to the end of the field. In one study of a pre-irrigation event, torpedoes reduced the amount of water applied on a quarter mile run from 12.9 inches without torpedoes to 9.4 inches on the "torpedoed" furrows. In that same study the water was also monitored at 600 ft. In this case, shortening the field by half would have resulted in an application of 7.1 inches without torpedoes and 4.3 inches with torpedoes (Table 1).

Another method to reduce infiltration with furrow irrigation is surge irrigation. With surge irrigation water is allowed to run a certain distance down the field and then the irrigation set is switched to a new set of furrows. While the alternate set of furrows get irrigated, the water in the original set drains. The water is then switched back to the original set where it runs beyond where it wetted before to a new distance. Then the water is turned back to the second set of furrows and this alternation between sets is repeated until the water reaches the end of the field. The idea is that when the water runs over the part of the furrow already wetted, infiltration is low, resulting in reduced water application. In the same study cited above on the impact of torpedoes, surge irrigation was also monitored (see Table 1). In the sets where surge irrigation was used, applied water was on average 75% of the amount applied on furrows without torpedoes and under continuous irrigation. It was not clear if surge provided a benefit to the irrigation sets that had been torpedoed probably due to issues of slope in block 5.

Table 1. Effects of surge irrigation, furrow torpedoes and field length on furrow-irrigation performance during a pre-irrigation event. (11)

			Applied water	
Block	Torpedoed	Flow	at 1,250 ft	at 600 ft
1	No	Continuous	12.0	7.1
2	No	Surge	9.1	5.4
3	No	Surge	8.4	5.2
4	Yes	Surge	7.8	5.0
5	Yes	Surge	10.5	4.8
6	Yes	Continuous	9.4	4.3

The benefit of surge irrigation depends on soil type. In 13 comparisons, 9 showed a reduction of 30% or more in the amount of water applied with surge irrigation compared to non-surged irrigation. Four comparisons showed a reduction of only 5% or less (4). Careful management is required to avoid under-irrigation or excess run-off and gated pipe is required. Although it can be done by manually switching irrigation sets, there are automated valves that reduce the labor involved.

If considering options other than furrow irrigation, sprinklers provide the ability to apply small amounts of water. Due to the height of corn, overhead linears or center pivots would be needed if using sprinklers for the entire season. However, hand lines could be used for the pre-irrigation and early season applications for better control over the amount of water applied when corn has not emerged or is still small. As corn increases in height and "lay-by" occurs, growers could switch to furrow irrigation. This use of sprinklers for early season irrigations could reduce early season losses due to deep percolation and also reduce leaching of nitrates. It might be a valuable strategy for dairy manure management.

There are a now over 25 center pivots in western Fresno County. Corn is not a common crop in this area but work at the UC West Side field station with an overhead linear has resulted in respectable yields of corn for grain. Corn is commonly grown under center pivots now in the Midwest (7). Corn has also been grown successfully with drip irrigation. Water quality and placement could be an issue if salt accumulation occurs (6).

Conservation tillage may be a strategy to reduce water applied to corn by furrow or flood but not all growers report, at least initially, that irrigations with conservation tillage take less water than conventionally tilled fields. If the conservation practice results in mulch on the soil surface, the evaporation component of ET could be reduced. This could be significant because researchers in one study claimed evaporation accounted for over 30% of ET (10).

Future Genetic Prospects

Drought tolerance involves many genes and pathways. Factors such as root architecture, silking kinetics, and chlorophyll synthesis rates under stress are involved. Genetic mapping and molecular techniques are helping corn seed companies identify genes contributing to drought tolerance and to select them through traditional breeding methods. Gene segments can be cloned and then introduced into new hybrids through traditional breeding or through genetic engineering. Several companies are testing hybrids now for release in the not too distant future (see Table 2). Due to the number of genes involved, these improvements most likely will be gradual increases in yields.

Companies are also exploring transgenic improvement in which drought tolerant genes are identified in other plant species and then introduced into corn through genetic engineering methods. Improved varieties based on these techniques are further away from commercialization but are being developed. These foreign genes need to be introduced into corn, expressed, and tested for agronomic characteristics. In addition, the regulatory process will delay commercial release of these varieties once developed (14).

Table 2. Examples of yield response for drought tolerant, intermediate, and susceptible hybrids (14).

	Grain yield (bushels/acre		
Hybrid	Irrigation	Dought stress	% Yield loss from stress
Tolerant	221	164	26
Intermediate	251	133	47
Susceptible	233	110	53

Alternative Crops
If all else fails, growers may consider planting different crops. Grain and forage sorghums have shown to use less water than corn and in some studies yield comparable to corn under low water conditions (1,2). Some forage sorghums have quality close to or similar to corn (1).

Summary
Reducing water amounts below what is required for corn ET will result in biomass reduction and, unless stress is very slight and occurs early in the season, grain yield reduction. Even if growers wanted to try to minimally stress corn, irrigation systems commonly for corn irrigation in California do not allow for such close management of stress. There is no really good time to withhold water from corn and maintain yields. However, there is one growth stage to avoid water stress if at all possible and that is the 2 weeks before through the 2 weeks following silk emergence.

If significant water savings can't be obtained by withholding water from the crop, then the way water is applied to the field must be improved. Strategies to maximize limited water include changes to irrigation management, design, or systems. Surface run-off ("tail water") needs to be utilized either through tail-water return systems or diversion to other fields being irrigated. Shortening runs or using alternate furrows may reduce water loss in furrow systems. Torpedoes, surge irrigation, or sprinklers in early irrigations, which tend to have the most loss due to deep percolation, have potential to save water. Variations in soil type, current irrigation system performance, water quality, crop alternatives, economics, and other factors require that no broad prescription can be applied to all situations.

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