Deficit Irrigation in Processing Tomatoes

A Proposal Based on Infield Spectral Measurements and Evaporative Demand

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DEFICIT IRRIGATION IN PROCESSING TOMATOES

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Deficit Irrigation: What, When, Why?

Regulated deficit irrigation (RDI) is an optimization strategy to increase soluble solid content (also known as Brix) through the calculated manipulation of water application. Maintaining a certain level of plant water deficit stresses the plant in a controlled way, telling it to send carbohydrates to its fruit, rather than its leaves and stalks. This drives up the fruit's soluble solid content, thereby growing a more valuable product that also saves energy at the processing plant: a fruit with more soluble solids has inversely less water to boil out. Thus, deficit irrigation reduces resource use at multiple points in the supply chain.

To achieve the desired levels of plant water deficit, a grower needs to have a good understanding of when to start manipulating the irrigation deficit and how much to adjust irrigation amounts. By using drip-fed RDI during the fruit ripening stage, growers can precisely manipulate crop evapotranspiration (ETc) levels that correlate with a desired soluble solid content. Moisture loss through ET is the reason we need to water plants; the ETc measurement is in equilibrium with a particular plant's seasonal water requirement, correlating directly with its irrigation needs. Accurate ETc tracking allows growers to prevent water stress during critical growth periods. At the same time, with accurate and reliable measurements, growers can dial in stress during the breaking stage to drive up soluble solids. The University of California Division of Agriculture and Natural Resources (UC ANR) has established some general parameters for irrigation management and RDI. Processing tomatoes thrive under plant water deficit conditions; the exact moment a crop is ready to start RDI is determined by its phenological stage, which we will discuss in this guide.

One challenge is identifying the transition between growth stages in a group of crops grown across a large number of acres, located in a variety of microclimates, and with different transplant dates. Arable uses an advanced method of spectral measurement to remotely monitor key metrics across all fields to trigger an RDI start date and calculate a percentage of ETc reduction. In addition to infield ETc, we monitor growing degree days (GDD) to target the breaking ("pink fruit") stage, which is inferred by measured Normalized Difference Vegetation Index (NDVI). Other important dimensions include end-of-season Brix measurements and the difference in leaf-to-air temperature, which indicates stress feedback.

Did you reach the targeted Brix yield? Did you start RDI on time to meet market demand? Did you reduce the amount of water applied to your fields without risking quality and yield? These are all questions that growers should be able to answer at the end of the season.

Key Variables

In this section, we will discuss in detail the measurements taken by the Arable Mark 2 that are used to determine the time at which processing tomatoes should begin RDI. We also describe other variables commonly used in RDI, and how these metrics compare to the Arable data. Though Arable collects over forty different data streams, we will only describe the measurements used for irrigation purposes in this guide.

EVAPOTRANSPIRATION (ET)

Evapotranspiration (ET) is the combined process of evaporation of water from the soil and plant surfaces and the transpiration of water from plant tissues. The ET is about the same as the seasonal water requirement, making it a direct measurement of how much irrigation a field needs to replenish the moisture loss.

A familiar source for irrigation management ET is called reference evapotranspiration (ET_o). It is a practical tool that estimates ET based on a thoroughly watered crop (alfalfa or standardized grass), with full canopy, growing under optimal agronomic conditions. Daily values of ETo can be found on networks like the California Irrigation Management Information System (CIMIS) at a 2km spatial resolution.

CROP EVAPOTRANSPIRATION

Occasionally, some growers may only have access to ET_o values to account for the water that needs to be replaced in their crops. The challenge with using ET_o is that it does not consider plants in different growth stages, soil types, nor the actual amount of plant material present. The amount of plant material (ground cover), the canopy properties (crop height and leaf area change), and the aerodynamic resistance each change as the crop develops. For example, soon after transplanting, ET is mostly a reflection of soil water evaporation, given that there is almost no crop ground cover. As the season progresses and the canopy grows, soil exposure decreases and ET is mainly driven by plant transpiration.

Arable derives the field evapotranspiration (ET_f), which is akin to ET_o, or the hypothetical evapotranspiration under a grass reference surface. We use Arable's unique machine learning (ML) model to predict this ET_f value, which makes use of the environmental variables listed here. The feature inputs into this ML model are similar to those inputs required for physical models, like the FAO Penman-Monteith method, but we achieve greater accuracy using the ML model, which is able to correct for errors and capture patterns that inflexible physical models do not. As a backup, when the ML model cannot be applied (only under rare circumstances), we use the FAO Penman-Monteith method with the Dong et al. net radiation approach. ET_f is a baseline (not species-specific) evapotranspiration rate based on your field's actual weather conditions over a homogeneous area.

We measure the Normalized Difference Vegetation Index (NDVI), to calculate the crop coefficient (Kc_{NDVI}; see description below) which is then multiplied by your field's ET_f to get the crop evapotranspiration (ET_c) value unique to your crop. You can use this value to devise a precise irrigation plan.

GROWING DEGREE DAYS

Crop physiology during the growing season is primarily driven by the accumulation of heat units, or growing degree days (GDD). GDD represent the temperatures at which a crop can thrive, and are used to predict crop growth, development, yield potential, water uptake, and stress.

Arable calculates a **horizontal cutoff** GDD using the maximum (upper) and minimum (lower) temperature thresholds **specific** to each crop and variety. GDD captures the heat that induces plant development through the following equation:

$$GDD = \frac{Tmax + Tmin}{2} - Tmin$$

We then add the sum of all the daily GDD values we have gathered since the Mark was deployed. This gives us cumulative GDD. For the most accurate results, the Mark should be set up and deployed the very morning the fields are planted so that it can capture the entire season's worth of daily temperatures.

NDVI & KC

Through a seven-band spectrometer (which captures wavelengths from the visible spectrum to the near-infrared spectrum), Arable calculates a daily Normalized Difference Vegetation Index (NDVI; Figure 1), which determines the density of green in a plant canopy. This index acts as a visual proxy for what is happening in the tomato fields; for example, as tomatoes enlarge and ripen, the NDVI values will lessen as the colors reflected will start looking less green and more pink, orange, yellow, red, or purple. A higher NDVI (from 0 to 1) is indicative of more canopy cover.

$$NDVI = \frac{\rho nir - \rho red}{\rho nir + \rho red}$$

NDVI is used to establish Kc_{NDVI}, a multiplier that accounts for the amount of sunlit leaf area, and therefore its evaporative demand, and adjusts ET to give a more accurate ET_c value. At the same time, we use a combination of field-level GDD and NDVI measurements to juxtapose the phenological development of the particular variety with environmental conditions and traditional crop models for processing tomatoes. Arable uses an estimation of Kc_{NDVI} based on the published research by Kamble et al.

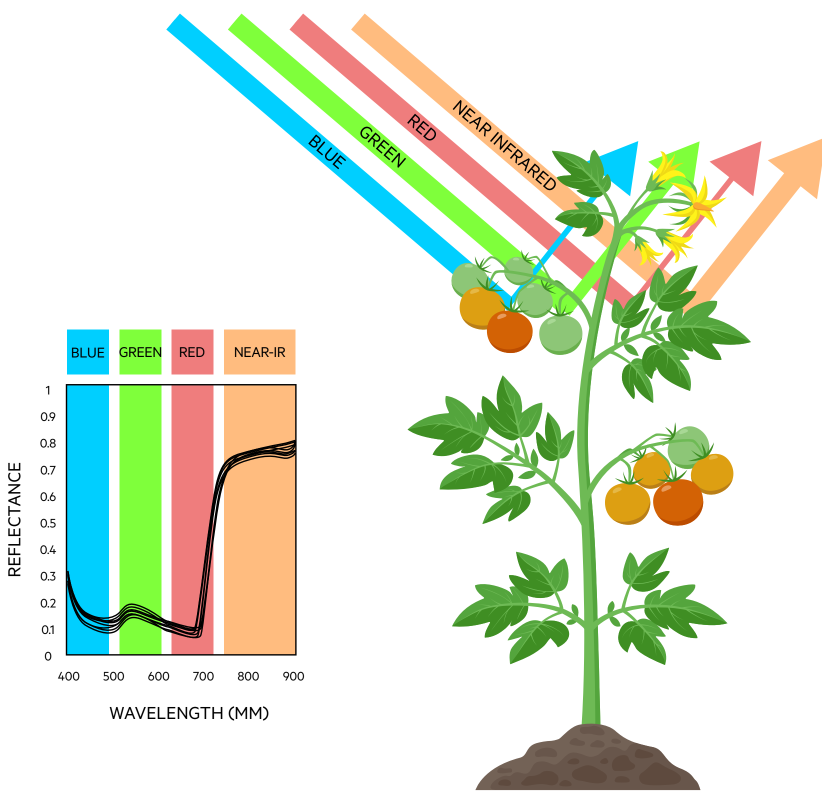

Figure 1. The visible and near infrared spectrum measured in NDVI. Image modified from publiclab.org

Phenology of Processing Tomatoes

Most crops go through predictable growth stages. Zalom, F. G. & Wilson L. T. collected 536 datasets from commercial processing tomato fields over four years, and isolated nine growth stages (Table 1) important to crop management, and predicted their occurrence based on GDD. In this guide, we describe an approach to deficit irrigation that uses GDD to determine when tomatoes are expected to reach these specific stages.

1	Bloom
2	Small green fruit
3	Medium green fruit
4	Mature green fruit
5	Pink fruit
6	10-30% red fruit
7	30-50% red fruit
8	50-75% red fruit
9	75-90% red fruit

Modified from Zalom, F.G. & Wilson L. T. (1999)

INSTRUMENTATION:

Prepare your Field

Before installing any of the devices, make sure that you have optimal device placement and spacing to capture the variability within each field. You need to decide ahead of time at what scale you want to monitor your data (i.e., by field, ranch, or irrigation management zone).

Factors such as slope, soil type and proximity to natural vegetation or water sources may influence the microclimate and plant response to management practices. For optimal sampling, we recommend that you take into account that variability in your fields and install the required number of Marks to account for this variability.

Tip: If you don't know the soil properties in your field, you can access the USDA web soil survey and download that information. You may need some basic GIS knowledge to get more detailed information for your region of interest.

Figure 2. Measure your fields

Field Installation

Once you know where you want to install your devices, deploying the Arable Mark is simple. You can find step-by-step deployment documentation at support.arable.com.

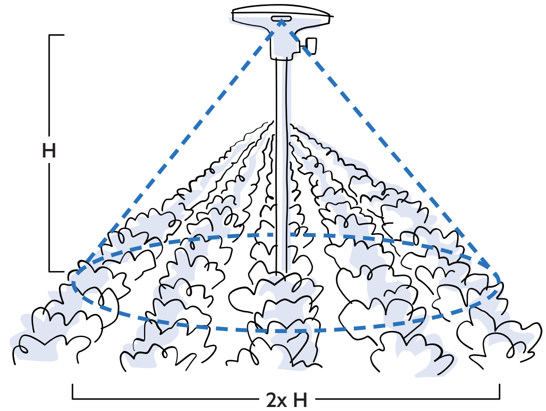

Figure 3. Arable Mark field of view

WHAT YOU WILL NEED

- Arable Mark (one device per 20 acres for processing tomatoes)
- Arable Bridge (enables connecting third-party sensors)
- A post to mount each device
- GEMS Pressure Switch 4 PSI with 10ft cable

INSTALL THE ARABLE MARK DEVICES

Your Mark should be installed directly over your tomatoes. To make sure that you measure the entire canopy, the above-ground height of the mounting pole should be half of the bed width. Depending on the estimated height of the full-grown plant, place the Mark at least 1 foot above the expected canopy. That way, you will consistently collect the crop's spectral data.

ARABLE MARK & MEASUREMENTS

The Arable Mark measures environmental and plant health variables, such as air temperature, canopy temperature, relative humidity, precipitation, pressure, solar radiation, photosynthetic active radiation, net radiation, dynamic crop coefficient (Kc_{NDVI}), and NDVI. An optional soil moisture probe can be connected to the Mark for soil moisture and salinity data. These measurements are synthesized in an integrated analytics platform, allowing growers to monitor their field data at all times. The data is sent to the cloud through a cellular network, providing hourly or daily reports, and can be viewed on the web or mobile app. To ensure data accuracy, the device should be placed above the crop canopy throughout the season.

ENSURING GOOD DATA COLLECTION

We recommend device health checks at every login to ensure high-quality data collection. For example, values of NDVI should always be positive between 0 and 1. If you suddenly see that your NDVI dropped from a consistent value to a value below zero, it's wise to go to the field and check on the device, as something may have knocked it off-kilter to affect its field of view. Here is an example of what that might look like:

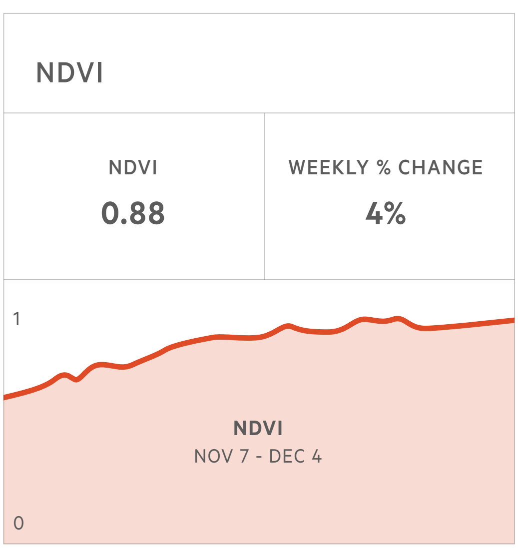

Figure 4. Normal values. NDVI maintains values between 0-1 and shows positive

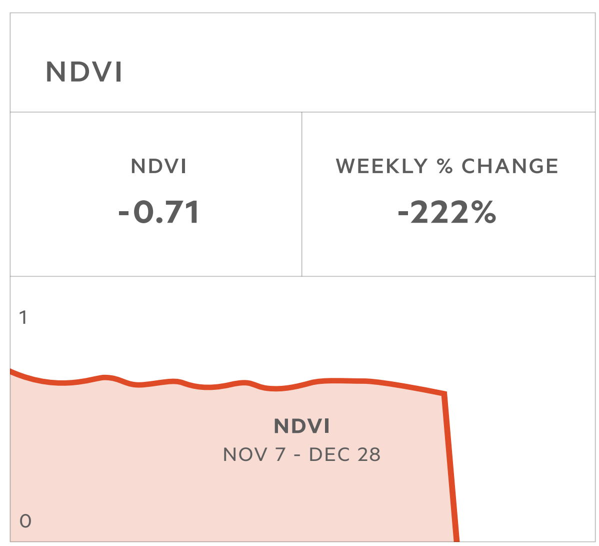

Figure 5. Odd values. NDVI drastically dropped below 0 and the weekly change (%) is negative

Inside the Arable Web Interface

HOW TO USE GROWING DEGREE DAYS

The GDD accumulation starts on the day you establish as the beginning of the current growing season. If the device is deployed in your field after the crop was planted (or transplanted), then the data will be backfilled with temperatures recorded by gridded data. On the graph menu in the web interface, you'll find the option to visualize a time series of the GDD data once you have created a growing season; this will give a good indication of the current stage of plant development.

HOW TO USE THE NDVI VALUES

The NDVI acts as a visual proxy for what is happening out in the tomato fields. You should expect to see a reduction in the NDVI values when the fields start looking less green and more a mixture of other colors. For example, when tomatoes start turning pink, the NDVI values will drop a few decimals. According to other studies in processing tomatoes (see Johnstone, P. R., et al.), the pink fruit stage is a good time to start deficit irrigation with a low risk of losing Brix yield. Since NDVI is a key factor in determining the start date for RDI, it is vital to keep track of it as the pink fruit growth stage approaches. The best way to do so is by checking for the telltale reduction in the daily and weekly values shown in your Arable account online. A small negative percentage change within the NDVI range for subsequent days means you are most likely seeing the change in color of your tomatoes as they ripen. Aligned with GDD, NDVI change is an indicator that it's time to implement RDI.

IRRIGATION DATA VIEWS IN THE ARABLE WEB INTERFACE

If you haven't yet familiarized yourself with your Arable web account, please take a moment to do so. This is where all the data collected by the Mark devices are posted; you can either see the current conditions (based on the last time the device connected to the cellular network) or the averaged daily data.

When you click on one of your devices, three tabs will come up, "Weather," "Plant," and "Notes." "Weather" includes rainfall and temperature forecasts at hourly resolution (for 24 hours) and daily resolution (10 days ahead). "Plant" provides a 10-day ETc and precipitation forecast in the Irrigation Overview section.

Arable collects weather data every five minutes to generate localized weather forecasts, including ET_o and ET_c. Under full irrigation conditions, the data shown in the Irrigation Overview (Figure 6) should give an idea of the amount of water you need to apply to your fields based on the forecasted ET_o or ET_c. See Appendix 1 for water application calculations.

Irrigation Overview — 01 Nov 2021 – 07 Nov 2021

Type	Mon 1	Tue 2	Wed 3	Thur 4	Fri 5	Sat 6	Sun 7	Weekly Insights
ETc	0.04"	0.06"	0"	0.03"	0.13"	0.12"	0.1"	0.48" Total
ETo	0.06"	0.1"	0.04"	0.05"	0.25"	0.22"	0.19"	0.91" Total
Precipitation	0"	0"	0"	0"	0"	0"	0"	0" Total

Figure 6. Irrigation Overview from the Arable web interface

Irrigation Formulas

Those looking for a more technical approach to RDI can use the following formulas. We reference the aforementioned guide for drip irrigation from the University of California Division of Agriculture and Natural Resources (UC ANR).

WATER APPLICATION

In addition to moisture loss caused by ET, irrigation inefficiency is another factor that affects the amount of water you should apply to your crops. The more inefficient a system is, the less water makes it from pump to plant. A well-designed and maintained drip or micro-sprinkler system should achieve efficiencies in the 85-95% range. Water application (AW) is equal to ET divided by the irrigation efficiency (IE); the irrigation efficiency recommended by UC ANR for drip irrigation is 0.95.

$$AW = \frac{ETc}{IE}$$

IRRIGATION TIME

This is the time (T) it takes to apply the desired amount of water. You will need to know the size of your field (in acres, A); the water application (AW); and the irrigation system flow rate (Q), in gallons per minute.

$$T = \frac{449 \text{ x } A \text{ x } AW}{Q}$$

We hope this guide has been helpful in describing the measurements and calculations that determine Arable RDI recommendations. If you have any further questions, please visit support.arable.com.

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Johnstone, P. R., Hartz, T. K., LeStrange, M., Nunez, J. J., & Miyao, E. M. (2005). Managing fruit soluble solids with late-season deficit irrigation in drip-irrigated processing tomato production. *HortScience*, 40(6) (pp. 1857-1861).

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