*From the Abstract*

Agriculture in Mediterranean climates relies on irrigation (blue water) to produce high-yielding, quality crops, but blue water supplies for agriculture are challenged by climate change, urban demand, and environmental uses. Optimizing use of green water, stored in soil from in situ rainfall, can reduce agricultural reliance on blue water, especially for deeply rooted perennial crops that have access to relatively large soil volumes.

Thus, in the world of green water for perennial crops, the glass is only marginally full at best.

Assuming the entire study area’s irrigation was managed shallowly with a 30% allowable depletion, 0.5 m rooting depth, and an average of 59 irrigations yr-1, then a transition to a moderate depth irrigation management scenario (50% allowable depletion, 1.0 m rooting depth, and 19 irrigations yr-1) would bring a 30 km3 reduction in soil surface evaporation through 13 years versus a gain of 7 km3 in green water; a deepening to 2.0 m rooting depth in the management scheme would bring an additional 11 km3 cumulative savings in evaporation by reducing irrigations to just 10 applications yr-1 with 5 km3 more green water utilized.

An open question is whether or not regular, effective soil water use through 1-2 m of soil can be accomplished without introducing harmful perennial crop stress and risk to farmers.

*From the Intro*

Given the above challenges to water resource management, solutions are needed. So far, water resource professionals and scientists have focused almost entirely on blue water resources and infrastructure, such as ongoing examples in California: (1) $2.7B of the $6.5B California Proposition 1 water bond funding appropriated for water storage projects such as new dams (Jezdimirovic and Hanak, 2016); (2) on-going analysis of a multi-billion dollar plan called California WaterFix to re-route north to south regional water transfers under the Sacramento-San Joaquin delta to meet environmental regulations (CDWR, 2018); and (3) since new dam capacity and regional water transfers are limited, groundwater banking on agricultural land with local flood flows is an active area of research to expand blue water storage capacity in wet years via groundwater storage (Kocis and Dahlke, 2017).

These hydroclimate-change effects include: expansion of Hadley cells that could particularly affect precipitation in regions between 30 and 40 degrees latitude (Seidel *et al.*, 2008); increases in watershed evapotranspiration may reduce downstream water supply (Goulden and Bales, 2014); loss of seasonal snow water storage could reduce reliability of water supply in snow and ice-dominated watersheds (Stewart *et al.*, 2005); and increased frequency of wet and dry extremes (Berg and Hall, 2015; Swain *et al.*, 2018) with droughts expected to be more severe, such as the 2012-14 California drought (AghaKouchak *et al.*, 2014).

Each particular soil has a particular plant available storage capacity defined as the difference between water retained against drainage by gravity (field capacity) and the water retained in soil when plants suffer water stress (wilting point).

These crops comprise approximately half of the irrigated acreage in CA and represent an expanding agricultural sector (Tindula *et al.*, 2013) with “hardened” water demands.

Examining how the size of the soil reservoir used in the irrigation management scheme affects irrigation water demand is a unique contribution to the literature on regional irrigation water demand analyses.

This study quantifies green water availability at the scale of available data: soil map unit and crop combinations at the scale of the field with climate data provided by publicly available 2-4 km raster resolution datasets.

*From the Methods*

This allows for consideration of interactive drivers of soil evaporation, such as frequency and depth of precipitation and irrigation, surface soil properties, and crop canopy cover, rather than assuming static evaporation-transpiration partitioning ratios which are built into the single Kc approach (Pereira *et al.*, 2015). Thus, the dual Kc is better suited to the subtleties of a green water resource analysis than the more simplifying, single Kc approach. In the dual Kc approach, a single crop coefficient (Kc act) is actually derived from three coefficients: first, a basal crop coefficient (Kcb), conceptually based on canopy cover and leaf characteristics and adjusted by a location’s daily minimum relative humidity (RHmin) and average daily wind speed at 2 m height (*u2*) according to Allen *et al.* (2005a); second, a soil water stress coefficient (Ks), derived from a daily root zone soil water balance (0.5-3.0 m depth, depending on the assumed soil reservoir scenario); and, third, a soil surface evaporation coefficient (Ke), derived from a daily surface soil water balance (0.1-0.15 m depth) and dependent on how much of the surface is wetted by irrigation and how much is exposed to evaporative energy.

During the simulation, water balance results were aggregated to annual, seasonal, and monthly time scales to save hard disk write time except for 1% of soil-climate-crop systems where detailed daily water balances and intermediate calculations were saved for quality control inspection. A desktop computer with a 4-core Intel Xeon 3.80 Ghz CPU and 64 GB of RAM was used to run the simulations and aggregate results. Model runs took approximately 0.75 days for all soil-climate-crop systems for a given root depth and allowable depletion scenario.

The FAO-56 approach assumes a bucket-based soil hydrology model that relies on the concept of field capacityto simplify soil water movement, such that when a root zone is at field capacity, additional precipitation is assumed to drain instantaneously. Drainage from root zones at or below field capacity is considered to be negligible. For finely textured soils with more limited infiltration and percolation capacities, deep percolation could be overestimated during wet periods, since this water may exit the crop root zone as overland flow even before field capacity is reached in the root zone (see section 1.2.2, equation 6).

Available water capacity is the ‘awc\_r’ variable (column 86) in SSURGO’s *chorizon.txt* table.

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Spatially, 88.5% of soils have only 1 major component that requires no component percent weighting results scheme; 11.1% have 2 major components; and 0.4% have 3 major components in this study area.

140,819 fields were identified as alfalfa, almonds, grapes, pistachios, or walnuts in this dataset, totaling 1,487,535 ha. A total of 1,455,204 ha were modeled, excluding some grapes and alfalfa located outside of the major growing regions or for fields where soils data was unavailable

*From Discussion*

Like the results, several of the soil reservoir scenarios are highlighted in the discussion: a shallow (0.5 m root depth and 30% allowable depletion); a moderate (1.0 m root depth and 50% allowable depletion); and a deep scenario (2.0 m and 50% allowable depletion).

*From Conclusion*

Future work is needed to validate the FAO-56 dual Kc method for predicting full season soil water balance under perennial crops and the extent to which deep soil moisture can be utilized without crop stress.

While cover crops have been generally viewed as adding to a farm’s demand for water, given the evaporative losses of rainfall estimated by this study on bare soil under dormant perennial crops, many locations could likely sustain cover crop growth during the winter without compromising green water availability to crops or increasing blue water demand. Moreover, cover crops may improve soil storage of rainfall on hydrologically limiting soils, providing a positive feedback to green water use.

If fall crop water stress can be tolerated, then soils can be drawn down to a greater extent to store winter rainfall.

This could be accomplished through a monitoring and modeling approach that combines soil moisture and crop stress sensors with water balance modeling such as the FAO-56 dual Kc methodology used in this study.