Crop Choices Under Limiting Water Supplies:

*Deficit Irrigation and Sensitive Growth Stages*

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and
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Good irrigation management decisions becoming more complicated

• Best practice or cost-effective choices not necessarily the same over time as water availability, equipment costs, labor costs and environmental conditions change

• Competition for less stable water supplies, potentially more salinity, trace element, and shallow groundwater issues all can come into play

• Options to consider keep changing under the conditions pressed upon us
Options with limited water

- Agricultural Water Users have multiple options when supplies limited:
  - Reduce planted acreage (such as San Joaquin Valley in recent years)
  - Change equipment to limit losses or improve application efficiency or scheduling
  - **Impose periods of deficit irrigation**

- Each of these options have problems, costs or consequences that are being considered at this conference
Objectives

- Describe some examples of crop and water management issues to think about when **deficit irrigation** is considered as a water saving approach.

- Provide some examples based on specific crops and responses to deficit irrigation.

- Some examples are from my work, but others are from mostly California-based deficit irrigation research studies by a range of researchers.
San Joaquin Valley situation – Central California

- Mediterranean-type climate:
  - Cool, wet winters with most rain Nov – April
  - Total rain for year 5 to 10 inches (125 to 250 mm)
  - Warm, dry rest of year
- Dominant characteristic is little chance of significant rain to meet much of crop ET during dry period

- Crop production costs tend to be high (land, labor, inputs including water)
- Most growers have produced crops under full irrigation
- Yields and crop quality under dryland/non-irrigation conditions considered uneconomic for most crops widely grown to date
To use or consider deficit irrigation requires:

- Identification of crop growth stages sensitive to deficit irrigation, if any

- Development of irrigation scheduling approaches that are based on periods with a level of plant water stress considered acceptable
  - Irrigation levels in this situation will not meet full crop water requirements during some growth stage(s) ... so some level of stress will be imposed
  - These efforts may include defining tools (plant or soil measurement) to monitor or make sure plant water stress is not excessive
Decisions to change types of crops

- Over the past 30+ years in California:
  - Shifts in acreage have been significant, with some explained as shifts away from lower profit potential crops
  - Ex: Dept Water Resources and CA Dept of Agriculture data comparing late 1970’s to early 2000’s shows:
    - About 2 mi. acre reduction in field crops
    - About 1.2 mi. acre increase in horticultural crops (orchards, vines, vegetables and fruit) during period
  - These shifts often did not represent changes to lower water use crops (ex: cotton replaced by orchards or double-cropped land for animal feed)
  - Changes more related to crops perceived as or having higher profit-potential
Consequences at Irrigation District or Farm Level

Shifting to a relatively higher ratio of permanent crop plantings to annual crop plantings means that when irrigation water supplies are limited, much of the pressure to cut back on irrigation water use focuses:

First – on reductions in annual crop plantings and increases in fallowed ground

Then – on deficit irrigation strategies for remaining crops

This has been seen in the San Joaquin Valley in recent years with cutbacks in irrigation water supplies
Deficit irrigation examples from California research efforts

Try to provide more of a perspective of what growers can do at the level of production of specific crops to reduce water applications:

• what can they do in terms of reduced applications?
• what might they think is too risky in terms of potential for yield loss and quality problems?
Drought or limited water supply – Options

Change irrigation mgmt with existing system & understand how the crop will respond

Cotton example: (Hutmacher, et al) - crop where ET not always linked to yields (about 100-125,000 ha recent years)

1. Reduce acreage  (option with all our crops, but unacceptable yield impact)
2. Delay first irrigation  (crop not very sensitive to water stress during early vegetative development – don’t jump the gun, consider use of plant indicators)
3. Increase interval between irrigations with goal to eliminate one or more total irrigations per season  (more possible in some soil types than others – can reduce duration of active growing and fruiting season – may need to focus more on protection of early crop so can set crop earlier and reduce need for later season production)
4. Reduce applied water per irrigation  (can manage growth and control when fruiting ends to larger degree, hard to achieve with flood or furrow unless surge or alternate furrow work well; can accomplish with drip or sprinkler)

* All of the above can save water for sure, but still need to operate so it covers costs and yields at a level with potential to deliver a profit or not a workable solution
Cotton sensitivity to water deficit periods

- Irrigation mgmt recommendations in CA include scheduling that imposes mild to moderate deficits to help manage vegetative growth and balanced fruiting.
- Most CA research suggests:
  - Growth stages least sensitive to water deficits are:
    - Early vegetative growth to about 7-9 nodes
    - After peak flowering into boll maturation
  - Most sensitive growth stages are:
    - Flower bud formation through early flowering
    - Later flowering intermediate in sensitivity
Cotton sensitivity to water deficit periods

To help decide on irrigation scheduling with allowable but not too severe deficits, there are a number of well-researched tools useful in assessing plant water stress in cotton:

- Leaf Water Potential (Grimes and Yamada, 1982; many others)
- Crop Water Stress Index / infrared thermometry (Howell et al, 1984, Hutmacher, 1995, others)
Cotton Lint Yields (kg/ha) with targeted water stress periods under subsurface drip irrigation (applied water reductions (mm) shown in red, base of about 700 mm) – SJV Acala

Stress duration imposed as a 0.3 Mpa (3 bar) difference in Leaf Water Pot.

- Lose fruiting sites

-35

-58

-62

-51
Crop Etc and lint yield responses in irrigation studies – West Side REC – Subsurface drip

700 mm = 27.5” (applied + soil water use)
Drought or limited water supply – Options
Change irrigation mgmt with existing system & understand how the crop will respond

Alfalfa example: (Blaine Hanson) - crop where ET tightly linked to yields (about 400,000+ ha recent years)

- all options shown below are likely to reduce yields

1. Reduce acreage irrigated (stand damage if no irrigation)
2. Fully irrigate early on, none later (full/deficit) (target early harvests with best ylds & quality, flood & sprinkler compatible)
3. Distribute reduced applications over entire field, full season (eliminate an irrig. between cuttings (ok with flood or spinkler); reduce irrigation amount per irrigation (more possible with drip or sprinklers)
4. Reduce applied water per irrigation (reduce yields, hard to achieve with flood or furrow; ok with drip or sprinkler; too small amts may result in uneconomical yields in terms of covering harvest costs)

* With alfalfa and even more with trees & vines, one of the major considerations may be the longer-term impacts of water mgmt practices on survivability and future productivity of the crop
Drought or limited water supply – Options

Alfalfa:

- Multi-location, multi-year studies of Hanson et al (2008) across CA identified climatic, soil-related differences in impacts of deficit irrigation on yields and quality
- Deficits of significant duration influenced yields the least when practiced during times of year when yields and quality were already more depressed (such as late summer into early fall some locations, peak heat periods elsewhere)
- **Irrigation water salinity & salt accumulation** are major grower concerns when it comes to any longer term deficit irrigation periods (ie. Colorado River water use in Imperial Valley, saline well water use in Central Valley)
- Salt accumulations and long-term stand survival can be key when trying to decide if better off with:
  - Full irrigation + leaching fraction on fewer acres, or
  - Deficit irrigation on all acres, but with no effective leaching at least during that period (may leach other time or count on rainfall?)
**Drought or limited water supply – Options**

**Pistachio example:** (Goldhamer and Beede, 2004, Goldhamer et al, 2005; others) about 70 - 80,000+ ha recent years)

<table>
<thead>
<tr>
<th>GROWTH STAGE</th>
<th>RELATIVE WATER STRESS SENSITIVITY</th>
<th>CONSEQUENCES / OPPORTUNITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 (bloom to shell expansion; April-mid-May in SJ Valley)</td>
<td>Moderate or higher</td>
<td></td>
</tr>
<tr>
<td>Stage 2 (shell hardening; mid-May through June)</td>
<td>Low to moderate relative to other periods</td>
<td>Mix of studies showed could tolerate up to 50% reduction in applied water</td>
</tr>
<tr>
<td>Stage 3 (nut fill, shell split, hull slip; July-mid-September)</td>
<td>Moderate or higher</td>
<td>IF DO BOTH THESE PERIODS reduction in applied water from 1040 mm (41+ inches) to about 820 mm (33+ inches)</td>
</tr>
<tr>
<td>Harvest (September)</td>
<td>Lower</td>
<td>Little impact yield/quality year #1</td>
</tr>
<tr>
<td>Post-Harvest (Oct-mid November)</td>
<td>Lower</td>
<td>Some studies showed tolerate up to 75% reduction post-harvest</td>
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</tbody>
</table>
Drought or limited water supply – *Options*

**Pistachio example:** (Goldhamer and Beede, 2004, Goldhamer et al, 2005; others)

**Other areas of concern:**
- what happens in year #2, etc. if continue deficit irrigation? (some evidence less sensitive than other trees, additional work?)

- salt accumulation if multiple years of deficit irrigation or if poorer quality irrigation water used at deficit level? (good news is Pistachio is among most salt-tolerant of tree crops)

- their research also pointed out that in low rainfall areas like SJV, important to assess whether or not winter rainfall is adequate to replenish some root zone water (if deficit irrigate post-harvest and/or rainfall low, may need to apply water well prior to following year’s bloom – can be critical to yield potential)
Drought or limited water supply – *Options*

**Walnuts examples:** (Goldhamer et al, 1988, 1990; Lampinen et al, 2003; Buchner et al, 2008) (about 25 to 30,000 ha recent years)

Walnuts represent interesting contrast to Pistachio responses in terms of severity and duration of impacts of deficit irrigation

<table>
<thead>
<tr>
<th>MAR</th>
<th>APRIL</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUG</th>
<th>SEPT</th>
<th>OCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid root growth</td>
<td>Male, female flowers form</td>
<td>Hull and nut expansion continues and shoot growth progresses</td>
<td></td>
<td>Kernel filling continues through Sept.</td>
<td></td>
<td>OK, mild stress post-harvest</td>
<td></td>
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<tr>
<td>Leaf development</td>
<td>Pollinate by end of April</td>
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<tr>
<td></td>
<td>Deficits at bloom &amp; into summer reduce nut size, shoot, leaf growth</td>
<td>Growth shifts from shoot &amp; fruit sizing to shell &amp; kernel development</td>
<td></td>
<td></td>
<td></td>
<td>Water stress hull split in Sept. can cause nut, kernel damage, $$ loss</td>
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</tbody>
</table>
Drought or limited water supply – *Options*

**Walnuts examples:** (Goldhamer et al, 1988, 1990; Lampinen et al, 2003; Buchner et al, 2008) *(about 25 to 30,000 ha recent years)*

**Several multi-year studies: Summary**

<table>
<thead>
<tr>
<th>Study</th>
<th>Irrigation Level (% Etc)</th>
<th>Yields – year 1 of study</th>
<th>Yields – cumulative yrs 1 thru 3</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldhamer 1988, 1990</td>
<td>Hedge-row Chico variety</td>
<td>100</td>
<td>100%</td>
<td>100%</td>
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<tr>
<td></td>
<td></td>
<td>66</td>
<td>96%</td>
<td>80%</td>
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<td></td>
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<td>33</td>
<td>93%</td>
<td>59%</td>
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Drought or limited water supply – *Options*

**Walnuts examples:** (Goldhamer et al, 1988, 1990; Lampinen et al, 2003; Buchner et al, 2008) *(about 25 to 30,000 ha recent years)*

Several multi-year studies: Summary

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<thead>
<tr>
<th>Study</th>
<th>Irrigation Level (% Etc) - mid to late season</th>
<th>Yields – cumulative years 1 thru 3 of study</th>
<th>Full recovery of yields after full irrig.?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lampinen, 2003, 2008, Buchner et al, 2008</td>
<td>Hedge-row 9-14 years, Sacr. Valley</td>
<td>100</td>
<td>-</td>
<td>Reduced new growth, # of fruit sites</td>
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<tr>
<td></td>
<td>Older, 20 yrs Conventional spaced, SJV, Chandler</td>
<td>65-70 50</td>
<td>74 %</td>
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<td></td>
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<td>60 %</td>
<td>100 %</td>
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<td>82 %</td>
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<td>80 %</td>
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<td>After 1 year</td>
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<td>After 2 years</td>
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Overall, results of deficit irrigation points out difficulty in developing strategy for reduced water applications that does not end up impacting yields or quality for multiple years.
Genetics & Reduced Irrigation Options instead of Targeted Deficit Irrigation

Available cultivars with shorter fruiting & growing seasons

- Example: Cotton cultivars in CA selected previously to make use of long growing season & available heat units. Reasonable when water was available and inexpensive. Need to re-evaluate shorter-season cultivar potential under new water situation?

- Cool Season Crops instead of warm, longer season crops

- Example: more lettuce, broccoli on west side San Joaquin Valley
- Evaluate potential for winter oilseed crops (canola, camelina) or winter forages for dairy or other animal feed
**Genetics / Breeding Efforts:** *Suggestion / Argument – What types of plant characteristics are needed or what genetics needed if have to cope with irrigation water deficits?*

Under the water supply, climate, economic and crop production constraints in central California . . . .

- Consider that selection approaches under rainfed, dryland production systems can focus on a mix of traits that produce yield stability across a range of timings and durations of water deficits .... (ie. Breeders are looking for cultivars that yield better than most others across a broad cross-section of types of temporal droughts ).
Genetics / Breeding Efforts: Suggestion / Argument – types of plant characteristics needed or genetics needed if have to cope with deficits?

FURTHER ....

- Hypothesize that in areas with little rainfall, that are traditionally fully-irrigated, a different selection approach may be needed since crop survival during drought and recovery after rain are not necessarily a good description of what is needed, but instead, we are looking for plants able to tolerate some deficit irrigations and stress, but with good water productivity.

- Will also need to think about plants best suited for productivity under irrigation when assessing transgenic programs aimed at drought tolerance (are the traits identified aimed more at survival during drought & recovery? or aimed at productivity under more moderate deficits such as might occur under deficit irrigation?)
Crop Choice / Suitability for Deficit Irrigation

affected by factors in addition to crop response to deficit irrigation:

- Salinity, trace elements in water supply (not just salts, but also elements such as Boron, others)
- Availability and quality of shallow groundwater
- Price, profit potential of crop
- Impacts of deficit irrig. on quality, yield, $ value
- Need for alternate, rotation crops for disease, insect mgmt.
- Equipment investments, use of infrastructure (packing houses, gin, etc.)
- Fulfillment of existing contracts (vegetables, biofuels, co-ops)
Concluding Comments:

- Not all crops (in research trials or grower fields) respond the same to deficit irrigation management, so the mix of crops in grower’s rotation plans needs to be considered before making irrigation management changes.

- Growers and Irrigation Districts should decide on yield targets, potential impacts of deficit irrigation on yields and crop quality (if any) that will work in terms of profitability when you consider deficit irrigation options in place of reductions in planted acreage.

- Assess what information is available regarding interactions between water and salinity stress when dealing with deficit irrigation in combination with degraded (saline) irrigation water supplies.
Limit risk with diversity of crops

Types of crops include:
- Vegetable or annual / biennial fruit crops
- Orchard crops
- Vines and berries
- Field crops (pasture, grains, alfalfa, feed & fiber crops)
- Ornamentals / floriculture

Diversity of crops can spread risk, but can also make it hard to decide what and where to cut when water supplies are limited or too expensive
Larry Schwankl, Terry Pritchard
UC Extension Irrigation Specialists

http://ucmanageddrought.ucdavis.edu
Options to consider to reduce total applied water & drainage

- **Eliminate or Delay Irrigations** - consider plant growth stage and measures of plant growth/progress in the season to avoid *(where possible)*:
  - **EARLY SEASON WATER APPLICATIONS** that are “too early” and not necessary –
    - example: cotton plants quite insensitive to water deficits until 7-8 node stage
  - **LATE SEASON WATER APPLICATIONS** that are not needed in some situations
    - Example: cotton - when late boll load is light, late-season irrigation could be eliminated in some soils

*May avoid one or more irrigations in some years when extra water unimportant to yield*
IRRIGATION DECISIONS TO CONSIDER:

- Irrigation System Choice
- Components of System and Design
- Operation and Management Decisions
- Plant Responses and Sensitivity to water & nutrient management

* Each of these can be important to success during drought or other water limits – details very involved, just present some examples of management options
Requirements to make deficit irrigation practices work:

- As stated before, you need knowledge of species-specific responses to timing and severity of water stress.
- Using that information, it should be possible to make more informed decisions regarding:
  - Which crops require irrigation at essentially full Etc or non-limiting levels to attain acceptable yield or quality goals and profits?
  - Which crops are better suited for economic production under short or longer-term deficit irrigation?
Future options related to crop responses to water quantity or quality for crops – 
*breeding and biotech*

• conventional breeding and identification of crops or varieties with more favorable responses under limited water
• transgenic characteristics related to water use efficiency or drought tolerance?
• transgenic characteristics related to tolerance to a range of soil salinity or trace element issues?