Reducing Irrigation Overuse through Research into Precision Irrigation

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Abstract

Managing Water Demand and Productive Capacity

Monsanto Hawaii is committed to sustainable farming practices and the careful stewardship of essential resources. Ongoing efforts to keep these commitments include improved water resource management, which has reduced the overall amount of water used to produce our seed crop. This achievement has been accomplished through a series of incremental advances that evaluated irrigation durations and frequencies, end of cycle shut-off times and precision application methods against yield and seed quality. In this abstract, these key improvements will be expanded on to provide support for how we got to our main objective: To improve water resource management and foster responsible irrigation practices for our farms in Hawaii.

Initially, research was conducted to explore irrigation volume and frequency combinations. It was found that one application of 1 acre-inch of water per week was enough to produce the seed we needed without affecting yield or seed quality. This was a major improvement over multiple short irrigation events and when combined with diligent shut-off practices, resulted in the reduction of irrigation use by more than 40% annually.

Currently, Monsanto Hawaii is researching methods of "precision irrigation" based on evapotranspiration models that can calculate when and how much water is used, based on the growth stage of the plant and weather data. With recent investments into irrigation infrastructure and valve automation, precision irrigation has enormous potential to further reduce annual water use.

While this research is ongoing, we can conclude that we can generate the amount of seed that we need and at the same time conserve water resources and repurpose their use to support other sustainability initiatives such as the establishment of rotating cover crop systems and beneficial insect sanctuaries. These results are significant because efficient water management in agriculture is critical for quality and demonstrating responsible resource stewardship is fundamental to sustain our productive capacity.

Key words: Irrigation, sustainability, evapotranspiration, irrigation practices, precision irrigation, resource management

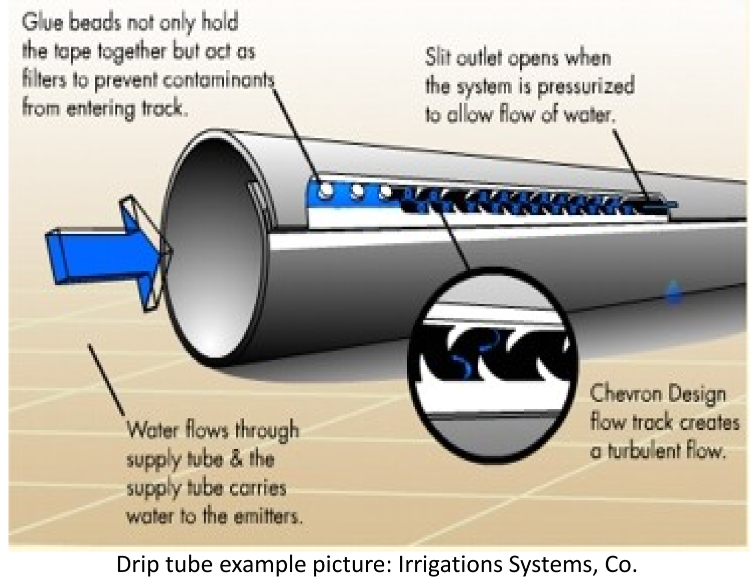
Introduction

Monsanto has been growing seed crops in Hawaii since the late 1960's and has continually focused on how to increase the quality and yield of the seed while also reducing inputs. The management of irrigation water is a specific area that Monsanto continually focuses on to improve the sustainability of our farms and improve our seed product. Converting all irrigation from overhead sprinklers to drip irrigation was a significant change in the process to grow our crops and the change increased the irrigation efficiency and reduced the overall water used by reducing evaporation (see Table 1). This process was later improved by slightly burying the drip irrigation tape 1-2 inches below the surface of the soil to essentially eliminate evaporation as a waste in our irrigation process. Drip tubing is installed on every row of the crop at planting and contains emitters spaced evenly along the length of the drip tube that slowly release water across the field. Today, we utilize drip irrigation to deliver water and nutrients directly to the root zone throughout the season without over-applying water or fertilizers.

This poster will summarize a variety of experiments and process changes that we have undertaken since the adoption of drip irrigation to explore ways to incrementally reduce the amount of irrigation used while improving or maintaining the quality and yield of our crops.

Type of System	Efficiency (%)
Drip	90
Micro sprinkler	80
Permanent sprinkler	75
Moving	80
Movable quick coupling sprinkler	70
Travelling and other movable sprinkler	65
Flood irrigation (piped supply)	80
Flood irrigation (earth channel supply)	60
Source: South African Irrigation Institute, 2005	

Table 1. Irrigation Efficiencies



Drip tube example picture: Irrigations Systems, Co.

Experiment Descriptions and Results

Irrigation Frequency and Duration Experiment:

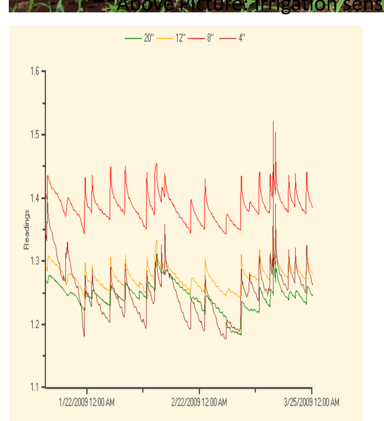
The first of this series of experiments was set up to examine weekly irrigation frequency and duration of set times. The standard practice up to this point had been variable from farm to farm, but typically had been multiple short events ranging from 1.0 to 1.6 acre inches of water per week, per acre. Seed corn raised in Hawaii will usually be harvested 13-15 weeks after planting, so there was potential to standardize and reduce the amount of irrigation necessary to produce the crop, and maybe see some added cost or quality benefits as well.

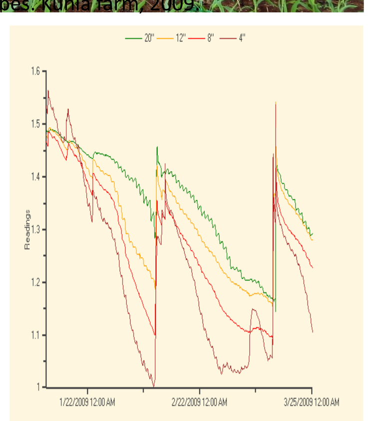
Experimental design:

The trials were set up and analyzed as a Random Complete Block Design with two factors: seed variety and irrigation practice. Four replicates of each irrigation treatment were carried out at three locations in Hawaii: Kunia, Haleiwa and Ho'olehua. There were 7 seed varieties included in the trial. The experiment was repeated during the subsequent year to validate the results. The irrigation treatments are described in Table 2.

Standard	2 x weekly, 0.5 acre-inch per set
Weekly	1 x weeky, 1.0 acre-inch per set
On-Demand	*Sentek* EnviroSCAN soil moisture probes

Table 2. Irrigation Treatment Description


Graph of data:
Standard treatment


Graph of data:
On-Demand treatment

Results:

In all cases, the metrics used to measure the effects of various treatments on seed production will be seed quality (measured in germination tests) and yield (measured in seed units of 80,000 kernels). The actual amount of water applied over 12 weeks of irrigation for the Standard practice was measured to be 20.9 acre-inches, the Weekly treatment was measured to be 13.5 acre-inches and the On-Demand treatment was measured to be 9.0 acre-inches. The results of these trials showed no statistically significant (P<.05) effect of irrigation practice on yield and quality for weekly, vs. twice weekly irrigation treatments for all seed varieties tested (Table 3). The on-demand treatment was found to result in significantly lower yields, with negligible effects on quality.

For our operations, greater labor efficiency and a reduction of total water use was realized, primarily as a result of standardizing practices. Additionally, the change from multiple watering cycles per week to once a week was found to deepen the moisture profile in soil and stimulate roots to grow deeper, potentially leading to stronger plants and a higher yield and quality potential.

	Standard	Weekly	On-Demand
All Replicates	89	86.1	71.9*
Probe Replicate	83	86.1	68.8*

Table 3. Yield in Seed Units per Acre

End-of-Cycle Irrigation Shut-Off Experiment:

Next, our end-of-cycle irrigation termination strategy was explored in an effort to optimize irrigation shut-off times to coincide with seed maturity stages. The initial research focused on enhancements to seed quality and increasing speed to harvest by accelerating senescence and field dry-down. Additional benefits of water savings were uncovered as a result of standardizing this practice.

Irrigation Shut-Off Treatments: 1 acre-inch per application	
Tmt 0	shut-off: at pollination
Tmt 1x	shut-off: 1 week after pollination
Tmt 2x	shut-off: 2 weeks after pollination
Tmt 3x	shut-off: 3 weeks after pollination
Tmt 4x	shut-off: 4 weeks after pollination

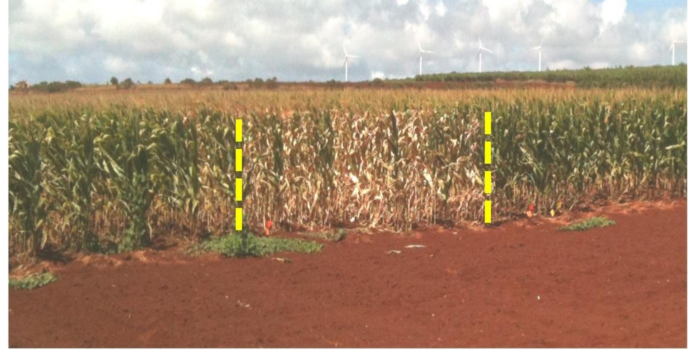
Table 4. Irrigation Treatment Description

LS Means Comparison: Tukey's HSD

Level					Least Sq Mean
2 x	A				53.0
4 x		B	C		44.0
1 x			C	D	40.8
at pollination				D	39.5
3 x					*no data

*levels not connected by the same letter are significantly different

Table 5.Yield in Seed Units per Acre



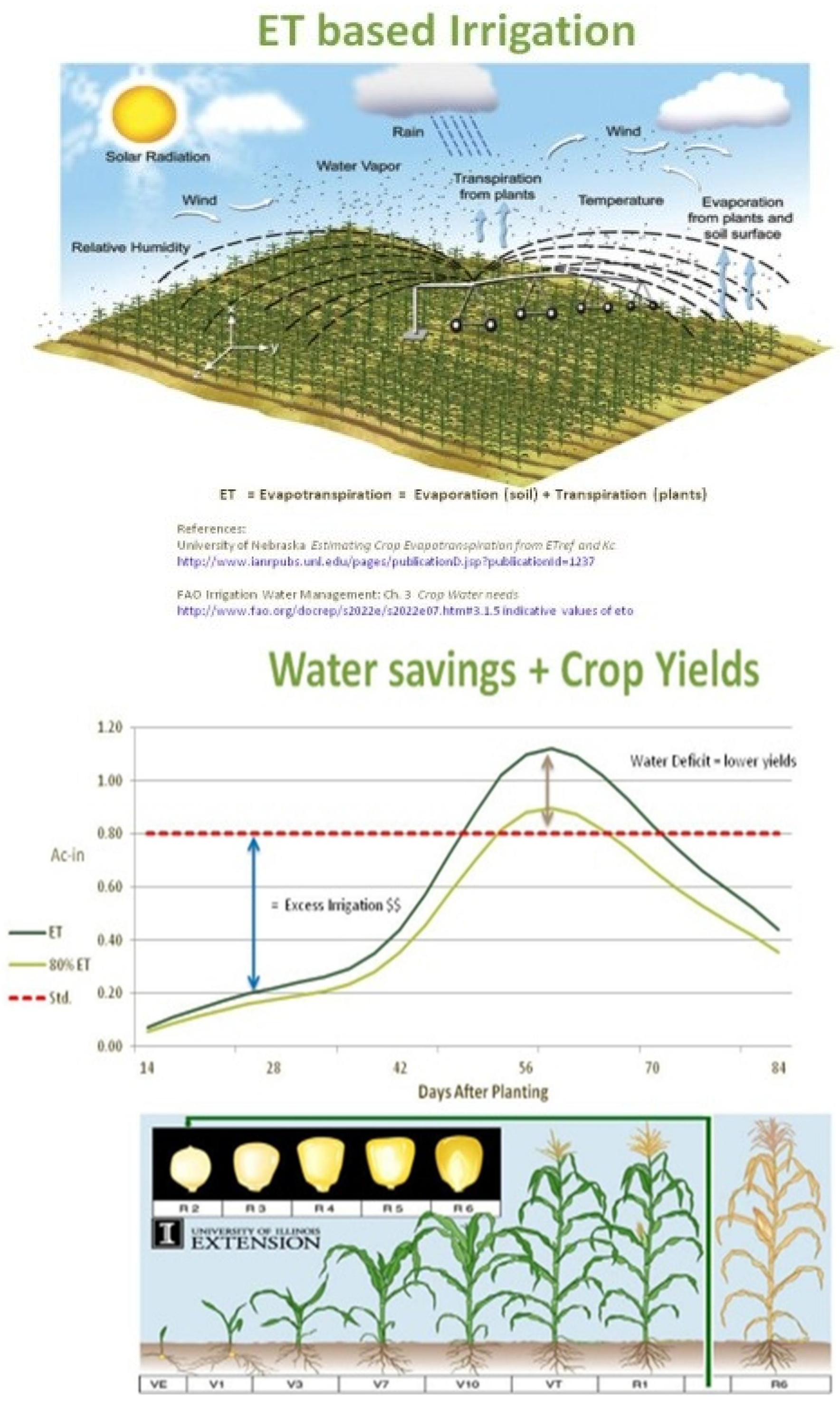
Experimental design:

Based on an initial study that produced encouraging results, a small-plot experiment was conducted to formally separate treatment effects. A strip-plot design was used with seed variety as the vertical plot and irrigation shut-off treatment as the horizontal plot. Four replicates of each irrigation treatment were again carried out at three locations in Hawaii: Kunia, Haleiwa and Ho'olehua. There were nine seed varieties included in the trial. The treatment descriptions are summarized in Table 4.

Results:

This experiment confirmed that irrigation practices influence seed quality and usable yield. The results indicated that two, 1 acre-inch irrigation events, once per week after pollination produced the highest useable yield in seed units (Table 5). Standard irrigation practices would often continue watering until just before harvest (Tmt 4x), slowing down production and inadvertently reducing quality (e.g. germination %).

As a result of this study, end-of-cycle irrigation has been standardized and a reduction in unnecessary irrigation has been achieved. This was an important finding for two reasons: first, it is important to understand that responsible irrigation management can result in an increase in the quality of our yields, and second because it reinforces the commitment of Monsanto Hawaii to our islands as a sustainable user of water resources.



Evapotranspiration Model (ETc) for Parent Seed Corn in Hawaii Experiment

Applying a different approach to sustainable water use, recent experiments have explored the use of data-driven methods to achieve further improvements in irrigation efficiency. A crop evapotranspiration (ET_c) calculation for hybrid corn has been developed by UC Davis and others using an alfalfa-reference evapotranspiration (ET_{ref}) factor in combination with a crop coefficient (K_c) that represents transpiration rates of maize by stage of growth. The equation is $ET_c = ET_{ref} \times K_c$. The model combines transpiration from weather and atmospheric factors over a uniform crop (alfalfa) with the physiological water requirements of maize based on the growth stage of the plant. This ET_c algorithm has been commercially applied to manage larger precision irrigation systems and has shown a significant use reduction, even while maintaining yield and quality of seed return. However, the calculation needs to be adjusted for Hawaii to correct for parent seed corn production and the subtropical environment.

Experimental design:

To develop an adjusted ET_c model, three static irrigation regimes: 100%, 80% and 60% of crop evapotranspiration (ET_c) and one dynamic irrigation regime (60% ET_c from emergence to pre-flowering, and 100% ET_c from flowering to maturity) were compared to determine effects on yield and seed quality.

To investigate the effects on yield, a strip-plot design was used with irrigation as the main plot and pedigree as the subplot. Four replicates of each irrigation treatment were installed in four locations in Hawaii: Kihei, Ho'olehua, and two in the Kunia area of Oahu. There were thirteen seed varieties included in the trial. Yield data was analyzed using a generalized linear model applied to the entire data set using JMP v.10.0.

LS Means Comparison: Tukey's HSD

Level			Least Sq Mean
60%Etc	A		1.41
80%Etc		B	1.26
100%Etc		B	1.24
60%Etc-100%Etc		B	1.22

*levels not connected by the same letter are significantly different

Table 6.Yield in Seed Units per Acre

Results:

The reduction of the current ETc algorithm to 60% of the predicted evapotranspiration rate produced the highest yields (P<.05, Table 6). Seed germination quality was variable across all treatments and seed varieties. Differences in the yield response to seed variety were expected as selections were based on a wide maturity range, however the experiment confirmed that further reductions in irrigation could be achieved by adopting a "smarter" irrigation model that measures water loss and only replaces soil moisture as plants need it.

Recent investments into irrigation infrastructure throughout our Hawaii sites has enabled real-time evapotranspiration calculations to direct automated section valves and irrigate more efficiently, further reducing water use over hundreds of acres in Hawaii. Since this trial only investigated several levels of a control (100% ET_c), the next step is to test the modified ET_c model against current standard irrigation practices to substantiate the effect on yield and seed quality. Experiments are underway to improve our design and integrate further conservation of water resources into Monsanto's larger farming plan.