Fertilizer Research and Education Program

Final Report

A. Project Information

Project Title	Efficient Water and Nitrogen Management Practices for Mixed Leafy Baby Green Vegetables in the Desert	
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B. Abstract

Over the past decade the production of high density mixed leafy green vegetables on large beds (80- and 84-inch beds) has increased significantly. While these crops are grown at a higher density than full season lettuce, they are harvested young and are short season (20 to 60 days) compared to the 80 to 150-day lettuce crops. We had no information how these factors affect fertilizer needs, no information on how irrigation interacts with N, and no information to modify N fertilizer and water recommendations for these crops. The objective of these studies is to evaluate various N and water management practices for mixed baby leaf conventional and organic production systems and calibrate “CropManage” as a management tool for desert production. Data collected during 2019 were focused on collecting background information needed for the calibration of “Crop Manage” for desert crop production systems. Data collected in 2020 and 2021 was aimed at continued collection of background data but we also began an evaluation of “CropManage” based recommendations. Overall, existing water use efficiencies for spring mix and baby spinach are high and water mismanagement is not factor in the poor efficiencies for N recovery in these systems. Overall, the data indicate some minor adjustments in “CropManage” are required for water management in the desert. As the result of field studies conducted in 2019, 2020, and 2021 we now have the data to make these modifications for spring mix and baby spinach. Nitrogen recovered in the harvested crop was generally less than 50% of that applied, and utilization of “Crop Manage” would have improved our efficiencies. However, utilizing “Crop Manage”, alone with current N application practices, would sometimes fall short of achieving the N recovery thresholds being sought by the California Water Quality Control Boards (CWQCBs). Thus, objectives for Task 6 were modified to test fertigation timing algorithms for improved N fertilizer use efficiency. Studies conducted in fall 2021 and fall-winter 2021 and Spring 2022 show baby spinach and spring mix yields were maximized at much lower N rates than we previously observed, showing that the evaluated fertigation strategies

potentially reduce N rates for maximum yield that more consistently match or exceed the CWQCB targets.

C. Introduction

Intensive vegetable production in the southwestern U.S. receives large annual applications of nitrogen (N) fertilizers. Amounts of N applied range from 200 to 400 kg/ha and crop recoveries are generally less than 50% (Mosier et al., 2004). There are numerous possible fates of fertilizer applied N in addition to the desired outcome of crop uptake (Sanchez and Dorege, 1996; Havlin et al., 2005). The urea and ammonium components of the N fertilizer might be lost through ammonia volatilization. The nitrate-N might be lost to leaching with irrigation water below the crop root zone possibly impairing surface and ground water (Sanchez, 2000). Nitrate might also be lost as N_2 and N_2O gasses via de-nitrification processes affecting air quality and climate. Furthermore, all forms of N might be immobilized into the organic soil fraction by the soil microbial population where availability to the crop is delayed. The global warming potential of N_2O is 300 times that of CO_2 and N fertilizer is estimated to account for one-third the total greenhouse gas production in agriculture (Strange et al., 2008). One study reported that N fertilization (inorganic or organic) accounted for 75% of the greenhouse gas emissions from agriculture production (including production, application, and nitrous oxide emissions) and after N is accounted for there are no significant differences between conventional, organic, or integrated farming practices (Hiller et al., 2009).

Over the past decade the production of high density mixed leafy green vegetables on large beds (80- and 84-inch beds) has increased significantly. These include various types of mixes for baby lettuce (often called spring mix), baby brassica, baby spinach, dandelions, and others. Work on the fertilizer requirements for these crops are lacking and many growers have simply utilized the fertilizer practices they currently use on full season iceberg, romaine, and leaf lettuce. While these crops are grown at a higher density than full season lettuce, they are harvested young and are short season (20 to 60 days) compared to the 80 to 150-day lettuce crops. We had no information how these factors affect fertilizer needs, no information on how irrigation interacts with N, and no information to modify N fertilizer and water recommendations for these crops.

Of paramount importance to N management is water management. In arid regions, most of agricultural crop water requirements come from irrigation. Irrigation water is applied to replace water lost from the crop rooting zone by transpiration through the crop leaf canopy and evaporation from the soil surface before plant physiological stress occurs. The combined loss of water from the rooting zone by transpiration and evaporation is crop consumptive use or crop evapotranspiration (ETc). The most comprehensive data base of consumptive water use of crops in the low desert was generated by Erie et al., 1981. However, baby leafy vegetables were not a crop produced when Erie did this work. Another source for crop ETc estimates is FAO 56 (Allen et al., 1998). The authors of this document complied ETc data from around the world and provided a protocol to estimate crop ETc from growing period, crop coefficients (Kc) characteristic to each growing period, and reference evaporation (ETo). ETo is calculated from local weather data using the Penman-Monteith approach. The Kc values are specific by crop-type and local climate and are determined experimentally from the ratio of measured ETc to ETo. While the data base compiled by Allen et al. is comprehensive and robust, it was compiled from areas around the world and was intended as a starting point, and not as a substitute for locally calibrated data. However, this data base only includes data for full season bunching spinach and lettuce and is not relevant to the short season baby spinach and spring mix cropping systems. More recent data, using weighing lysimeters, developed crop coefficients for longer season bunching spinach but not for baby spinach (Piccinni et al., 2009).

Beyond the water required for crop ET, there are other beneficial uses of water. These might include, land preparation, residue decomposition, germination, irrigation to address distribution uniformity issues, frost control, and salt management. Salt management in particular, is of paramount importance to sustainability in the arid agricultural areas of the low desert. Soil minerals, irrigation water, and shallow ground water in much of the flood plain districts, near Yuma all contain salts that accumulate in the fine textured soils. Without management, salt concentrations would become too high to grow crops. Salinity thresholds of 1.3 and 2 dS/m had been established for lettuce and spinach, respectively (Mass and Hoffman, 1977). However, more recent data shows spinach much more tolerant to salinity, with no production loss with irrigation water exceeding 9 dS/m and soil ECe levels approaching 5 dS/m (Ferreira et al., 2018; Ors and Suarez, 2016).

Typically, some level of excess irrigation (beyond ETc) must be applied to leach salts below the crop root zone. Effective leaching is especially important in this region because many of the high value horticultural crops produced are sensitive to salinity (Sanchez and Silvertooth, 1996). Leaching requirements are typically estimated on steady state mass balance assumptions (Rhoades et a;., 1974). Steady state assumptions ignore salt uptake by plants and precipitation and dissolution reactions of carbonates in the roots zone. Ignoring plant uptake results in insignificant errors because the amounts of salt taken up by plants are small relative to the total in the rooting zone. However, the significance of precipitation and dissolution can be important when water high in bicarbonate are used for irrigation. Thus, steady state assumptions can overestimate required leaching and transient models often give better results (Corwin et al., 2007; Letey et al., 2011). However, the steady state approach remains the best approach for field practitioners since the input data for transient models are not available across a wide range of soil types. The leaching requirement in complex cropping systems are aimed toward the most salt sensitive crop in the rotation. For the flood plain irrigation districts in Yuma this is lettuce with a leaching requirement of 20% if irrigated with Colorado River water. For economic and environmental reasons, the required leaching for salt management is deferred to a pre-irrigation off-season. This has enabled better disease management and reduced non-point source pollution from improved in-season management of N fertilizers, soil herbicides, and soil insecticides.

These data gaps for baby leafy greens were of concern since over 35% of the industry has converted to these high-density large bed production systems and this acreage continues to grow. Further, many leafy vegetable crops have shallow root systems which limit opportunities for N uptake within the soil profile. Overall, achieving efficient N management for horticultural crops remains a challenge (Hartz, 2006). More recently the California Water Quality Control Boards have taken an active role in monitoring fertilizer N use with the ultimate goal of regulating rates applied. Their ultimate target is to limit N application rates such that N fertilizer application less N removal in the harvested crop does not exceed 50 kg N/ha.

D. Objectives

The objective of these studies is to evaluate various N and water management practices for mixed baby leaf conventional and organic production systems and calibrate "CropManage" for desert production. Most experiment-demonstrations were conducted in grower fields to hasten technology transfer.

E. Methods

General Methods

For tasks 1 through 5, and part of 6, we worked in grower-cooperator fields to measure water inputs by various methods, ETc by eddy covariance, crop growth and N accumulation by plant sampling, final yield determinations, salt balance by EM 38 conductance surveys and soil sampling.

Crop Water Budgets

Crop evapotranspiration (ETc) was measured with an instrument system known as Eddy Covariance (ECV) (Figure 1). ECV obtains ET by measuring incoming and outgoing energy fluxes over the cropped landscape. The ECV measures four energy flux components- net radiation (Rn), ground heat flux (G), sensible heat flux (H), and latent heat flux (LE). Rn represents absorbed solar and infrared radiation, G is heat transported into the soil, H is turbulent heat above the crop due to air temperature gradients, and LE is latent heat energy due to ET. While ET can be estimated from just the LE component, accurate estimates require collecting all four components. ECV data values are reported in energy flux units (W/m^2), with water-specific quantities also reported as depths over time (e.g. mm/day). Each ECV system requires sensors, one or more data loggers, power supplies, and mechanical supports. Sensors measure air temperature, humidity, wind speed, wind direction, water vapor concentration, CO_2 concentration, soil temperatures, soil moisture, solar and infrared radiation, all at sample rates up to 20 Hz. Data loggers collect, analyze, and store analog and digital signals from the sensors; in some cases, they are connected to a cellphone modem for transmitting synopses of data and system health information to one of our home offices. Power supplies consist of 12V batteries, voltage regulators, grounding rods, and solar panels. The mechanical supports include tripods, masts, lightning rods, anchors, and guy wires to ensure the sensors, loggers, and power supplies remain accurately aligned in all weather conditions. For all sites we collected root zone samples and determined soil texture. These data were used as a component of calculating ground energy storage.

On these sites irrigation and rainfall inputs were measured with manual and automatic rain gauges. We used manual gauges primarily to collect water samples for salt balance estimates. Data were downloaded and processed after each irrigation event. We collected detailed data on selected sprinkler irrigation events using methods described previously (Zerihun et al., 2014a) to calculate indices of distribution uniformity (Burt et al, 1997). Christiansen's' index (UCC) measures the mean deviation from the average amount of water applied while low quarter (DU) measures localized extreme negative deviations from the average amount applied. Thus, both indices are useful in obtaining a complete picture of the uniformity.

Satellite Data
Data from Sentinel 2a/2b https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2) to process normalized difference vegetation index (NDVI) data streams (French et al., 2020). Weather data streams, including ETo, were taken from the AZMET weather network. In most cases we used the AZMET station nearest to the field study location. Temperature data was used to calculate heat unit accumulation, based on the literature and our own comparison of alternatives, we selected a base of 0° C and a maximum of 25° C. While lettuce would normally use a 4C/28C base we found no improvement for spring mix in using lettuce base/maximum limits vs. the 0/25C we used for baby spinach, so for simplicity we used 0/25C throughout. Both crop NDVI and HU were evaluated as a means of tracking crop growth remotely.

Salt Balance
Soil salinity was monitored at multiple scales. At the point scale, sensors and data loggers measured soil moisture and bulk conductance. On a larger scale we used electromagnetic conductance surveys. Both are ground-trothed with soil sampling. Fields were surveyed using a Geonics Dual-dipole EM38 meter mounted on a mobilized assessment platform with an integrated sub-meter accuracy GPS system, with all survey and GPS position data logged into an on-board portable computer. In baseline surveys, EM38 signal data was collected once every two seconds within transects spaced 10 to 20 meters apart, typically generating from 1000 to 5000 survey positions per field (transect spacing and the total number of survey positions will depend on the field size). These data were analyzed using the ESAP software package (https://www.ars.usda.gov/pacific-west-area/riverside-ca/us-salinity-laboratory/docs/esap-model/) and the spatial response surface sampling algorithm in the ESAP-RSSD program. At each sampling location, a single 1.2 m soil core was extracted using automated soil auguring equipment and split into four depth-specific 30 cm samples. The soil samples collected from each core were bagged, labeled, and subsequently used for the chemical and physical analyses. Subsets of all soil samples were oven-dried to determine soil moisture content. The remainder of the soil samples were air-dried prior to laboratory analysis. After obtaining saturated paste extracts from all soil samples, we determined electrical conductivity (ECe), and cation/anion quantities for Ca^{+2}, Mg^{+2}, Na^{+}, K+, Cl^{-}, $SO4^{-2}$, NO_3^{-} and CO_3 by ion chromatography. The Ca, Mg, and Na, and HCO_3 were used the calculate adjusted SAR. All the cation and anion data were also used with a speciation program (MINTEQ 3.1) to gain a preliminary understanding of the chemistry of soil reactions and potential for salt precipitation with respect to these salinity ions. Because of the short timeline between land preparation and planting we did not have an

opportunity to collect salinity data for one study site (IS 20 20B). These data were collected for all other sites.

Growth, Yield, N Accumulation, and residual Soil N

Above ground plant samples were collected during the season to estimate growth and correlate to estimates obtained by HU summations and satellite NDVI. We did not collect in-season growth until 2020. These data were collected for YID 19-20A, YID 19-20B, IS 20B. and YID 21 for baby spinach and YMIDD 20, IS 20A, IS 20C and IS 21A for spring mix. Baby spinach and spring mix are fast growing crops and often only three sample times were collected in each site. All replicate above ground samples were weighed, dried, and processed for N analysis. Tissue samples were ground, digested, with peroxide and sulfuric acid and analyzed for total N. Total N in digest was determined using the indophenol blue method.

Final marketable yields were collected for all studies on the same GPS coordinates where we took soil samples based on the ESAP sampling scheme. Yields were collected by cutting all spinach from 1 m of row at each sample location. All samples were weighed, dried and processed for N analysis as described above for the plant growth samples. Total N was determined as describe above.

Our initial plan was to conduct small N rate studies in the same fields described above. However, this proved impossible as we could not isolate small study areas from the N fertigation applied to the larger production area. Therefore, we conducted N rate studies in small plots at the Maricopa Agricultural Center. These simple studies used top dress applications of ammonium sulfate and urea applied before sprinkler irrigation to simulate fertigation. Rates applied were 0, 100, and 200 kg N/ha not including the 36 kg N/ha received from MAP in the pre-plant P fertilizer application. Yields were measured at harvest, and N accumulation was processed as noted above. We wish to note that yields are a little lower in these studies because we used 40-inch rather than 80- or 84- inch beds, necessitated by available equipment.

Soil samples were collected for residual N analysis. For the grower cooperator experiment-demonstration sites, residual nitrate from the saturated past extracts were converted to mg/kg using the measured SP. For the N rate studies, soils were extracted with 2N KCl and ammonium was determined using the indophenol blue method and nitrate was determined using Griess-Ilosovay method after reduction with copperized cadmium (Mulvaney, 1996).

Crop Manage

In 2020, we began comparisons with grower standard practice with crop manage. Because we did not yet have sufficient data for modifying crop manage, we only compared measured and recorded outcomes to those predicted by CropManage" default options for predicted ET and growth. In these evaluations, we did not ask the growers to modify practices by "CropManage", but only informed them, because we had insufficient basis to make such recommendations at that time and we were disinclined to risk damage to large commercial acreages.

Fertigation Studies

We modified the objectives for Task 6 based on findings in 2019-2020, and spring 2021. We found that simply using "Crop Manage" alone with current N application timing practices, would often fall short of achieving the N recovery thresholds being sought by the CWQCBs. Therefore, work in the fall of 2021 and spring 2022 was focused on evaluating timing strategies based on N uptake patterns compiled as part of these studies. These experiments were facilitated by constructing a sprinkler manifold network fitted with valves to manipulate rates of N and water applied to different plots. Because we sought to apply the irrigation rates to all plots approximating ETc replacement, the manipulation was to achieve different N rates.

F. Data/Results

In this final report we will discuss water management and N management in separate sections for clarity of presentation, but we will address interactions where appropriate. We have some other data sets collected with other funding other than FREP that enhance this data base and relevant to final conclusions. This includes site YID 17E, YID 17F, and a subset of the of N response curves.

Water Management

The experiment-demonstration sites used for tasks 1 through 5 are shown in Table 1. Soil texture ranged from sand to clay but trended as loam and clay loam. Cropping seasons included fall, winter, and spring. For baby spinach, management units always included more than one cultivar of spinach. And for spring-mix sites there were multiple types of baby lettuce and sometimes mizuna and kale, and arugula.

The quality of the irrigation waters used in these studies is summarized in Table 2. Most sites used surface water from the Colorado River but the sites on the Island used ground water. The Island is an area surrounded on the south, west, and north by the old Colorado River channel and on the east by the current Colorado River channel. The land cropped on the Island has no surface water rights and relies on ground water. The ground water used on the Island was more saline than the surface water diversion from the Colorado River. For example, 100 mm of Colorado River water has about 260 kg of salt, whereas 100 mm of ground water on the Island might have 900 kg of salt.

For all sites we measured ETc using eddy covariance, compiled NDVI from satellite data streams, computed ETo and heat units from nearby weather stations, and measured irrigation events. In previous reports we showed the processed data from each site as it became available. Here we present two examples from YID 19-20B and YMIDD 20 for baby spinach and spring mix, respectively (Figure 2). The data from all sites is summarized in Table 3. Measured seasonal ETc ranged from 79 to 127 mm for baby spinach and from 109 to 147 mm for spring mix. Irrigation application amounts ranged from 77 to 175 mm and was sometimes augmented by rainfall. Water application efficiencies are generally high with some exceptions. Some exceptions occurred due to rainfall that occurred shortly after irrigation. Growers will delay irrigation due to rainfall, but they will not take the risk of crop damage by delaying a required irrigation to forecasted potential rainfall.

The cumulative heat units and NDVI data streams were evaluated as a tool to track and delineate growth for crop coefficient application. Baby leaf is planted from late September to early March, and we could not expect days after planting as a reliable indicator of physiological growth stage. Growth period ranged from 26 to 48 days for baby spinach and 31 to 61 days for spring mix. The relationships between HU and growth and NDVI and growth for YID 19-20B are shown in Figure 3. Data for all sites and a proposed generalized relationship are summarized in Table 4. The coefficient of determination largely reflects the variation among replicates but also reflects model bias. Overall, both heat units and NDVI track growth reasonably well if needed. Actual harvest time is also determined to a great extent by market demand. Both these crops might harvest early if there is strong demand or delayed as long as possible when demand is low. Thus, although HU and NDVI did a better job of tracking growth stage than time, there was 15 to 20% variation on harvest.

We used the data base summarized in Table 3 to develop crop coefficients relevant to desert productions systems, The data for baby spinach are shown in Figure 4. The Kc is initially 0.4 at planting but becomes 1 at about 300 HU. NDVI would be less useful, as values do not emerge from background readings until about 200 HU. The maximum crop coefficients provided in FAO 56 approached 1 (Allen et al.,), and that reported by Piccinni et al., (2009) approach 1.05 at about 50 or 60 days. The longest growing period for baby spinach in our studies was 48 days. The observation that Kc approached 1 in 15 to 20 days in our studies maybe due to the season-long sprinkler irrigation resulting in higher evaporation. For spring mix, we observed ETc close to ETo all season and ETo is a reasonable estimate of crop water requirement (data not shown). We wish to note that even for spinach, only 15% of the seasonal water occurs before ETc approaches 1, thus ETo would not be a bad estimate of water required for baby spinach.

Another consideration in water management is distribution uniformity (DU). The calculated DU and UCC for 50 individual sprinkler events are shown in Figure 5. Although, the solid set sprinkler irrigation systems used in the area are very well engineered and potentially provide uniform irrigation (Zerihun et al., 2014a; b), the variation in frequency, speed, and direction of wind in Yuma (Brown et al., 1995) can significantly distort wetting patterns, and one should not anticipate average distribution uniformities exceeding 85%. With the generally high application efficiencies (AE) obtained for baby spinach and spring mix, and typical observed seasonal DUs, it is likely portions of the fields were sometimes underirrigated. However, these irrigation efficiencies are at the limit when considering water distribution uniformities. Thus, we consider irrigation of baby spinach and spring mix at 1.15 ETo a rational irrigation management strategy.

One final consideration in water management is salt leaching requirement. An example of seasonal salt accumulations is shown for YID 21 and YID 19-20B in Figures 6 and 7. Data for all sites are summarized in Table 6. Generally, salinity increased when leaching fraction approached and declined below 20%. One notable exception was IS 21. For this site, the water applied in season was less than measured ETc, yet salts did not increase. This, site in contrast to others, had root zone soil moisture at planting close to 0.1 bar and it was frequently irrigated, almost every other day in-season.

Data presented in Table 7 show the results of the chemical equilibrium analysis of the paste extracts using MINTEQ. The data show soil solutions from all sites are supersaturated with respect to a number of Ca and Mg carbonate minerals and some soil solutions from site are supersaturated with respect to sulfate minerals. However, no soil solutions were supersaturated with Cl minerals. In these carbonate rich systems, the Cl data shown in Table 6 are a better indicator of leaching than the ECe data.

Growers in the desert often restore salt balance in a summer flood irrigation to minimize leaching during the season so that they can better manage N and soil pesticides in-season. This is fine provided salinity does not increase to problematic levels during the season. Yields can vary for many reasons, but the variation among sites is largely due to cutting time which is affected by market and demand. If demand is high, spinach or spring mix might be cut a week early. However, if demand is low, the shipper will sit on the crops as long as possible before quality is compromised. The data presented in Figure 8 show marketable yields of spinach by measured soil ECe across all our studies. These data suggest that as ECe increased above 5 dS/m yield potential was limited. Interestingly, most of these points with ECe greater than 5 dS/m are associated with the Island site (IS 20B). This site was harvested after an accumulation of 690 HU, well above the average of 600 for baby spinach, and we conclude the lower yields in this study were associated with salinity stress and not with an early harvest. Further, a statistical evaluation of each site individually showed no decrease in yield to ECe within sites for any site irrigated with Colorado River water. Thus, deferring much of the required leaching off season does not appear to produce negative consequences to salinity buildup in-season.

One objective of this project was to evaluate “Crop Manage” as a water and N management tool. Interestingly, “Crop Manage” often recommended irrigations closely aligned with those applied but there were sometimes inconsistences (Figure 9). Note the divergence for YID 19-20, where the crop was irrigated efficiently in-season and the large leaching fraction was due to rainfall after crops harvest. Some adjustments in “CropManage” are required for implementation in the desert. As the result of field studies conducted as part of this project, our direct measurement of crop ETc, and growth, with corresponding HU or satellite derived NDVI, we now have the data to make these modifications for baby spinach and spring mix.

Overall, with or without “Crop Manage” current irrigation practices in the desert are generally efficient, and poor water management is not the reason for our poor N use efficiencies.

N Management

A summary of the N application practices shown in all experiment-demonstration sites are shown in Table 7 for baby spinach and Table 8 for spring mix. The rates of N applied ranged from 141 to 290 Kg N/ha. The inorganic systems used a combination of controlled release N fertilizers applied pre-plant and soluble inorganic fertilizers applied through the sprinklers. The organic production systems used low analysis N and P analysis products originally derived from animal waste applied pre-plant, top dress, or by sprinklers.

Many sites showed that the growers often failed to consider the high pre-plant soil NO_3-N levels in fertilizer decisions. This was the case for YID 17e, YID 17F, YCWUA 18A, YID 19-20A, and YID 19-20B (Table 9). Overall, the organic production sites (IS 20A, 20B, and 21A) had very low levels of inorganic N.

A comparison of N recovered in the harvestable crops and N applied show applied N less removal (A-R) was well above the targeted 50 kg N/ha being sought by the CWQCBs (Table 9). The high residual inorganic soil N after harvest for several sites supports the conclusion that much of the N applied was not utilized by the crop in-season. The ancillary N rate studies we conducted also fell short of the A-R target of 50 kg N/ha and also generally shows high residual inorganic (Table 10). Interestingly, “CropManage” would have called for 0 to 47% less N than was actually applied (Table 11). While we believe these rates are possible without yield reduction, this reduction would still often fall short of the thresholds being sought by the CWQCB.

In all the aforementioned evaluations, the split N applications were applied without regard to N accumulation patterns. Previous work has shown N efficiencies can be enhanced by timing application to anticipated uptake (Sanchez and Doerge, 1999). The generalized above ground N accumulation for baby spinach and spring mix is shown in Figure 10. Data from all sites where these data were collected are summarized in Table 12.

Studies initiated in the fall of 2021 were focused on seeking improved N efficiencies by modifying N fertigation strategies (Table 13). The fertigation strategies implemented aim to apply N fertilizers generally guided by the generalized N accumulation patterns illustrated in Figure 10 (Table 14). The measured growth, NDVI, marketable yield, and above ground N accumulation are shown in Tables 15 through 20. Overall, they track anticipated growth and N accumulation as predicted. The NDVI measured here with a hand-held unit on these small plots are a little higher than those measured by satellite on large production areas because they do not consider the furrows between beds.

Overall, studies conducted in fall 2021, fall-winter 2021, and Spring 2022 show baby spinach and spring mix yields were maximized at much lower N rates than we previously observed, showing that the evaluated fertigation strategies potentially reduce N rates for maximum yield that more consistently match or exceed the CWQCB targets (Table 21).

G. Discussion and Conclusion

Measured seasonal ETc ranged from 79 to 127 mm for baby spinach and from 109 to 147 mm for spring mix. Irrigation application amounts ranged from 77 to 175 mm and were sometimes augmented by rainfall. Overall, water application efficiencies are generally high and poor irrigation management is not the reason for poor N utilization efficiencies. Overall, there was a trend for salinity to accumulate as leaching fractions decreased below 20%. However, growers often use a summer leaching irrigation to restore salt balance. Irrigation with Colorado river water would not result in problematic soil salinity levels in season. This project has generated a data base for continued efficient water management using "Crop Management" or other irrigation management model. Because of uncertainties regarding distribution uniformity for sprinkler applied water to wind distortions, we recommend applying water at 1.15 ETo for baby spinach and spring mix all season.

Data collected show that current N fertilizer practices result in N fertilizer rates far exceeding N removal by the crops and having high residual inorganic N after harvest. The differences between N applied and crop removal did not come close to the target sought by the CWCB by current N management practices. While "Crop Manage" did improve N management, its use with current timing strategies sometimes fell short of the CWQCB targets.

Studies conducted in fall 2021, fall-winter 2021, and Spring 2022 evaluated N timing strategies more consistent with N above ground N accumulation patterns identified in these studies. The results show baby spinach and spring mix yields were maximized at much lower N rates than we previously observed, showing that the evaluated fertigation strategies potentially reduce N rates for maximum yield. The difference between N applied and N recovered more consistently match or exceed the CWQCB targets.

H. Challenges

Challenge	Corrective Action and/or Project Change/lessons learned
Early in this project we found the ancillary N rate studies could not be conducted in the grower-demonstration sites due to the fact that we could not isolate from the sprinkler applied fertigation.	We used small plots at the University Center and simulated fertigation by top-dressing soluble N fertilizers immediately before sprinkler irrigation. However, the MAC was not equipped for 80- or 84-inch beds so we used multiple lines on 40-inch beds. Thus, yields per total area were a little lower do to more frequent interrow unplanted area.
We had to develop protocols for COVID 19 mitigation and submit a plan to the University to continue field operations.	Our plan for field operations was approved and field operations were only minimally disrupted in March and early April 2020. This protocol included travel to field sites

Challenge	Corrective Action and/or Project Change/lessons learned
	with one person per vehicle, two-meter minimal separation of individuals working together in fields, and PPE when such distancing is not possible.
Due to COVID-19 social distancing mandates we had to temporarily close our laboratories in 2020.	Special operation protocols were developed to insure safe social distancing in our laboratories. After our re-opening plan was reviewed and approved by the appropriate committee at the UA, our laboratories at MAC were re-opened May 18, 2020. All analyses quickly got back on track and on schedule
Due to the COVID 19 we were not able to meet in groups and could not hold in-person field days and workshops for about 18 months. More recently group sizes have not been restricted.	We have had informal field days within filed sites with small groups. Outreach activities are ongoing.
The fertigation studies implemented as part of the revised task 6 required a more sophisticated irrigation conveyance system that could be accomplished in grower fields sites.	We engineered the system required at the MAC research farm.

I. Project Impacts

This project generated a data base for water and N management for baby spinach and spring mix that did not previously exist. The data base developed tools to track ETc using ETo, crop coefficients, HU or satellite NDVI. This data base also facilitates effective salinity management.

The studies also generated a data base to project N uptake patterns by spinach and spring mix. Using this data base, we have proposed fertigation timing strategies that facilitate more efficient N management more closely approaching targets by regulators.

Overall, this data base can be used with “Crop Manage” or any other water and N fertilization algorithm for improved management.

J. Outreach Activity Summary

Unfortunately, due to gathering restrictions associated with Covid we did not have as many outreach activities as originally planned. We did increase the number of small gatherings at experiment-demonstration sites and had one program by zoom. Due to the challenges of drought, we have been invited to use the water objectives of this project in more programs Below is listed what was accomplished and outreach is on-going.

March 15, 2019. Small gathering (about 4 growers) at BWD 19 site.

Feb.,10, 2020. Small gathering (about 7 growers) at YID 19-20A site.

Feb. 25, 2020. Southwest Ag Summit 2020. Presented a talk on BMPs that included sharing preliminary data from this study. Also shared data on water managemnt

Nov. 10, 2020. Small gathering (about 7 growers) at IS 20B site.

Feb. 25, 2021. Southwest Ag Summit. 2021. Presented talk on mandated BMPs in California and Arizona, and covered promising N management strategies, including some data from the FREP project. This was entirely by zoom and over 50 participated.

March 15, 2021. Small gathering (about 7 growers) at YID 21 site.

Feb. 24, 2022. Southwest Ag Summit 2022. Presented data from this project and introduced new APP that will include data from this project.

April 28, 2022. Desert Ag Conference. Presented data on water management generated from this project.

Feb. 23, 2023. Schedules to presented data on Fertigation Management with a focus on data generated in this FREP Project.

K. References

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L. Appendix

Tables and Figures

Table 1. Field sites used to collect water and salt balance data for spinach and spring mix in 2017-2021.

Site	Cultivars	Soil texture	Wet date	End Date
Baby Spinach				
YID 17E[a]	2146/Marabu	Loam	Oct. 25, 2017	Nov. 27, 2017
YID 17F	PV1237/Meerkat/Sparrow	Loam	Dec. 11, 2017	Jan. 19, 2018
YCWUA 18A	PV/1237Woodpecker/Piano	Clay Loam	Feb. 5, 2018	Mar. 21, 2018
YID 18A	PV1237/Marabu/Piano	Silt Loam	Mar. 12, 2018	Apr. 8, 2018
YID 19A	Aztec/Gila/Woodpecker	Clay Loam	Mar. 5, 2019	Apr. 9, 2019
YID 19-20A	Banjo/Sioux/Tasman	Sandy Loam	Jan 6, 2020	Feb. 17, 2020
YID 19-20B	Galah/Revere	Sandy Loam	Jan 9. 2020	Feb. 25, 2020
IS 20B	SV2157	Clay	Oct. 8, 2020	Nov. 12, 2020
YID 21	Sioux/Aztec	Loam	Feb. 29. 2021	Mar. 31, 2021
Spring Mix				
YID 18-19	3SX3202/3SX3404/3SX601	Loam	Nov. 30, 2018	Jan. 29, 2019
BWD 19	Green Romaine/Green Oak/Green Tango/Red leaf/ Red romaine/Lola Rosa	Clay Loam	Feb. 7, 2019	Mar. 29, 2019
YMIDD 20	Clearwater/3SX3104/ Cavendish/ Celinet	Sand	Feb. 20, 2020	Mar. 31. 2020
IS 20A	Clearwater//Cavendish/ Celinet/Ruby Red/Fordhook Giant	Silty Clay Loam	Feb. 28. 2020	Mar. 29, 2020
ISC20C	Fordhook Giant/Mizuna	Silty Clay	Nov. 11. 2020	Dec. 22, 2020
IS 21A	Tamarindo/Twist	Clay	Feb. 18, 2021	April 6, 2021

[a] Sites are labeled by irrigation district and letter designations for order of deployment of eddy-covariance system within year. Our projects include multiple commodities, so letters are not necessarily sequential for baby spinach and spring mix. YID is Yuma Irrigation District, YCWUA is Yuma County Water Users Association, IS is Island, YMIDD is Yuma Mesa Irrigation and Drainage District, and BWD is Bard Water District.

Table 2. Chemical quality of irrigation water used in studies.

Parameter	Colorado River[a]	Island ground water[b]
pH	8.22 (0.07)	7.66 (0.02)
ECw (dS/m)	1.09 (0.06)	3.55 (0.05
Ca (meq/L)	4.03 (0.22)	12.75 (0.64)
Mg (meq)/L)	2.25 (0.13)	7.28 (0.64)
Na (meq/L)	1.19 (0.07)	3.84 (0.34)
HCO3 (meq/L)	2.89 (0.12)	6.49 (0)
Cl (meq/L)	2.99 (0.23)	15.75 (1.46)
SO4 (meq/L)	5.41 (0.35)	12.38 (0.15)
RSAR	3.01 (0.2)	5.81 (0.3)

[a] The mean for Colorado River represents the average of 36 monthly samples collected during study period. This was the source of water for all sites in YID, YCWUA, YMIDD, and BWD.

[b] The mean for the Island represents the average of samples from two wells blended for irrigation sampled immediately before study period in this area. Values in parentheses are standard deviations on the means.

Table 3. Summary of water balance during baby spinach and spring mix cropping systems.

Site	Irrigation #	Irrigation (mm)	Rainfall (mm)	Measured Cumulative ETc (mm)	Leaching Fraction[a] ((WR-ETc)/WR)x100
Baby Spinach					
YID 17E	3	111.7	1.3	103.1	9
YID 17F	6	127.3	1.8	79.3	39
YCWUA 18A	9	159.1	0.5	129.7	19
YID 18A	5	133	0	129.8	2
YID 19A	8	101.1	2.4	95.6	8
YID 19-20A	7	118.9	17.6 (61)	98.8	27 (50)[b]
YID 19-20B	5	84.8	18.5 (61)	122.4	0 (25)[b]
IS 20B	8	99.9	0	105.9	0
YID 21	7	88.5	0	126.7	0
Spring Mix					
YID 18-19	6	130.7	0	109	22
BWD 19	11	175.4	2.5	170.6	8
YMIDD 20	15	150.5	63.7	137.1	77
IS 20A	7	76.7	61.8	119.7	19
IS 20C	9	93.7	0	104.9	0
IS 21A	19	141.5	2.7	146.5	0

[a] WR is irrigation plus rainfall received by crop.

[b] These two sites received significant rainfall immediately after harvest. Although this rainfall was not within the cropping season, it occurred before we conducted final EM 38 surveys and soil sampling. The values in parentheses are additional rainfall and adjusted leaching fraction to post-harvest rainfall, respectively.

Table 4. Relationship between growth and HU and NDVI for baby spinach and spring mix.

Site	Growth by HU		Growth by NDVI	
	Relationship	R^2	Relationship	R^2
	Spinach			
YID 19-20A	$DM=1x10^{-6}HU^{3.05}$	0.83	$DM=1307NDVI^{4.07}$	0.81
YID 19-20B	$DM=1x10^{-7}HU^{3.41}$	0.93	$DM=957.3NDVI^{3.39}$	0.91
IS 20B	$DM=0.053e^{0.014HU}$	0.96	$DM-918.7NDVI^{4.32}$	0.83
YID 201	$DM=5x10^{-7}HU^{3.30}$	0.85	$DM=2.291NDVI^{4.51}$	0.90
Overall	$RDM=1x10^{9}HU^{3.18}$	0.67	$RDM=3.34NDVI^{3.85}$	0.89
	Spring Mix			
YMIDD 20	$DM-0.048e^{0.012HU}$	0.72	$DM=0.029e^{15.4NDVI}$	0.73
IS 20A	$DM=0.042e^{0.017HU}$	0.92	$DM=875.1NDVI^{4.37}$	0.93
IS 20C	$DM=0.033e^{0.016HU}$	0.60	$DM=0.009e^{11.89NDVI}$	0.58
IS 21A	$DM=2x10^{-9}HU^{2.27}$	0.76	$DM-0.092e^{14.63NDVI}$	0.76
Overall	$RDM=5x10^{-8}x^{2.92}$	0.68	$RDM=3.53NDVI^{3.64}$	0.30

RDM is relative dry matter relative to maximum each site.

Table 5. Measured ECe, chloride, and adjusted SAR in saturated paste extracts before and after cropping of baby spinach and spring mix.

Site	Salinity Parameters								
Site	ECe (dS/m)			Cle (meq/l)			Adjusted RNa		
	Before	After	Stat.	Before	After	Stat.	Before	After	Stat.
	Spinach								
YID 17E	1.62	2.90	***	4.03	7.10	**	6.35	5.28	**
YID 17F	4.26	3.47	NS	7.22	4.71	***	7.08	7.30	NS
YCWUA 18A	5.19	2.98	***	8.66	3.80	***	7.20	5.39	***
YID 18A	3.06	4.68	**	4.23	6.40	***	7.50	9.22	***
YID 19A	2.51	4.19	***	3.86	5.47	*	4.12	5.06	**
YID 19-20A	1.33	1.67	NS	4.73	2.37	***	4.53	5.08	NS
YID 19-20B	2.37	1.85	NS	4.37	3.94	NS	5.54	5.79	NS
IS 20B	11.50	12.64	NS	25.8	32.80	NS	12.84	12.19	NS
YID 21	1.27	3.40	***	1.69	7.19	***	4.41	6.13	***
	Spring Mix								
YID 18-19	2.40	3.72	***	6.54	8.34	NS	6.85	6.60	*
BWD 19	3.11	3.13	NS	4.82	6.31	**	4.78	5.89	**
YMIDD 20	0.77	0.34	***	3.16	1.81	***	3.26	2.44	***
IS 20A	12.11	12.20	NS	23.0	30.8	**	9.32	12.34	***
IS 21A	14.12	15.51	NS	59.0	37.4	**	16.18	12.69	***

*,**,***Significant at 10, 5 and 1% levels respectively. NS=P>0.1.

Table 6. Saturation indices for soil solutions after harvest in study sites.

Site	Saturation index[a] (log IAP-log Ks)									
	Anhydrite	Aragonite	$CaCO_3xH_2O$	Calcite	Dolomite ordered	Dolomite unordered	Gypsum	Huntite	Magnesite	Vaterite
	Baby Spinach									
YID 17F	-0.15	1.43	0.23	1.57	2.39	2.94	0.09	1.33	0.22	1.00
YID 17F	-0.57	1.37	0.18	1.52	2.07	2.62	-0.33	0.47	-0.05	0.95
YCWUA 18A	-0.57	1.36	0.17	1.50	1.97	2.52	-0.22	0.21	-0.13	0.94
YID 18A	-0.47	1.43	0.24	1.58	2.16	2.71	-0.22	0.62	-0.02	1.01
YID 19A	-0.30	1.38	0.18	1.52	2.20	2.75	-0.05	0.87	0.08	0.95
YID 19-20A	-0.37	2.08	0.89	2.22	3.82	4.37	-0.13	4.33	1.00	1.66
YID 19-20B	-0.50	2.12	0.93	2.26	3.84	4.39	-0.25	4.30	0.98	1.70
IS 20B	0.62	1.73	0.54	1.88	3.10	3.65	0.85	2.84	0.62	1.31
YID 21	-0.31	1.46	0.27	1.61	2.39	2.94	-0.06	1.26	0.18	1.04
	Spring Mix									
YID 18-19	-0.09	1.63	0.43	1.77	2.85	3.40	0.15	2.32	0.48	1.20
BWD 19	-0.37	1.38	0.19	1.53	2.38	2.93	-0.13	1.41	0.26	0.96
YMIDD 20	-0.02	2.67	1.47	2.81	4.87	5.42	0.23	6.28	1.45	2.25
IS 20A	0.84	2.49	1.29	2.63	4.43	4.98	1.07	5.33	1.20	2.06
IS 21A	0.79	1.95	0.75	2.10	3.42	3.96	1.02	3.36	0.72	1.53

Saturation indices are shown only for forms where there was oversaturation in a least one site.

Table 7. N fertilization program for baby spinach in all sites.

Site	Date	Method	Product	Rate Product/A	N Applied (lbs/A)
YID 17E	10/10/17	Preplant	11-52-0 (lbs)	476	52.4
	10/10/17	Preplant	Duration (lbs)	239	105.2
	11/03/17	Sprinkler	UAN 32 (gal)	10	35
	11/25/17	Sprinkler	UAN 32 (gal)	10	35
					228 (255)
YID 17F	12/05/17	Preplant	11-52-0 (lbs)	350	38.5
	12/05/17	Preplant	Duration (lbs)	250	110
	12/16/17	Sprinkler	UAN 32 (gal)	10	35
	12/27/17	Sprinkler	UAN 32 (gal)	10	35
					219 (245)
YCWUA 18A	1/24/18	Preplant	11-52-0 (lbs)	301	33.1
	1/24/18	Preplant	Duration (lbs)	210	92.4
	2/14/18	Sprinkler	UAN 32 (gal)	10	35
	2/22/18	Sprinkler	UAN 32 (gal)	10	35
					196 (219)
YID 18A	2/23/18	Preplant	11-52-0 (lbs)	407	44.8
	2/23/18	Preplant	Duration (lbs)	205	90.2
	3/23/18	Sprinkler	UAN 32 (gal)	10	35
	3/30/18	Sprinkler	UAN 32 (gal)	10	35
					205 (230)
YID 19A	2/26/19	Preplant	11-52-0 (lbs)	303	33.33
	2/26/19	Preplant	Duration (lbs)	193	84.9
	3/23/19	Sprinkler	UAN 32 (gal)	10	35
	3/30/19	Sprinkler	UAN 32 (gal)	10	35
					184 (211)
YID 19-20A	12/7/19	Preplant	11-52-0 (lbs)	407	44.8
	12/7/19	Preplant	Duration (lbs)	205	90.2
	2/4/20	Sprinkler	UAN 32 (gal)	10	35
					170 (190)
YID 10-20B	12/7/19	Preplant	11-52-0 (lbs)	407	44.8
	12/7/19	Preplant	Duration (lbs)	205	90.2
	2/4/20	Sprinkler	UAN 32 (gal)	10	35
					170 (190)
IS20B	10/6/20	Preplant	6-2-2 (lbs)	1400	84
	10/28/20	Broadcast	4-2-2 (lbs)	800	32
	11/10/20	Sprinkler	4-2-2 (lbs)	1016	40.6
					157 (175)
YID 21	2/5/21	Preplant	11-52-0		49.5
	2/5/21	Preplant	Duration		73.5
	3/13/21	Sprinkler	UAN 32 (gal)	20	70
	3/26/21	Sprinkler	UAN 32 (gal)	20	70
					259 (290)

Values in parenthesis within last column are total N received in kg N/ha.

Table 8. N fertilization program for spring mix in all sites.

Site	Date	Method	Product	Rate Product/A	N Applied (lbs/A)
YID 18-19	10/30/18	Preplant	11-52-0 (lbs)	552	60.7
	10/30/18	Preplant	Duration (lbs)	190	83.6
	12/21/18	Sprinkler	UAN 32 (gal)	10	35
	12/30/18	Sprinkler	UAN 32 (gal)	20	70
					249 (279)
BWD 19	2/15/18	Sprinkler	AN20	20	42
	2/20/18	Sprinkler	AN 20	20	42
	2/25/18	Sprinkler	AN 20	20	42
					126 (141)
YMIDD 20	2/11/20	Preplant	11-52-0 (lbs)	550	60.5
	2/11/20	Preplant	Duration (lbs)	190	83.6
	3/2/20	Sprinkler	UAN 32 (gal)	10	35
	3/12/20	Sprinkler	UAN 32 (gal)	10	35
					214 (240)
IS 20A	2/10/20	Preplant	4-4-2	1810	72.7
	2/14/20	Preplant	8-2-2	642	51.4
	3/4/20	Broadcast	4-4-2	1053	42.1
	3/25/20	Sprinkler	2-1-1	78	15.7
					182 (204)
IS 20C	10/31/20	Broadcast	4-4-2	1400	55.3
	12/26/20	Broadcast	8-2-2	1527	122.6
					178 (199)
IS 21	2/4/21	Preplant	6-2-6	1400	84
	2/23/21	Broadcast	4-2-2	800	32
	3/26/21	Broadcast	4-2-2	1016	41
					157 (175)

Values in parenthesis of last column is total N received in kg N/ha.

Table 9. Summary of N applied above ground -N accumulation, soil nitrate, and A-R for experiment-demonstration sites.

	Preplant NO3-N (mg/kg)	N Fertilizer Applied (kg/ha)	N uptake (kg/ha)	A-R	Residual NO3-N (mg/kg)
	Baby Spinach				
YID 17E	9.9 (50)	255	42	213	30 (29)
YID 17F	40 (20)	245	29	216	26 (9)
YCWUA 18A	56 (25)	219	85	134	19 (10)
YID 18A	37 (14)	230	30	200	35 (26)
YID 19A	6 (5)	211	25	186	25 (12)
YID 19-20A	25 (18)	190	60	130	<LOQ
YID 19-20B	25 (24)	190	82	108	0.1 (0.4)
IS 20B	<LOQ	175	100	75	<LOQ
YID 21	<LOQ	290	93	197	0.6 (0.5)
	Spring Mix				
YID 18-19	1.3 (2.1)	279	44	235	13 (14)
BWD 19	2 (3.1)	141	39	102	36 (24)
YMIDD 20	6 (10)	240	47	193	2 (3)
IS 20A	<LOQ	204	45	159	<LOQ
IS 21A	<LOQ	175	24	151	0.6 (1.9)

DLOQ Below level of quantification. LOQ=0.04 mg/L.

Table 10. Summary of yield N accumulation, A-R, and residual inorganic N for three rate studies conducted at the Maricopa Agricultural Center.

Study	N Source[a]	N Rate[b] Kg N/ha	Yield MT/ha	N Uptake Kg N/ha	A-R	Residual NH4-N (mg/kg)	Residual NO3-N (mg/kg)
1	Urea	136	6.8 (1.1)	10.8 (2.0)	125	38 (11)	24 (29)
1	AS	136	7.4 (1.5)	11.2 (2.5)	125	45 (10)	94 (98)
2	Urea	136	13.0 (0.8)	19.6 (2.9)	116	52 (43)	35 (19)
2	AS	136	13.0 (2.8)	19.5 (5.3)	117	63 (23)	38 (23)
3	Urea	136	9.1 (2.1)	12.1 (3.3)	124	57 (26)	27 (11)
3	AS	136	9.2 (4.6)	11.2 (5.3_	125	91 (44)	46 (32)

[a] AS is ammonium sulfate

[b] This is the applied N rate where yields were maximized. A quadratic model would have resulted in a consistent high N bias.

Values in parentheses are standard deviations.

Table 11. Comparison of N applied at sites, N recommended by “CropManage” and measured crop removal.

Site	Seasonal N Applied (kg N/ha)	Seasonal CropManage N Recommended (kg N/ha)	Crop N removal (kg N/ha)
BWD 20A	152	154	101
BWD 20B	199	118	49
IS 21	79	56	24
YID 21	290	173	92.6

Table 12. Relationship between N accumulation and HU and NDVI for baby spinach and spring mix.

Site	NU by HU		NU by NDVI	
	Relationship	R^2	Relationship	R^2
	Spinach			
YID 19-20A	$NU=1x10^{-5}HU2.44$	0.81	$NU=0.037e^{12.22NDVI}$	0.78
YID 19-20B	$NU=9x10^{-7}HU2.83$	0.96	$NU=0.028e^{10.62NDVI}$	0.94
IS 20B	$NU=0.062e^{0.012HU}$	0.93	$NU=0.057e^{9.81NDVI}$	0.89
YID 201	$NU=0.067e^{0.016HY}$	0.86	$NU=0.0683e^{10.48NDVI}$	0.93
Overall	$RNU=1x10^{-8}HU^{2.58}$	0.74	$RNU=2.48NDVI^{3.21}$	0.87
	Spring Mix			
YMIDD 20	$NU=-0.056e^{0.010HU}$	0.77	$NU=0.0371e^{12.22NDVI}$	0.73
IS 20A	$NU=0.050e^{0.013HU}$	0.93	$NU=0.0275e^{10.62NDVI}$	0.92
IS 20C	$NU=0.043e^{0.013HU}$	0.50	$NU=0.0154e^{9.48NDVI}$	0.53
IS 21A	$NU=0.113e^{0.008HU}$	0.65	$NU=0.0705e^{11.90NDVI}$	0.68
Overall	$RNU=3x10^{-7}x^{2.30}$	0.72	$RNU=2.56NDVI^{2.93}$	0.42

RDM is relative dry matter relative to maximum each site.

Table 13. Fertigation studies conducted in Fall 21, Fall-Winter 21, and Spring 22 at MAC research center.

Experiment	Task	Crop	Wet Date	Harvest Date
Fall 21a	6	Spring Mix	Oct. 19. 2021	Nov. 21, 2021
Fall 21b	6	Baby Spinach	Oct. 19. 2021	Nov. 21, 2021
Fall-Winter 21a	6	Spring Mix	Nov. 22, 2021	Jan. 24, 2022
Fall Winter 21b	6	Baby Spinach	Nov. 22, 2021	Jan. 24, 2022
Winter 22a	6	Spring Mix	Feb. 8, 2022	April 1, 2022
Winter 22b	6	Baby Spinach	Feb. 8, 2022	April 1, 2022

Table 14. Fertigation methods used in Fall 2021, Fall-Winter 2021 and Winter-Spring 2022.

Experiment	Fertilization Date	Treatment				
		0	1	2	3	4
			lbs N/A (kg/ha)			
Fall 21a and b	Pre-Plant	33	33	33	33	33
	10/29/21	0	20.9	13.9	10.5	7
	11/4/21	0	34.5	13.9	17.4	7
	11/12/21	0	41.8	13.9	20.9	7
	Season Total	33 (37)	131 (147)	75 (84)	82 (94)	55 (62)
Fall Winter 21a and b	Pre-Plant	33	33	33	33	33
	12/6/21	0	20.9	13.9	10.5	7
	12/21/21	0	34.5	13.9	17.4	7
	1/4/22	0	41.8	13.9	20.9	7
	Season Total	33 (37)	131 (147)	75 (84)	82 (94)	55 (62)
Winter Spring 22a and b	Pre-Plant	33	33	33	33	33
	3/7/22	0	20.9	13.9	10.5	7
	3/16/22	0	34.5	13.9	17.4	7
	Season Total	33 (37)	88 (99)	61 (68)	61 (68)	47 (53)

All plots received 300 lbs MAP as a P source which resulted in 33 lb N/A pre-plant. Thereafter, all N applied as timed fertigation of UAN 32. For Winter-Spring 22a and 22b we only were able to get on two fertigation events before harvest. Thus, treatments 2 and 3 received an equal final total N rate but it was not applied at the same increments of time. Values in parentheses are kg N/ha.

Table 15. Dry matter, above ground N accumulation, NDVI, and marketable yield of baby spinach to fertigation in experiment Fall 21a.

N Rate (kg/ha)	Plant Dry weight (g/m2)				N Accumulation (g/m2)				NDVI			Yield (MT/ha)
33	16.5	45.5	130.8	136.8	0.94	2.30	3.78	4.49	0.53	0.72	0.83	16.2
55	22.8	42.8	116.9	173.8	0.95	2.18	3.80	5.70	0.50	0.76	0.89	20.7
75	21.0	40.9	119.2	126.0	0.75	2.34	3.68	4.31	0.43	0.76	0.88	18.7
94	19.6	40.0	102.3	147.0	1.01	2.10	3.50	4.60	0.53	0.84	0.88	18.1
147	16.9	38.8	115.0	178.3	0.67	1.89	3.54	5.48	0.44	0.78	0.88	22.3
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4.2

[a] Multiply g/m^2 by 10 to get kg/ha.
LSD is least significant difference ay $P<0.05$. NS=$P>0.05$.

Table 16. Dry matter, above ground N accumulation, NDVI, and marketable yield of spring mix to fertigation in experiment Fall 21a.

N Rate (kg /ha)	Plant Dry weight (g/m2)			N Accumulation (g/m2)[a]			NDVI			Yield (MT/ha)
33	3.5	44.8	173.0	0.13	1.30	4.23	0.17	0.52	0.86	14.2
55	3.6	56.7	125.1	0.12	1.71	4.09	0.19	0.57	0.85	20.2
75	2.9	39.7	116.9	0.10	1.17	3.81	0.20	0.59	0.86	16.6
94	3.6	60.0	143.3	0.13	1.89	4.53	0.21	0.66	0.86	23.1
147	2.3	39.0	101.7	0.08	1.16	3.44	0.19	0.50	0.86	16.6
LSD	NS	15.0	58.6	NS	0.53	NS	0.03	0.06	NS	4.1

[a] Multiply g/m^2 by 10 to get kg/ha.
LSD is least significant difference ay $P<0.05$. NS=$P>0.05$.

Table 17. Dry matter, above ground N accumulation, NDVI, and marketable yield of baby spinach to fertigation in experiment Fall-Winter 21a.

N Rate (kg/ha)	Plant Dry weight (g/m2)			N Accumulation (g/m2)			NDVI			Marketable Yield (MT/ha)
33	33.4	118.3	163.0	1.28	5.01	5.97	0.52	0.87	0.90	12.4
55	22.8	142.6	131.5	0.96	4.69	4.30	0.57	0.86	0.92	14.1
75	16.3	113.7	125.1	0.67	4.18	4.34	0.55	0.88	0.91	12.6
94	17.4	167.8	187.5	0.71	5.10	6.18	0.48	0.85	0.91	18.0
147	23.1	116.2	158.4	0.94	4.67	5.26	0.57	0.86	0.90	14.6
LSD	10.9	34.5	37.8	0.40	1.13	1.15	0.09	NS	NS	3.4

[a]Multiply g/m^2 by 10 to get kg/ha.
LSD is least significant difference ay $P<0.05$. NS=$P>0.05$.

Table 18. Dry matter, above ground N accumulation, NDVI, and marketable yield of spring mix to fertigation experiment Fall-Winter 21a.

N Rate (kg/ha)	Plant Dry weight (g/m2)			N Accumulation (g/m2)			NDVI			Marketable Yield (MT/ha)
33	13.2	59.0	98.8	0.46	1.44	2.62	0.24	0.73	0.90	8.2
55	4.6	66.7	205.5	0.17	1.82	6.17	0.19	0.70	0.90	19.0
75	2.6	49.8	151.0	0.11	1.38	4.35	0.20	0.65	0.90	15.8
94	4.2	68.6	200.8	0.16	2.11	5.62	0.22	0.66	0.90	20.3
147	4.2	61.7	201.5	0.16	1.49	5.58	0.22	0.64	0.89	17.8
LSD	1.7	NS	72.1	NS	0.52	2.56	NS	NS	NS	6.7

[a]Multiply g/m^2 by 10 to get kg/ha.
LSD is least significant difference ay $P<0.05$. NS=$P>0.05$.

Table 19. Above ground N accumulation and marketable yield of spring mix to fertigation in Winter 22a.

N Rate kg N/ha	N Uptake (kg/ha)	Marketable yield (MT/ha)
37	13.6	4.0
47	14.6	4.1
68	11.8	3.3
68	13.7	3.4
99	16.8	4.0
	NS	NS

LSD is least significant difference ay $P<0.05$. NS=$P>0.05$.

Table 20. Above ground N accumulation and marketable yield of spring mix to fertigation in Winter 22a.

N Rate lbs N/A (kg/ha)	N Uptake (kg/ha)	Marketable yield (MT/ha)
37	5.6	2.1
47	15.0	5.7
68	13.3	5.0
68	25.4	8.8
99	31.9	9.7
LSD	8.6	2.4

LSD is least significant difference ay $P<0.05$. NS=$P>0.05$.

Table 21. Calculated A-R from fertigation studies conducted in 2021-2022.

Experiment	N rate for Maximum yield (kg N/ha)[a]	N Accumulation at maximum yield (kg N/ha)	A-R
	Baby Spinach		
Fall 21a	86	45	41
Fall-Winter 21a	97	56	41
Winter 22	89	32	57
Average	91	44	46
	Spring Mix		
Fall 21b	79	46	33
Fall Winter 21b	100	62	38
Winter 22	33	14	19
Average	71	41	30

[a] Calculated from quadratic curve fit of yield to N rate.

Figure 1. Typical eddy covariance set up in a baby spinach production field.

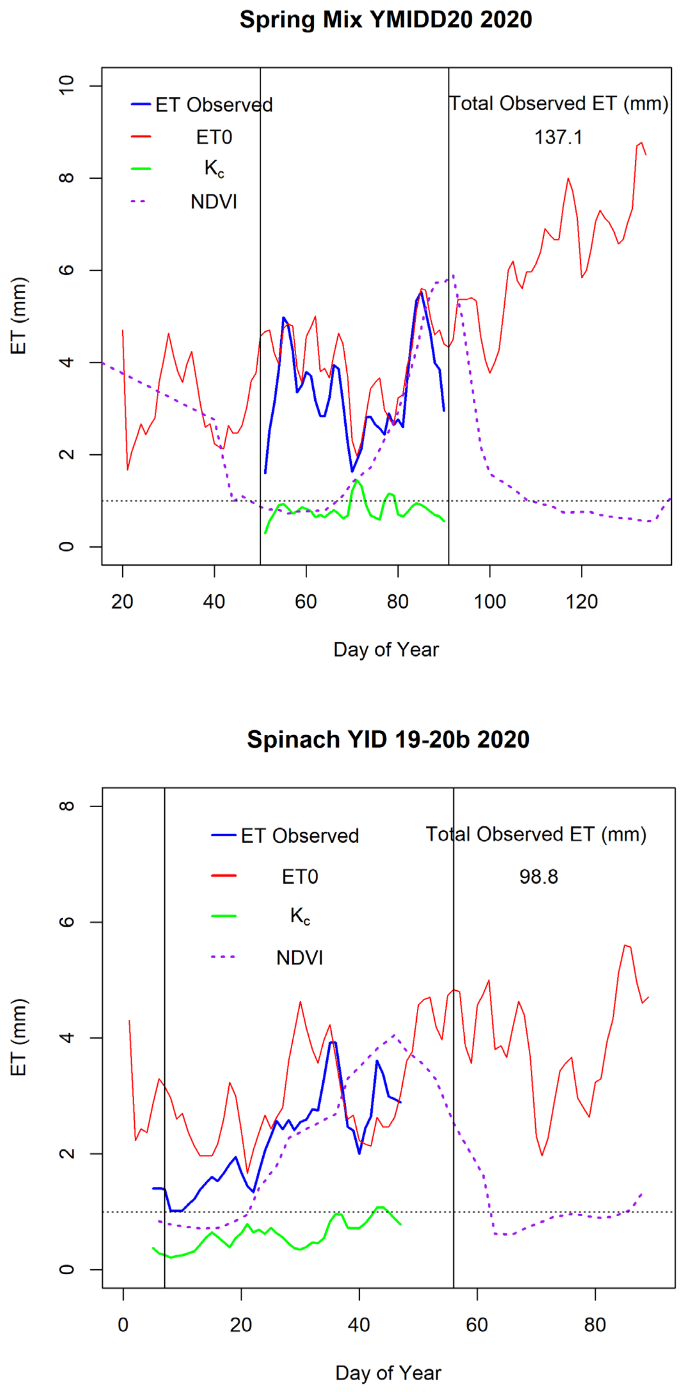

Figure 2. Examples of data collected in all sites shown for YID 19-20 B and YMIDD 20.

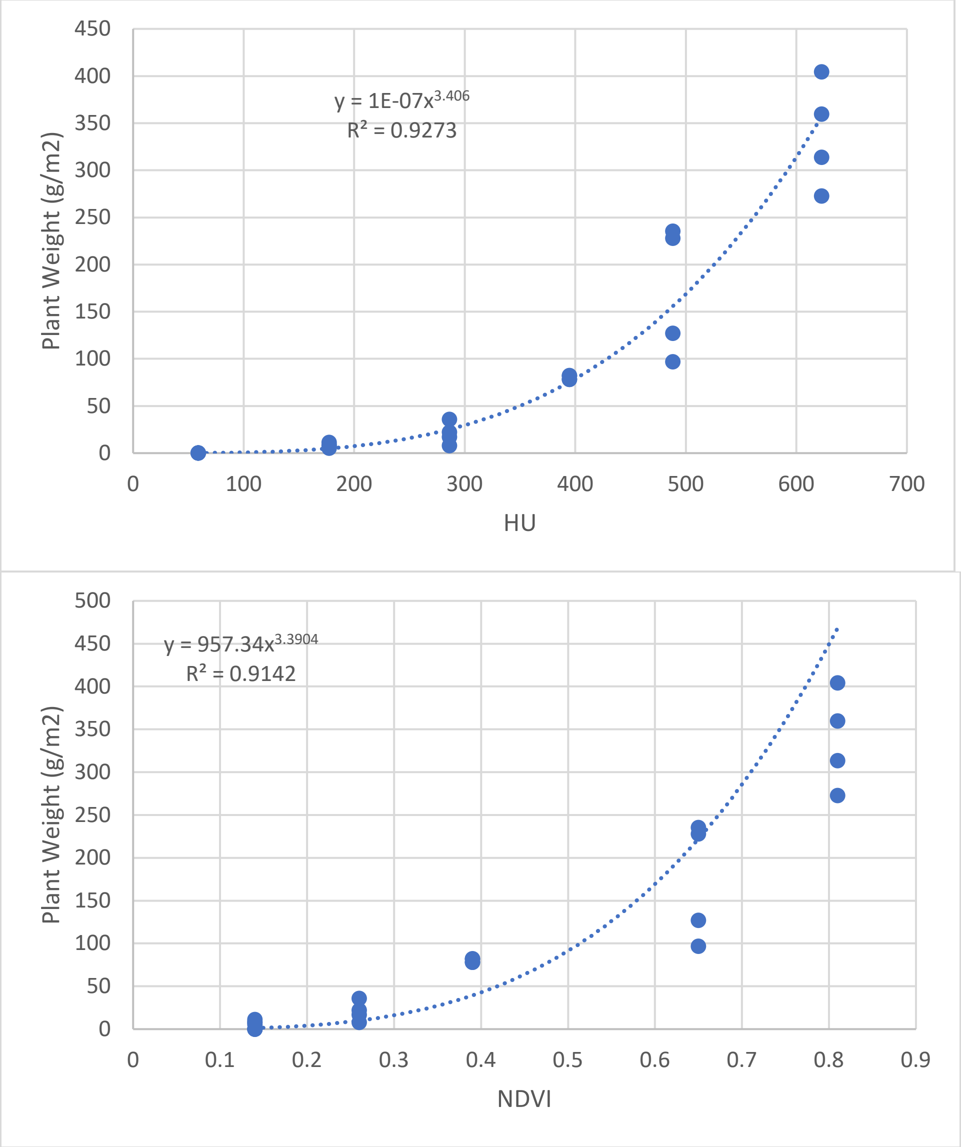

Figure 3. Relationship between growth and calculated heat units or NDVI for YID 19-20B.

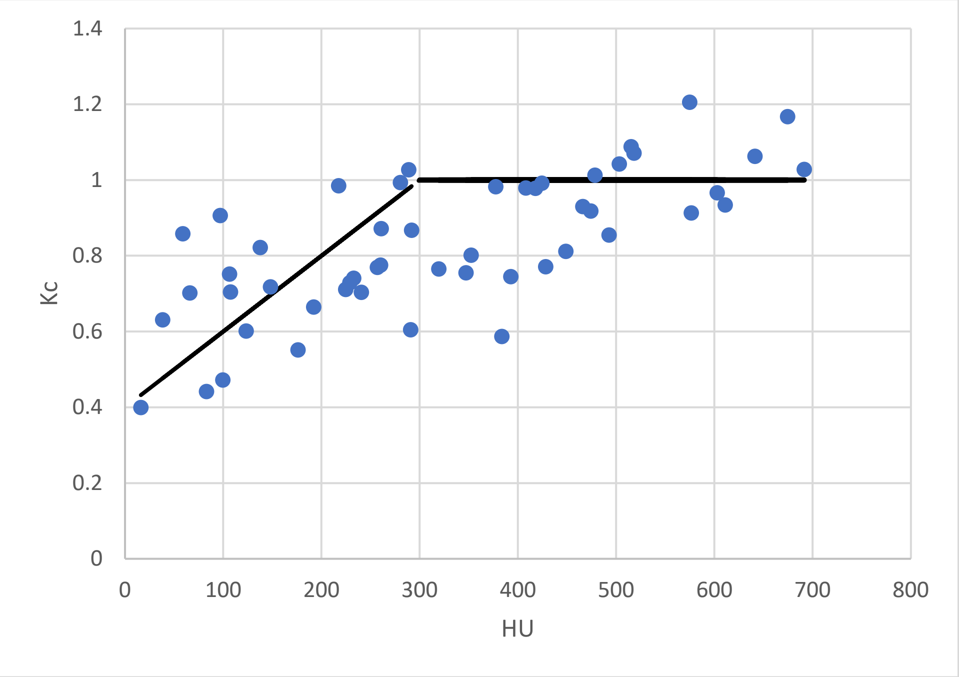

Figure 4. Crop coefficient by HU for baby spinach.

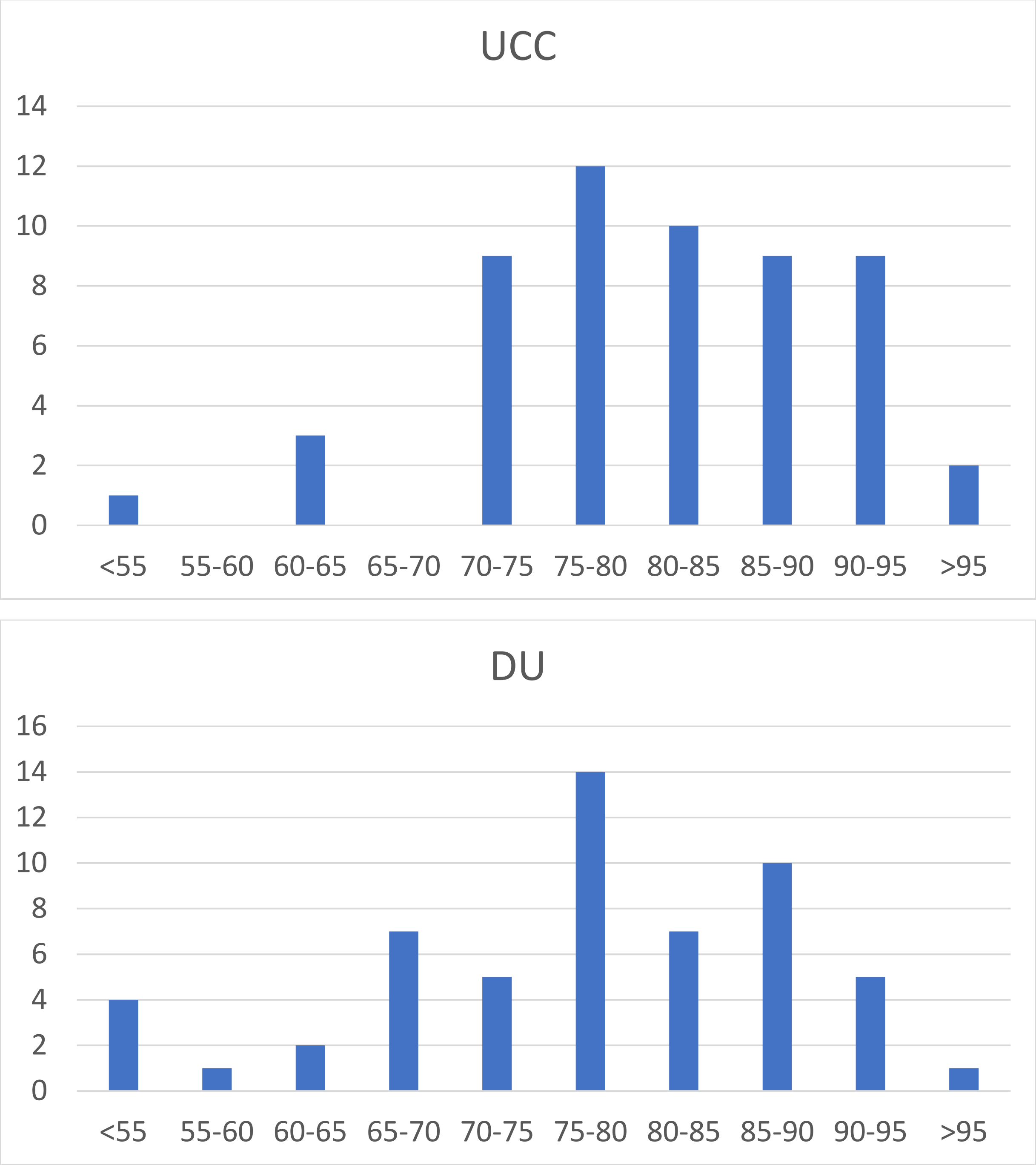

Figure 5. Frequency of UCC and DU for 50 individual sprinkler events.

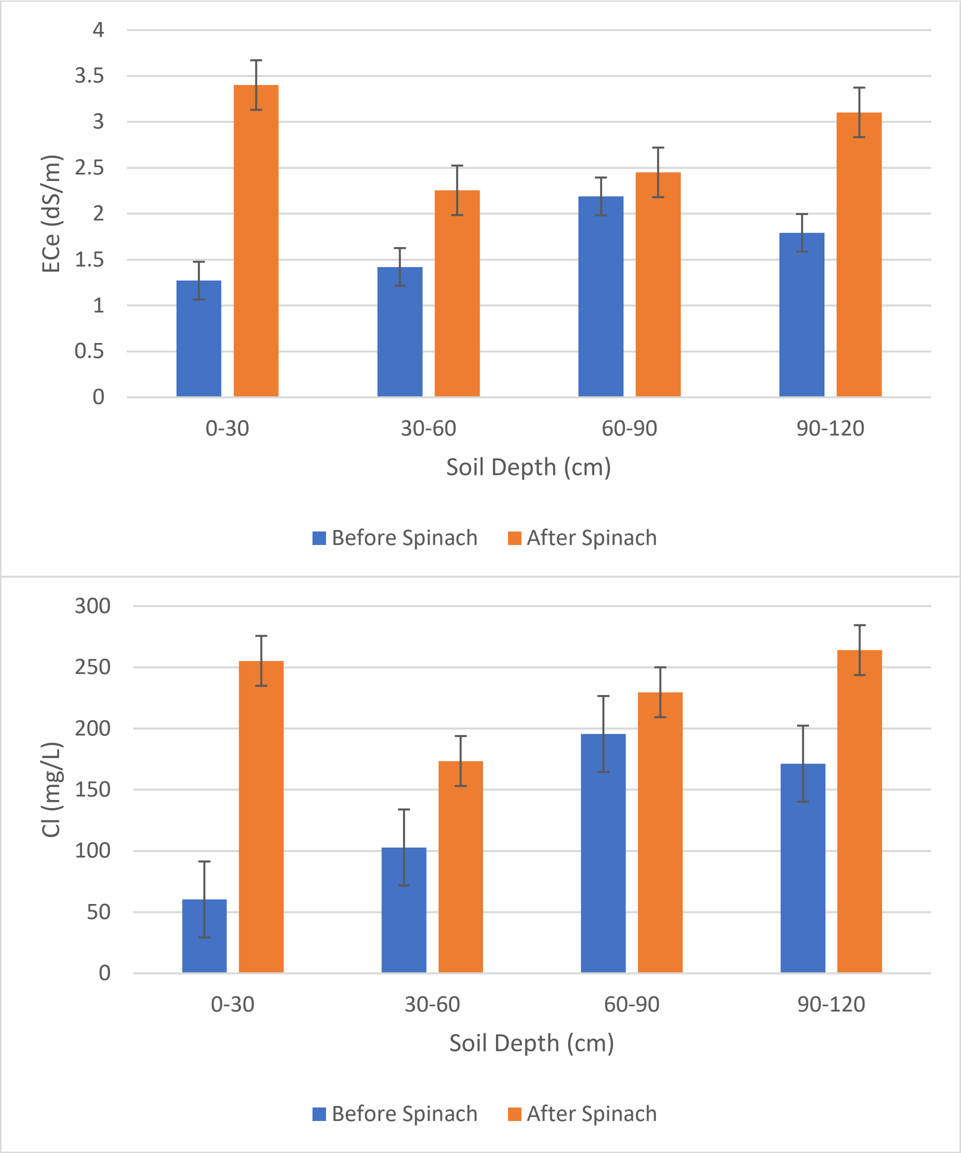

Figure 6. An example (YID 21) where salinity increased in-season (no leaching fraction).

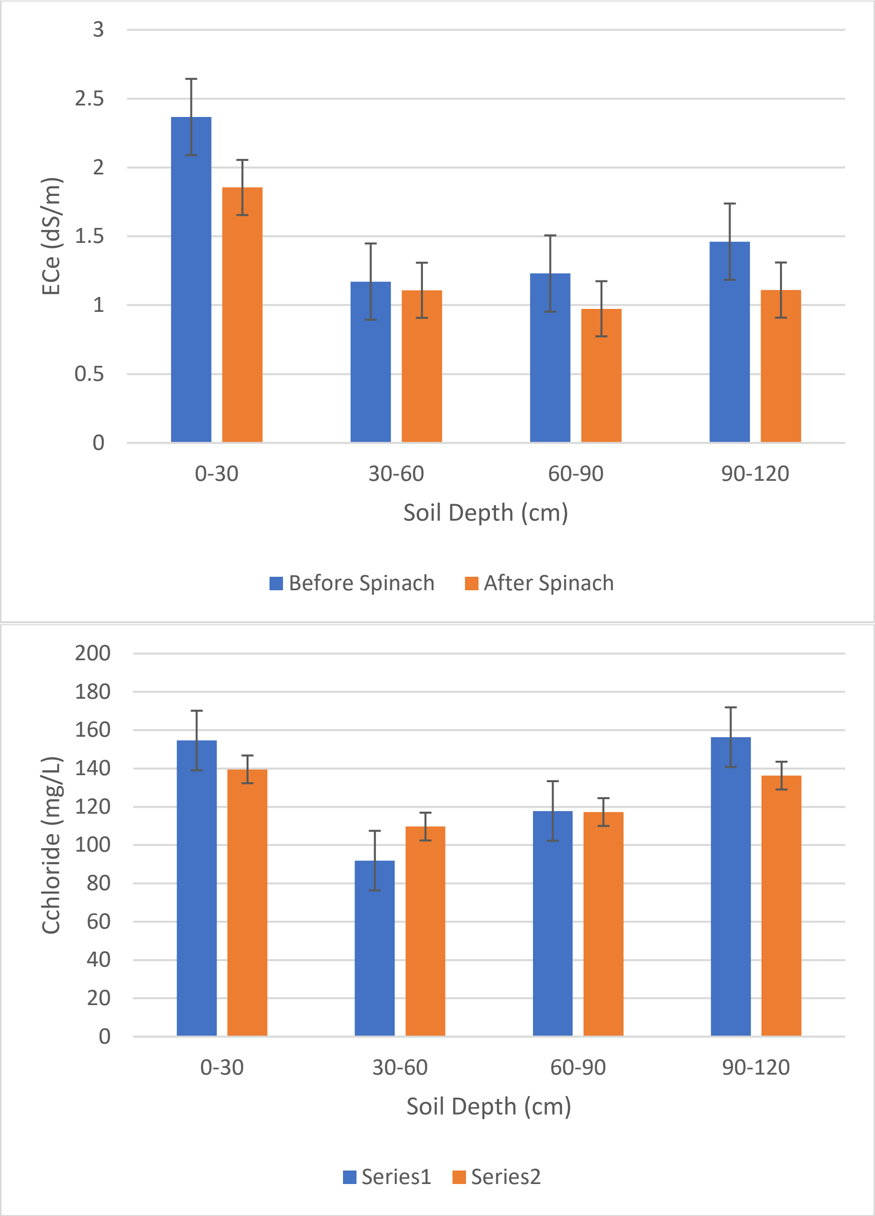

Figure 7. An example (YID 19-20B) where salinity decreased in-season (a leaching fraction of 25%).

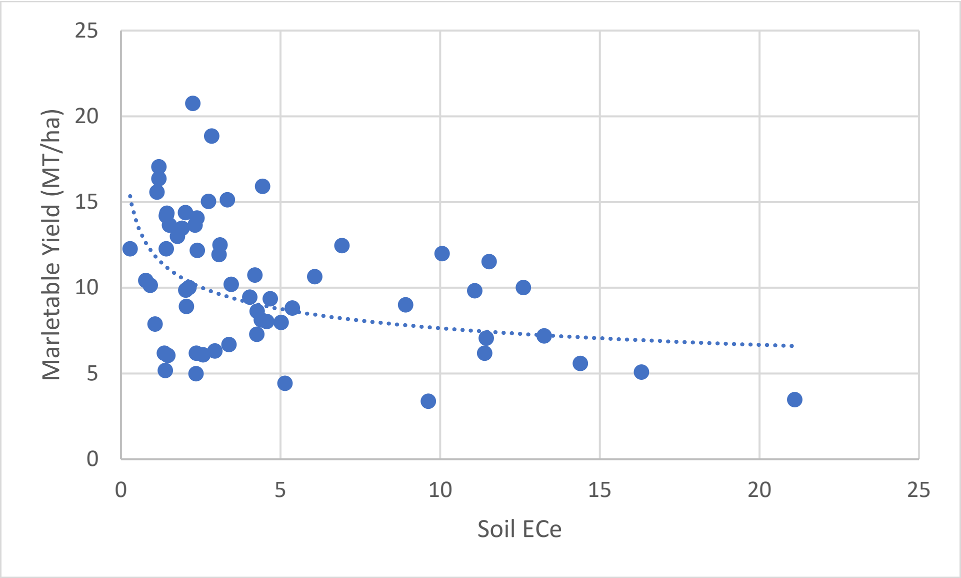

Figure 8. Relationship between measured yield and ECe across all spinach sites.

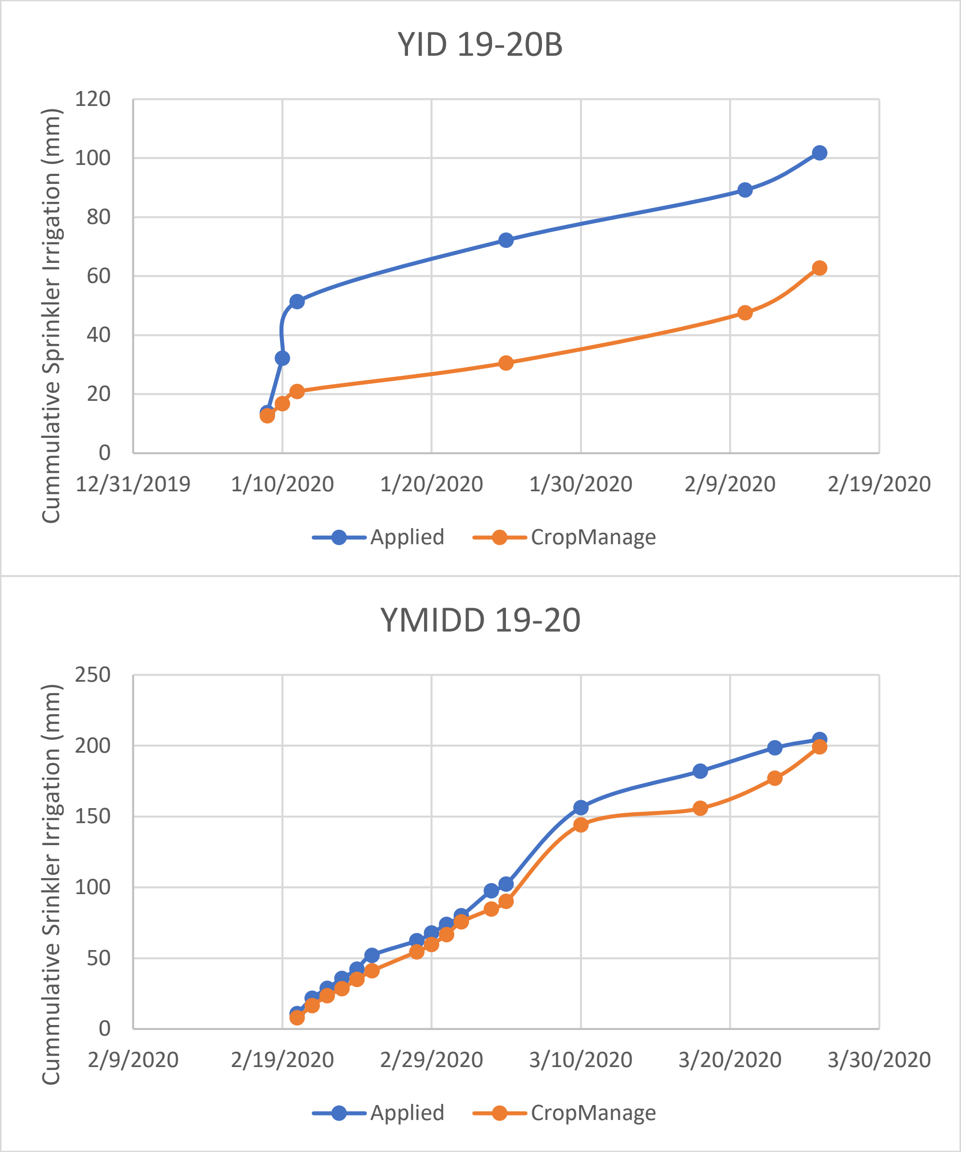

Figure 9. Comparison of irrigation water applied and that called for by “Crop Manage”.

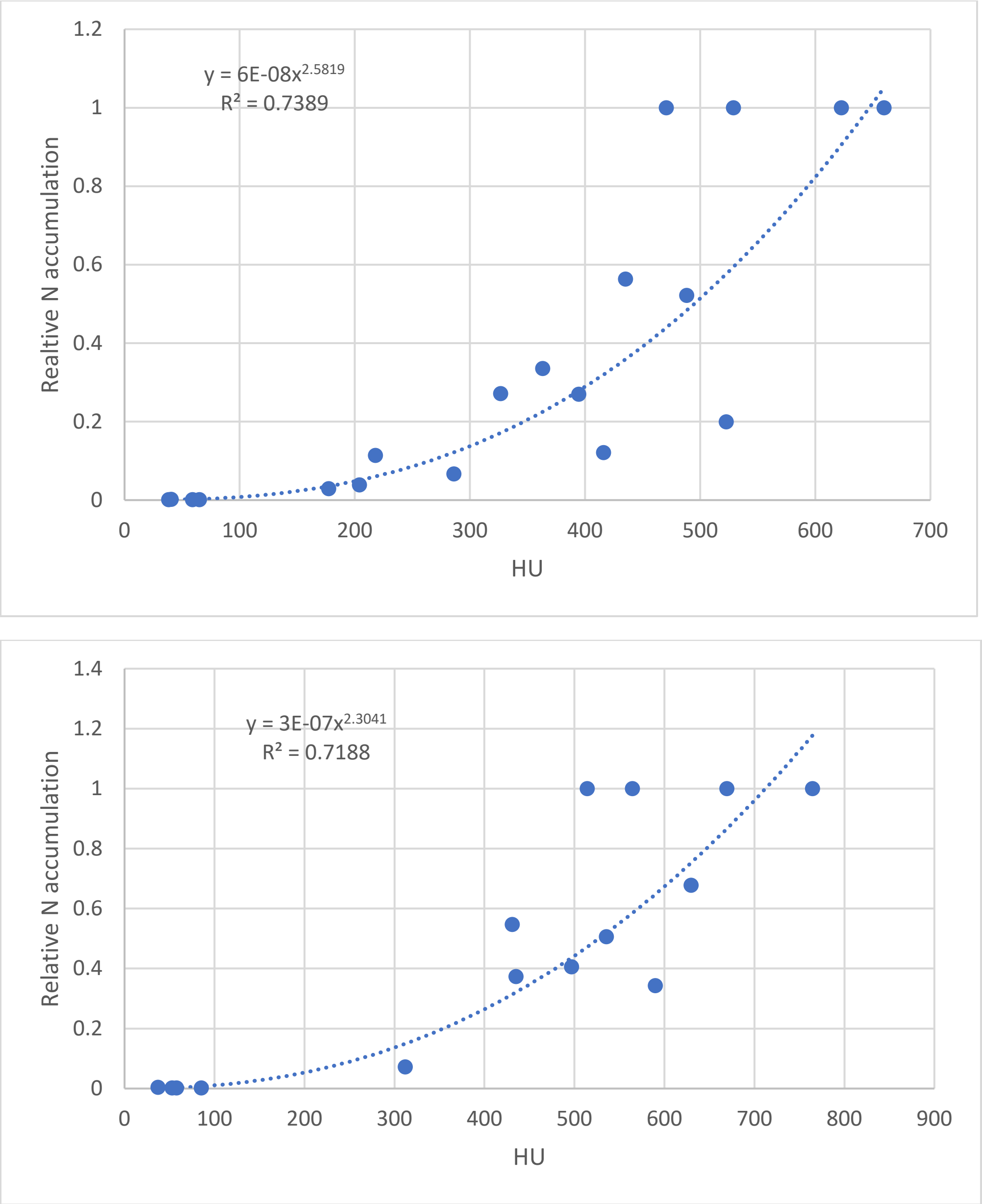

Figure 10. Relative above-ground N accumulation for all spinach (A) and spring mix (B), sites

M. Factsheet/Database Template:

1. **Project Title:** Efficient Water and Nitrogen Management Practices for Mixed Leafy Baby Green Vegetables in the Desert.

2. **Grant Agreement Number:** 18-059
3. **Project Leaders:** Charles A. Sanchez and Andy French

4. **Project Duration**: Start Date: 1/1/2019; End Date:010/30/2022

5. **Locations**: Low desert regions of California and Arizona

6. Counties: **Imperial, CA, Yuma, AZ, Maricopa, AZ**

7. **Highlights:**

This project generated a data base for water and N management for baby spinach and spring mix that did not previously exist.

The data base developed tools to track ETc using ETo, crop coefficients, HU or satellite NDVI. This data base also facilitates effective salinity management.

The studies generated a data base to project N uptake patterns by spinach and spring mix. Using this data base, we have proposed fertigation timing strategies that facilitate more efficient N management more closely approaching targets by regulators.

Overall, this data base can be used with "Crop Manage" or any other water and N fertilization algorithm.

8. **Introduction:**

Intensive vegetable production in the southwestern U.S. receives large annual applications of nitrogen (N) fertilizers. Amounts of N applied range from 200 to 400 kg/ha and crop recoveries are generally less than 50%. Over the past decade the production of high density mixed leafy green vegetables on large beds (80- and 84-inch beds) has increased significantly. These include baby spinach and spring mix. Work on the fertilizer requirements for these crops are lacking and many growers have simply utilized the fertilizer practices they currently use on full season lettuce. While these crops are grown at a higher density than full season lettuce, they are harvested young and are short season (20 to 40 days) compared to the 80- to 150- day lettuce crops. We have no information how these factors affect fertilizer needs, no information on how irrigation interacts with N, and no information to modify N fertilizer recommendations for these crops. These data gaps are of concern since over 35% of the industry has converted to these high-density large bed production systems and this acreage continues to grow.

9. Methods/Management.

Evapotranspiration was measured using Eddy Covariance methodology (ECV). Briefly, ECV measures four energy flux components- net radiation (Rn), ground heat flux (G), sensible heat flux (H), and latent heat flux (LE). Rn represents absorbed solar and infrared radiation, G is heat transported into the soil, H is turbulent heat above the crop due to air temperature gradients, and LE is latent heat energy due to ET. ECV data values are reported in energy flux units (W/m^2), with water-specific quantities also reported as depths over time (e.g. mm/day). Salt balance was monitored using sensors and data loggers during the season and conductance (EM 38) surveys conducted before and after the cropping season. Irrigation water amounts applied to all fields was also monitored using automated rain gauges. Ground measurements were used to calibrate ET estimates from space-based sensors. Satellite data used included Sentinel 2a/2b. Nitrogen accumulation during the season was monitored by collecting aboveground plant samples and calculating N accumulation from total dry matter and N content, after laboratory analysis.

10. Findings

Measured seasonal ETc ranged from 79 to 127 mm for baby spinach and from 109 to 147 mm for spring mix. Irrigation application amounts ranged from 77 to 175 mm and were sometimes augmented by rainfall. Overall, water application efficiencies are generally high. Poor irrigation management, when it does occur, is not the reason for poor N utilization efficiencies. Overall, there was a trend for salinity to accumulate as leaching fractions decreased below 20%. However, growers often use a summer leaching irrigation to restore salt balance. Irrigation with Colorado river water would not result in problematic soil salinity levels in season. This project has generated a data base for continued efficient water management using “Crop Management” or other irrigation management models. Because of uncertainties regarding distribution uniformity for sprinkler applied water to wind distortions, we recommend applying water at 1.15 ETo for baby spinach and spring mix all season.

Data collected show that current N fertilizer practices result in N fertilizer rates far exceeding N removal by the crops and having high residual inorganic N after harvest. The differences between N applied and crop removal did not come close to the target sought by the CWCB by current N management practices. While “Crop Manage” did improve N management, its use with current timing strategies fell short.

Studies conducted in fall 2021, fall-winter 2021, and Spring 2022 evaluated N timing strategies more consistent with N above ground N accumulation patterns identified in these studies. The results show baby spinach and spring mix yields were maximized at much lower N rates than we previously observed, showing that the evaluated fertigation strategies potentially reduce N rates for maximum yield. The difference between N applied and N recovered more consistently match or exceed the CWQCB targets.

N. Copy of Results/Products

We have just started composing papers and we have no products to submit at this time.