Project Abstract

The applicant entity name: University of Hawaii.
The duration of project in months: 36 months (1/2/2020 – 1/1/2023).
Federal funding requested: $900,000; **Non-Federal contributions committed:** $935,581
The project title: Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture; **The geographic location of the project:** Hawaii (HI) [Oahu, Maui, and Big Island], Guam (GU), and Nebraska (NE); **A brief project description and the problem:** Daily reference evapotranspiration (ET_o) and rainfall (R) forecasts have a vital role in real-time decisions on water resources management by quantifying the prospective changes in agricultural and hydrological processes. The real-time decisions on irrigation scheduling are mainly made based on the agricultural water demand (which itself strongly depends on ET_o) and R predictions. Hence, the accurate forecast of ET_o and R plays a key role in the optimal irrigation scheduling and efficient management of water resources. Despite the vital importance of ET_o and R forecast in irrigation scheduling, the CropManage (https://cropmanage.ucanr.edu/Home/SplashPage?ReturnUrl=%2F) tool has simply used the long-term ET_o (R) average as the ET_o (R) forecast for the next 7 days to schedule irrigation of farmlands in the U.S. Pacific Islands and CA. This often can lead to an erroneous irrigation scheduling because ET_o and R in the days ahead can be very different from their corresponding long-term averages. Given this shortcoming, the CornSoyWater (http://hprcc-agron0.unl.edu/cornsoywater/public_html/Home.php) tool in NE used the NOAA ET_o and rainfall forecast products, but its performance did not improve mainly due to the low spatial resolution of these products that cannot capture variations in the microclimate at the farm scale. In summary, by using inaccurate ET_o and R forecasts, both the CropManage and CornSoyWater tools can generate incorrect irrigation scheduling; **Project objectives to address the issue or problem, and the innovative approach to be employed:** 1) use hybrid wavelet-Artificial Neural Networks to accurately forecast daily ET_o and R across different agricultural irrigation areas in HI (Oahu, Maui, and Big Island), GU, and NE, 2) utilize the ET_o and R forecasts to improve irrigation scheduling in NE, 3) incorporate the forecasted ET_o and R values into CropManage tool, and develop "*Advanced CropManage*" to improve water use efficiency for farmlands in HI (Oahu, Maui, and Big Island) and GU, 4) validate Advanced CropManage in improving water use efficiency at the farm level with field trials, and 5) implement an outreach program (workshops and field days) targeting farmers and other agriculture professionals to enhance their awareness and adoption of advanced web-based irrigation tools that conserve water resources and enhance farm productivity; **How the impact will be quantified:** A set of farmers will implement on-farm evaluations of the advanced irrigation scheduling tools. The research team will closely work with farmers to quantify savings in water, energy, and fertilizer in comparison to the traditional irrigation techniques; **The predicted benefits or deliverables:** Benefits: 1) scheduling watering that optimizes crop water use efficiency, 2) reducing farmers' cost of water and labor, and 3) increasing net returns by enhancing crop yields and quality. Deliverables include: 1) ET_o and R forecasts in HI, GU, and NE, 2) one advanced web-based smart irrigation scheduling tool that will serve HI and GU, 2) five field days and workshops and one extension article in each state/territory, and 3) three scientific publications; **The national priority that is addressed by the project:** Water Quantity; **Funding pool:** The 10 percent set-aside and general funding pools; **A technical and administrative contact for the project:** Dr. Sayed Bateni (smbateni@hawaii.edu) and Georgette Sakumoto (gsakumot@hawaii.edu).

Project Narrative

Forecasting Daily Reference Evapotranspiration and Rainfall for Water Resources Conservation and Sustainable Agriculture

a. Project background:

Climate change including severe and extended droughts, water quality degradation, and population growth are anticipated to cause significant future water shortages due to the combination of increased demand and expected long-term reductions in freshwater supplies. These pressures on available freshwater supplies are creating unprecedented political, socioeconomic, engineering, and management challenges for both rural and urban communities. Competing demands for freshwater are related to agricultural, industrial, urban, and environmental uses. There is an urgent need for an overall improved water use efficiency and enhanced water resources management strategy.

Agriculture is often the dominant water user, consuming 70% of world's freshwater withdrawals (UN-Water, 2006; UNEP, 2007). There is a need for sound practical applied science targeting irrigation and the related need for an overall improved water resources management. With 9.7 billion people projected to populate the world by 2050, irrigation systems and their management must rapidly evolve to sustain food production with reduced water availability.

Optimal irrigation scheduling involves applying water in the right amount and at the right time in order to conserve water resources and energy, improve root zone aeration and crop yields, reduce negative environmental impacts, such as leaching of fertilizers to groundwater aquifers, and minimize soil erosion. The additional advantage is the reduction of production costs and labor requirements due to fewer irrigation events. The resulting improved crop yield and quality coupled with reduced costs of production typically lead to increased profitability.

Reference evapotranspiration (ET_o) and rainfall (R) forecasts have a key role in real-time decisions on water resources management by quantifying the prospective changes in agricultural and hydrological processes. In fact, the accurate forecast of ET_o and R has a vital importance in the optimal irrigation scheduling and efficient management of water resources. Real-time decisions on irrigation scheduling are mainly made based on the agricultural water demand (which strongly depends on ET_o) and rainfall predictions (Wang and Cai, 2009; Cai, et al., 2011; Mishra et al., 2013; Perera et al., 2014; Lorite et al., 2015; Manikumari et al., 2017; Chang et al., 2019).

Recently, the University of California Cooperative Extension (UCCE) developed CropManage (https://cropmanage.ucanr.edu/Home/SplashPage?ReturnUrl=%2F). CropManage is an online weather-based irrigation scheduling tool that assists growers and farm managers in California (CA) to determine water applications on a field-by-field basis (Cahn et al., 2013). In a previous study, the PI of this proposal adapted this online tool for farmlands of Hawaii (HI), Guam (GU), and American Samoa (AS). CropManage provides daily irrigation recommendations for the following 7 days by utilizing the long-term ET_o and R averages respectively as the ET_o and R forecasts during these days. This often can lead to erroneous irrigation scheduling because ET_o and R in the next 7 days can be very different from their corresponding long-term average. In this case, the CropManage online tool generates a poor irrigation scheduling, which can damage crops and reduces yields.

In a similar effort, the University of Nebraska-Lincoln (UNL) developed the online weather-based CornSoyWater irrigation scheduling tool for producers in Nebraska (https://water.unl.edu/article/agricultural-irrigation/water-optimizer-tool). The National Oceanic Atmospheric Administration (NOAA) ET_o and R forecasts for the 7 days ahead are used in the CornSoyWater tool. The NOAA ET_o forecast product (https://www.weather.gov/abr/etforecasts) has a coarse spatial resolution of 5 km that typically cannot capture the microclimate at the farm scale. Moreover, this product is obtained by using the air temperature, cloud cover, wind speed, and relative humidity forecasts into the Food and Agriculture Organization-Penman Monteith (FAO-PM) equation (Palmer et al., 2013). Hence, errors in all of the abovementioned forecasted variables directly transfer into the NOAA ET_o forecast. These shortcomings can result in erroneous irrigation recommendations by the CornSoyWater tool. It also worth mentioning that the NOAA ET_o forecast product is only available for the Continental United States, CONUS (and not the US Pacific Islands Area (PIA)). In addition, the NOAA rainfall forecast product has a spatial resolution of 5 km in the CONUS, and 10 km in the US PIA. Since rainfall varies widely, even over short distances, incorporating the NOAA rainfall forecast with the coarse resolutions of 5-10 km into the irrigation tools can simply generate wrong irrigation recommendations.

It is evident that feeding the online irrigation tools with accurate ET_o and R forecasts is of vital importance (Mishra et al., 2013; Lorite et al., 2015; Bachour et al., 2015). Reliable ET_o and R forecasts are required as the key inputs in the CropManage irrigation scheduling tools in order to 1) conserve water resources, 2) lower farmers' cost of water and labor through fewer irrigation events, 3) allow farmers to schedule watering to minimize crop water stress and maximize yields, 4) reduce fertilizer costs by minimizing deep percolation (leaching), and 5) increase farmers' profit by enhancing crop yields and quality.

In this project, artificial neural network (ANN) approaches will be used to forecast ET_o and R based on their time-series (i.e., past evolution). ANN benefits four distinct advantages when dealing with nonlinear time-series: 1) ANN is flexible and does not require to assume *a priori* a specific form of function or a probability distribution for the data, 2) ANN does not assume the time-series is stationary and follows normal distribution, 3) ANN could learn and generalize from a representative sample to generate a meaningful solution even when the input data contains error or is incomplete, and 4) ANN is a robust approach capable of handling the chaotic components in time-series. These advantages have made ANN approaches superior than other forecasting methods such as stochastic, statistical, and numerical weather prediction models (Tahir, 1998; Koizumi, 1999; Toth et al., 2000; Landeras et al., 2009; Nayak et al., 2013; Jabbari and Bae, 2018), and thus have caused the immense utilization of ANN approaches in forecasting single- and multi-daily ahead ET_o and R (Toth et al., 2000; Luk et al., 2001; Trajkovic et al., 2003; Cai and Mu, 2005; Monira et al., 2010; Sumi et al., 2012; Charaniya and Dudul, 2013; Subramanian et al., 2014; Bachour et al., 2015; Luo et al., 2015; Gocic et al., 2015; Darji et al., 2015; Devi et al., 2016; Traore et al., 2016; Manikumari et al., 2017; Alves et al., 2017; Unnikrishnan and Jothiprakash, 2017; Sachin et al., 2018; Mohammadpour et al., 2018; Bateni et al., 2019). Several of the above studies showed that the number of multi time step ahead prediction varies from 7 days to 10 days for daily ET_o and from 3 days to 7 days for daily R, after which the ANN models perform poorly. Given these findings, in this proposed study, the ANN models will be run every 7 days for ET_o prediction, and every 3 days for R prediction. The most widely used neural network in time-series forecasting has been the multilayer perceptron (MLP) (Moreno et al., 2011). Recent studies have indicated the use of nonlinear autoregressive network with exogenous inputs (NARX) in time-series forecasting (Nanda et al., 2016; Tian et

al., 2018). However, there is no consensus on the application of a particular type of ANN in time-series forecasting. In this project, both the MLP and NARX neural networks will be used to forecast ET_o and R.

In recent years, wavelet transformation has become a useful technique for analyzing variations, periodicities, and trends in time-series (Chou and Wang, 2002; Labat et al., 2005; Kucuk et al., 2009). Wavelet transformation breaks down a complex time-series into simpler units to make more accurate forecasts, and has shown an excellent performance in non-linear modeling (Partal, 2009; Cobaner, 2013). The application of wavelets has led to improvements in the analysis of hydrological time-series. Hence, several studies applied hybrid models that combined wavelet transforms with ANN to more accurately forecast different hydrologic variables including ET_o and R (Wang and Luo, 2007; Partal, 2009; Nourani et al., 2014a, b; Rani et al., 2014; Uysal and Sorman, 2017; Londhe and Narkhede, 2018). In these works, initially, the wavelet transform is used to decompose the complex time-series into simpler units. Then, the ANN approach is applied.

The ET_o and R forecasts from the wavelet-NARX approach are shown versus the corresponding measurements at the Dunning Weather Station in Nebraska for June 28-July 28, 2019 (Figure 1). For comparison, the long-term ET_o and R averages (which are used by CropManage) as well as the NOAA ET_o and R forecasts (which are used by CornSoyWater) are also illustrated on the same figure. As can be seen, the wavelet-NARX approach significantly improves the ET_o and R forecasts at the Dunning station.

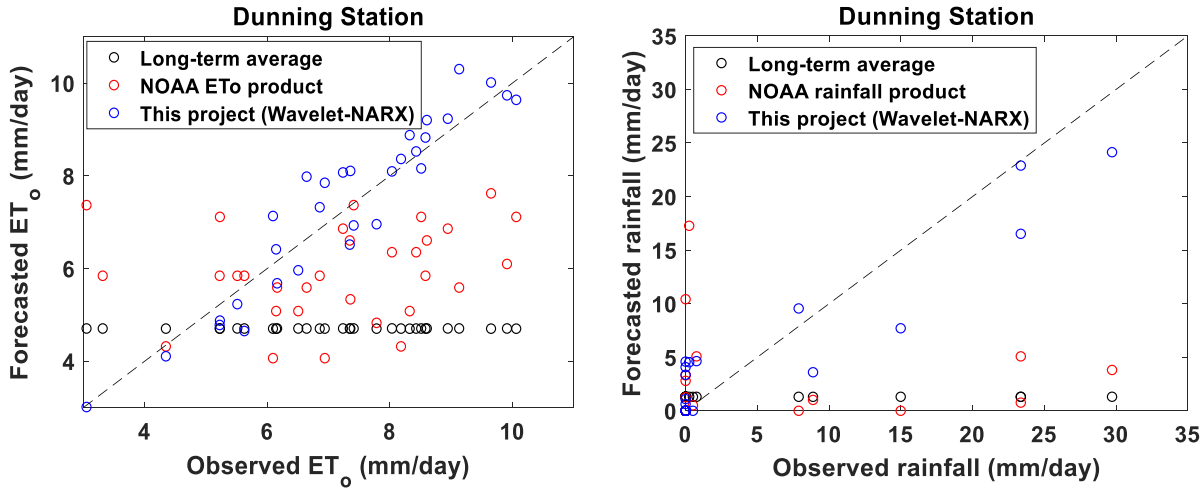


Fig. 1. (left) The ET_o and (right) R forecasts from the wavelet-NARX approach versus the observation at the Dunning Station in Nebraska for June 28-July 28, 2019. For comparison, the long-term ET_o and R averages and the NOAA ET_o and rainfall forecasts are also shown.

To evaluate the effect of different ET_o and R forecasts in Figure 1 on irrigation scheduling, a numerical experiment is performed. In this experiment, it is assumed that CropManage neglects the soil water deficit on the previous day, the irrigation amount that infiltrates into the soil, and surface runoff, and they work based on a simplified water balance equation that only takes into account rainfall and evapotranspiration [i.e., recommended irrigation water for day *i* = evapotranspiration forecast on day *i* - rainfall forecast on day *i*]. Table 1 compares the irrigation

water recommendations (mm/day) using long-term ET_o and R averages, NOAA ET_o and R forecasts, wavelet-NARX ET_o and R forecasts, and ET_o and R observations at the Dunning Station for July 1-7 (herein, we assumed crop coefficient is 1 and thus actual evapotranspiration is equal to the reference evapotranspiration (ET_o)). As indicated in Table 1, the irrigation water based on the wavelet-ANN ET_o and R forecasts (third row) is closest to the correct irrigation water based on the ET_o and R observations (fourth row). Two conclusions can be drawn from Table 1: 1) the ET_o and R forecasts significantly affect performance of smart irrigation tool (herein, CropManage), and 2) the ET_o and R forecasts from this project can significantly improve water use efficiency.

Table 1. Irrigation recommendations (mm/day) based on four different scenarios: 1) long-term ET_o and R averages, 2) NOAA ET_o and R forecasts, 3) Wavelet-NARX ET_o and R forecasts (the focus of this project), and finally 4) ET_o and rainfall observations at the Dunning Station [it should be noted that these irrigation recommendations are based on the aforementioned simplified water balance equation].

Different Scenarios	July 1	July 2	July 3	July 4	July 5	July 6	July 7
Long-term ET_o and R averages	3.40	3.40	3.40	3.40	3.39	3.40	3.39
NOAA ET_o and R forecasts	2.79	0.0	3.56	5.33	0.25	1.27	3.05
Wavelet-NARX ET_o and R forecasts	3.87	6.41	6.95	7.32	0	7.13	1.07
ET_o and R observations	**5.22**	**6.14**	**7.78**	**6.34**	**0**	**6.09**	**0**

b. Project objectives:

This study specifically will address water resources conservation in HI (Oahu, Maui, and Big Islands), GU, and Nebraska (NE). As these States and the territory of Guam continue to grow and develop, water resources for crops will become more and more scarce. Smart irrigation scheduling refers to technologies that can help farmers determine the timing and amounts of irrigation. As shown in Table 1, the ET_o and R forecasts significantly affect performance of smart irrigation tools. The objectives of this study are: 1) to develop the hybrid wavelet-MLP and wavelet-NARX approaches to accurately forecast ET_o and R at the cooperative farms in HI, GU, and NE, 2) to assess the performance of wavelet-MLP and wavelet-NARX in the designated farms with various climatic conditions, and choose the best approach for each climatic condition, 3) to significantly improve performance of CropManage by incorporating ET_o and R forecasts into it, and developing "*Advanced CropManage*", 4) to evaluate the use of Advanced CropManage tool to improve water use efficiency for selected high value vegetable crops, and 5) to implement an outreach program to increase growers' awareness and adoption of irrigation management strategies that maintain profitable crop yield and quality.

By incorporating the precise ET_o and R forecasts into CropManage, farmers will be able to irrigate more efficiently and reduce the amount of applied water, while maintaining or even improving yields. By the end of this project, farmers will be able to schedule the irrigation water supply according to the water needs of the crops via taking into account near-future weather conditions. The results of this project will significantly assist irrigators since the information can be delivered electronically to farmers and eliminates much of the labor involved in measuring soil water content through sampling.

c. Project methods:

c.1. Wavelet transformation

Wavelet transforms are a set of mathematical functions that decompose original time-series into a number of various sub-series, depending on the level of decomposition (Chaovalit et al., 2011). The technique is suitable for denoising non-stationary time-series (i.e., where the mean and autocorrelation of the signal vary with time) (Nury et al., 2017). Most climatic time-series (e.g., ET_o and R) are non-stationary, and therefore wavelet transforms have been used for noise removal (Bachour et al., 2015).

Wavelet transform can be categorized into continuous wavelet transform (CWT) and discrete wavelet (DWT). CWT is rarely used for forecasting because of its computational complexity and time requirements (Kisi et al., 2011a, b). Due to the discrete nature of measured ET_o and rainfall data, the DWT is preferred (Nourani et al., 2014a, b; Nanda et al., 2016; Khan et al., 2018). DWT is computationally less expensive and is easier to apply. In this study, the DWT will be used to retain features in the data and reduce the noise of daily ET_o and rainfall time-series. Detailed description of the DWT can be found in Tiwari and Chatterjee (2010).

c.2. Artificial Neural Networks (ANN)

Artificial Neural Network (ANN) is a mathematical tool that is inspired by the biological nervous system. It is an intelligent system that has the ability to recognize nonlinear characteristics and time-series patterns, and has been widely used for modeling nonlinear time-series (Moreno et al., 2011). It has a powerful capacity to learn, store, and recall information, and approximate any type of arbitrary function to map an n-dimensional input space onto an m-dimensional output space, when the relations between the input and output spaces are unknown (Boussaada et al., 2018). ANN learns the underlying relation of the data during training, so that a valid forecast is made when a new input vector value is presented to the trained neural network.

c.2.1. Multi-layer Perceptron (MLP) ANN model

The most extensively used neural network in time-series forecasting has been the MLP. It consists of three layers (input, hidden, and output layer), neurons, weights, and activation functions, *f* (Fig. 2). MLP is the simplest form of a layered network. An input layer of source nodes projects onto an output layer. This network is designed as a feedforward type, i. e., the information transfers through layers in the forward direction, from input to output layer. Connection weights and bias connect the neurons. The strength of a connection between two neurons *i* and *j* is denoted by w_{ij}. Experimental knowledge, acquired by the network through a learning process, is stored by massively interconnected weights and biases.

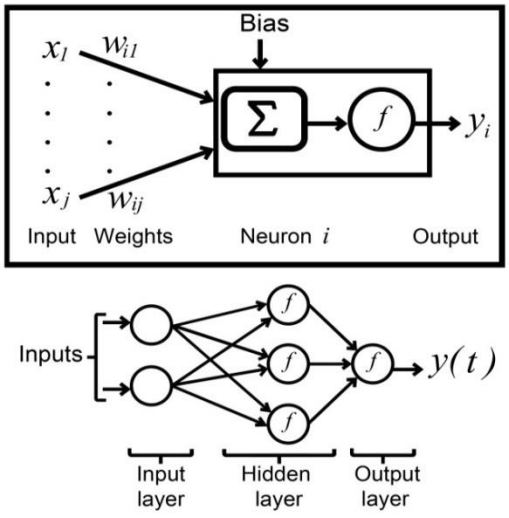


Fig. 2. Details of a neuron (top), and the MLP network with on hidden layer, one input layer, and one output layer (bottom).

In MLP, each neuron multiplies the input x_j given by the previous layer by the weight vector (w_{ij}) to generate the scalar product $x_j \times w_{ij}$. These products for all inputs are summed and then pass through a transfer function (*f*) to generate a result, as follows,

$$y_i = f(b + \sum_{j=1}^{n} x_j w_{ij}) \quad (1)$$

where b is the bias for the neuron, x_j is the value of the jth neuron in the previous layer, n is the number of input neurons, and w_{ij} is the weight of the link joining the ith neuron in a layer to the jth neuron in the pervious layer. The commonly used transfer functions are linear, sigmoid, and hyperbolic tangent. The MLP is trained with a training set of known input and true output data. In the training step, many learning examples are repeatedly presented to the network, and the connection weights and bias values are tuned via the back-propagation (BP) algorithm. The BP method is one of the most famous and commonly used learning techniques for training MLP (Bateni et al., 2007, 2019; Ali et al., 2017). It minimizes the quadratic error between the network output and the desired target by adjusting the weights and bias values. The training of the network is repeated for many examples in the set until the network reaches a steady state where there are insignificant changes in the weights. Details of BP algorithm can be found in Rumelhart et al. (1986) and Hecht-Nielsen (1989).

c.2.2. Nonlinear autoregressive network with exogenous inputs (NARX) network

The nonlinear autoregressive network with exogenous inputs (NARX) network is a recurrent dynamic network, which can have several hidden layers. Unlike the MLP network that transfers information only in the forward direction, a recurrent network (e.g., NARX) has at least one feedback loop (Fig. 3). The feedback loops enclose several layers of the network and improve the learning capacity and performance of the network (Sheremetov et al., 2015; Vaz et al., 2016; Boussaada et al., 2018). Furthermore, the feedback loops use unit-delay elements (z^{-1}), which yield nonlinear dynamical behavior. This architecture makes NARX well suited for modeling nonlinear systems, especially time-series (Sheremetov et al., 2015; Chang et al., 2016; Boussaada et al., 2018). The NARX network can be used to simulate a wide variety of nonlinear dynamic systems, and can be mathematically represented by,

$$y(t) = g(y(t-1), y(t-2), \ldots . y\left(t-n_y\right), u(t-1), u(t-2), \ldots, u(t-n_u)) \quad (2)$$

where $y(t)$ and $u(t)$ denote the output and input of the model at the time step t, n_y and n_u are the number of delays in the output and input of the network, and g is a nonlinear mapping function. The mapping function g is approximated by the MLP neural network. The MLP provides a powerful tool that allows learning any type of continuous nonlinear mapping. Training of MLP network via the BP algorithm was explained in the previous section. In equation (2), the output at time t, $y(t)$, depends on past outputs [i.e., $y(t-1), y(t-2), \ldots$, and $y\left(t-n_y\right)$] and past independent (exogeneous) inputs [i.e., $u(t-1), u(t-2), \ldots, u(t-n_u)$]. A complete description of NARX neural network can be found in Sheremetov et al. (2015).

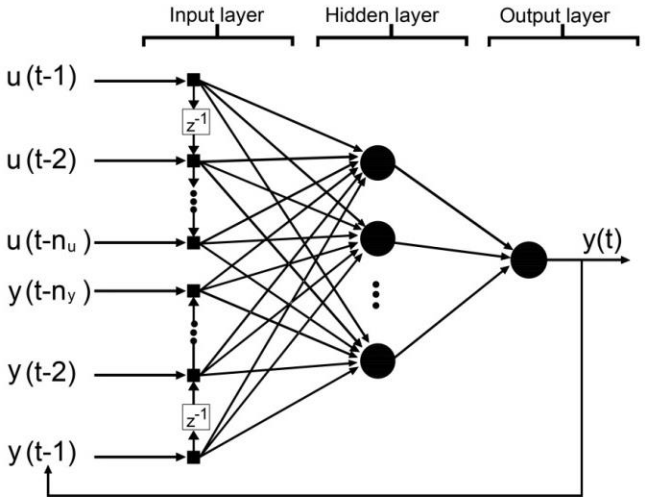


Fig. 3. Structure of the NARX neural network.

c.3. Historical time-series of daily reference evapotranspiration (ET_o) and rainfall (R)

The reference evapotranspiration (ET_o) is defined as the evapotranspiration rate from a well-watered theoretical grass reference crop with an assumed crop height of 0.12 m, an albedo of 0.23, and a constant surface resistance of 70 s m^{-1} (Droogers and Allen, 2002). In this project, the well-known FAO Penman-Monteith (FAO-PM) method will be used to calculate ET_o. It has been chosen by FAO as the reference because it accurately estimates grass ET_o and takes into account both physiologic and aerodynamic parameters, and is recommended as the standard ET_o method (Allen et al., 1998). It can provide accurate ET_o values in many climates and regions (Allen et al., 2005, 2006; Cai et al., 2007), and has long been recognized as a reliable ET_o estimator, especially for daily computations (Garcia et al., 2004; Temesgen et al., 2005). The FAO-PM equation is given by,

$$\mathrm{ET_o} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} U(e_s - e_a)}{\Delta + \gamma(1 + 0.34U)} \quad (3)$$

where ET_o is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the ground heat flux (MJ m^{-2} day^{-1}), T_a is the daily average air temperature (^oC), U is the wind speed at 2 m above the ground (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope of vapor pressure curve (kPa $^oC^{-1}$), and γ is the psychrometric constant (=66.6 kPa $^oC^{-1}$). Since the surface is covered by vegetation and ET_o is calculated on daily basis, the ground heat flux (G) is negligible compared to R_n and is assumed to be zero (Allen et al., 1998).

For estimating historical time-series of daily ET_o, the FAO-PM method requires T_a, R_n , e_a, and U, which have been recorded by the automatic weather stations (AWS) at all the cooperating farms. The saturation vapor pressure (e_s) (needed in equation 1) will be calculated from the Clausius-Clapeyron equation. The historical time-series of daily rainfall have been also measured via the AWS at all the collaborating farms.

Historical time-series of dependent variables of interest (i.e., ET_o and R) and the independent climatic variables that may affect them (e.g., air temperature, vapor pressure, atmospheric pressure, wind speed, dew point temperature, incoming solar radiation, etc.) at the collaborating farms will be used to train and test the wavelet-MLP and wavelet-NARX networks. Finally, the fully trained networks will be used to forecast ET_o and R for 2021 and the following years. It is evident that longer time-series of the abovementioned dependent and independent variables lead to better trained wavelet-MLP and wavelet-NARX networks, ultimately resulting in more accurate ET_o and R forecasts.

c.4. Evaluating the use of Advanced CropManage

Once the Advanced CropManage tool has been developed, we will implement field trials to validate their use in improving water use efficiency at the farm level. The field trials will consist of side-by-side strip trials comparing current farmer irrigation practice to optimal irrigation scheduling using the Advanced CropManage in HI (Oahu, Maui, and Big Island) and GU. Collected data including water use and cost coupled with crop yield and revenue will be used to obtain net farm profit. The net benefit when Advanced CropManage is used will be compared to the net benefit in the control plot. The increase in the net benefit will allow us to quantitatively evaluate the advantage of using ET_o and R forecasts in irrigation scheduling. Based on the results in Figure 1 and Table 1, it is anticipated that this project will advance water use efficiency and

help famers save dollars by decreasing production costs and preserving or even improving crop yields.

d. Geographic location and size of project area:

Twelve collaborating farmers from Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska have been chosen to cover a diverse set of farm sizes, crops, and microclimates. Below we describe the sites by each State/Territory.

1. Hawaii: Oahu (Fig. 4): MA'O Organic Farm (24 acres) is located in the arid Lualualei Valley and consists of a clay-rich Vertisol (Lualualei series, fine, smectitic, isohyperthermnic, Typic, Gypsytorrerts). Its crops are romaine lettuce, eggplant, carrot, cauliflower, parsley, onion, lemons, and lime. Aloun Farm (3000 acres), the second largest commercial vegetable operation in Hawaii, is located on the arid plains west of Pearl Harbor and on the weathered Oxisols of Central Oahu (Wahiawa series, very-fine, kaolinitic, isohyperthermi isohyperthermic, Rhodic Haplustox). Its crops are lettuce, broccoli, head cabbage, Chinese cabbage, onion, eggplant, and watermelon. Corteva Agriscience (1000 acres) is a seed corn operation farm and its soil is similar to that of Aloun Farm.

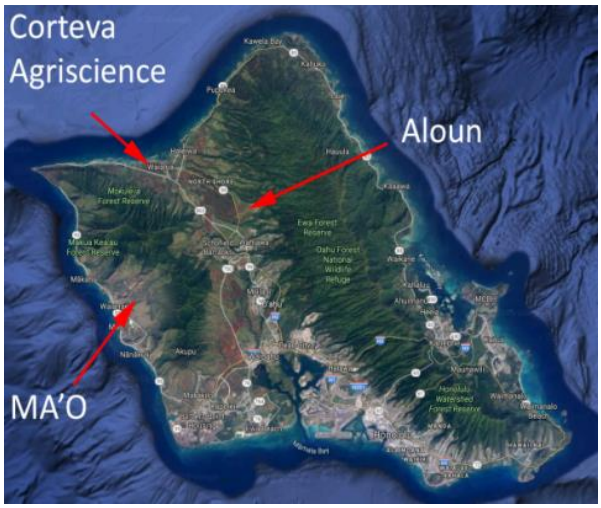


Fig. 4. Locations of cooperating farms on Oahu.

2. Hawaii: Maui (Fig. 5): Mahi Pono is a Maui farming company working to transform 41,000 acres of vacant former sugar cane land into a thriving hub of diversified agriculture. (https://www.mahipono.com). This includes all of the Central Maui farm lands, and several parcels located in north and east of Maui. Its mission is to sustain the well being of Hawaii Ohana through responsible farming. Mahi Pono is located on the Keahua soil (fine, kaolinitic, isohyperthermic, ustic, Haplocambids). It crops are mainly potato, peppers, sweet onion, head cabbage, and romaine lettuce.

Fig. 5. Location of Mahi Pono on Maui.

3. Hawaii: Big Island (Fig. 6): The Hirako Farm (80 acres) is located in Waimea, which is the most important vegetable growing farm on the Big Island. It is a domestic profit corporation. The soils are the Waimea series (medial, amorphic, isothermic, humic, Haplustands). Its major crops are romaine lettuce, head cabbage, and Chinese cabbage.

Fig. 6. Location of Hirako on Big Island.

4. Guam (Fig. 7): Watson's Farm (30 acres) is located in the northern part of Guam in the village of Yigo. Soil in the Watson's Farm is a 'Guam cobbly clay loam', very shallow, well drained, nearly level to moderately sloping soil. Its crops are bitter melon, banana, eggplant, cherry, and tomato. MEDA Farm (30 acres) is located in the southern part of Guam in the village of Inarajan. MEDA has a mixture of northern and southern Guam soils. It sits on top of limestone, but has deep pockets of southern soils (Pulantat clay) which are shallow, well drained, gently sloping to extremely steep soils. Its crops are eggplant, hot pepper, cucumber, cherry, tomato, and watermelon. Island View Farm (60 acres) is in the north of Guam in the village of Dededo. Its mail crops are sweet corn, Chinese cabbage, cherry tomatoes, pole beans, and watermelon, and its soil is similar to that of Watson's Farm.

Fig. 7. Locations of cooperating farms on Guam.

5. Nebraska (Fig. 8): Stahr Farm (700 acres of irrigated lands using center pivots) is close to York, NE, and its crops are corn and soybean. Hunnicutt Farm (2500 acres) is located in the west of York, NE. Its crops are mainly a corn/soybean rotation. LT Farm is close to Grant, NE (212 acres), and produces corn, soybean, dry bean, and wheat. Midplains Ag (720 acres of irrigated lands using center pivots) is located close to Elgin, NE, and its crops are mostly corn and soybean. The soil ranges from sandy loams in the west and northeast (LT and Midplains Ag Farms) to silt loams in the

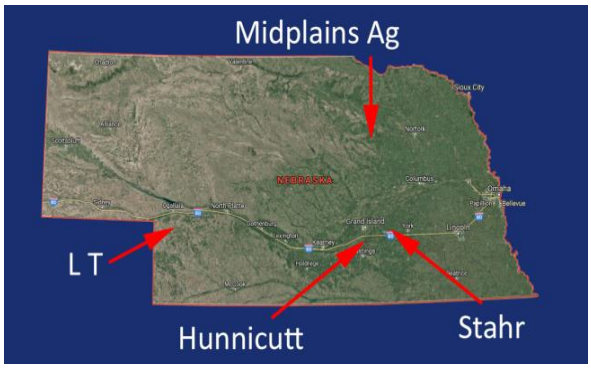


Fig 8. Locations of cooperating farms in Nebraska

southeast (Stahr and Hunnicutt Farms). The cooperating farms are chosen strategically to cover the climatic transition from the semi-arid western portion of the state to the humid eastern portion of the state.

e. EQIP eligible producer participation:

Most of the producers involved in this proposed project are eligible for EQIP. Ten farms (three from Hawaii (Oahu), three from Guam, and four from Nebraska) have sign up to collaborate on this project (please see letters of commitment attached). The Mahi Pono farm in Maui (HI) and Hirako farm in Big Island (HI) will also cooperate on this project. All of them will assist in conducting field trials on their farms.

Producers in Hawaii (Oahu): MA'O Organic Farm on Oahu provides vegetable to local consumers while also offering career direction and leadership training to Oahu's youth. MA'O is a historically underserved (Native Hawaiian) producer, and is eligible for EQIP. Aloun Farms, also EQIP eligible, on Oahu has expanded production to approximately 3000 acres. Its mission is to provide the people of Hawaii with the highest quality of fresh locally grown produce. Aloun Farms is also a strong supporter of community outreach through educational tours and collaboration with the future farmers. Corteva partners with local farmers and ranchers to help develop sustainable agricultural practices and increase their productivity. As a longstanding member of Hawaii's community, Corteva has a vested interest in empowering local farmers to success. Hence, it is very beneficial to have Corteva as our partner in this proposed project although it is not eligible for EQIP.

Producer in Hawaii (Maui): The Mahi Pono Farming Company on Maui is the biggest farm in the State of Hawaii. It provides vegetable to local consumers, while also offering career direction and leadership training to Maui's youth. Mahi Pono goals are to 1) feed, nourish, and sustain Hawaii Ohan with healthy produce, 2) build positive relationships with the community, 3) educate to create long-term career paths and job opportunities for Maui residents, 4) provide opportunities for the success of local farmers and related businesses. In addition to the Mahi Pono farm, three other farms on Maui (i.e., Benny Farm, Traje Farm, and Robert Ito Farm) also directly benefit from the proposed project because the PI of this proposal already installed weather stations in these farms and connected the stations to CropManage.

Producer in Hawaii (Big Island): The Hirako Farm (80 acres) is the most important vegetable growing farm in Waimea on Big Island. It primarily operates in the vegetables and melons business within the agricultural production. This farm has been operating for approximately 78 years. In addition to the Hirako farm, two other farms on Big Island (i.e., Robb Farm and Kawano Farm) also directly benefit from the proposed project because the PI of this proposal already installed weather stations in these farms and connected the stations to CropManage.

Producers on Guam: Bernard Watson (Watson's Farm), Mike Aguon (MEDA Farm), and Ernest Wusstigs (Island View Farms). All of them are historically underserved and EQIP eligible. Guam has bright prospects for agricultural sustainability, and these three farms have a major role for achieving that goal (https://www.postguam.com/news/local/guam-has-bright-prospects-for-agricultural-sustainability/article_b360982e-2115-11e8-a633-1bf036a2e359.html).

Producers in Nebraska: Ted Tietjen (LT Farm), Jerry Stahr (Stahr Farm), Brandon Hunnicutt (Hunnicutt Farm), Richard Uhrenholdt (Midplains Ag Farm). They are all EQIP eligible. Ted Tietjen is also the founding member of the Nebraska Water Balance Alliance (NEWBA) whose goal is to help conserve Nebraska's water resources for future generation. Tietjen and NEWBA have worked with irrigators to monitor daily water applications, consumptive water use, and power company energy use. Brandon Hunnicutt serves as a member of the Corn Board of the National Corn Growers Association. Midplains Ag partners with farmers in NE to assist develop sustainable agricultural practices and improve their productivity.

f. Project action plan and timeline:

Project Activities	2020			2021			2022		
Objective 1	Jan.-Apr.	May-Aug.	Sep.-Dec.	Jan.-Apr.	May-Aug.	Sep.-Dec.	Jan.-Apr.	May-Aug.	Sep.-Dec.
Calculate historical time-series of ET_o at the cooperating farms	**X**								
Use hybrid wavelet-ANNs to forecast ET_o and rainfall at the cooperating farms		**X**	**X**	**X**					
Store the ET_o and rainfall forecasts on servers, and incorporate them into CropManage					**X**				
Objective 2									
Test Advanced CropManage in HI (Oahu, Maui, and Big Island) and GU					**X**	**X**	**X**	**X**	
Use the ET_o and rainfall forecasts in NE to schedule irrigation water					**X**	**X**	**X**	**X**	
Objective 3									
Workshops, field days at experimental sites, and software demonstration activities		**X**			**X**			**X**	
Extension publication (all PIs)								**X**	
Scientific publications									**X**

g. Project management:

PI-Bateni is an Associate Professor of Computational Hydrology and Ecohydrology in the Department of Civil and Environmental Engineering and Water Resources Research Center (WRRC) at the University of Hawaii at Manoa (UHM). Dr. Bateni's expertise includes irrigation scheduling, and forecasting hydrological time-series, such as ET_o and rainfall via ANN approaches. Using the FAO-PM equation and climatic variables at the cooperative farms, he will calculate time-series of ET_o. He will also generate necessary MATLAB codes to forecast ET_o and rainfall at the cooperative farms by the hybrid wavelet-ANN approaches. The ET_o and rainfall forecasts for farms of HI (Oahu, Maui, and Big Island) and GU will be stored on a UHM-

based server. The ET_o and rainfall forecasts for farms of NE will be stored on a UNL-based server. Finally, the forecasts will be incorporated into the CropManage online irrigation tools by Dr. Bateni to assist growers and farm managers in HI and GU schedule irrigation water on a field-by-field basis. Dr. Bateni has successfully managed his federal grants from NRCS, NASA, USGS, and NOAA. He will oversee the overall progress of the project and submit progress reports.

Co-PI Deenik is a Professor/Extension Specialist of Soil Science and Irrigation in the Department of Tropical Plant and Soil Sciences at UHM. He will significantly contribute to implementing and testing the Advanced CropManage tool in farmlands of Hawaii. Dr. Deenik has effectively managed his federal funds from USDA-NIFA, USDA-NRCS, USDA-SARE, etc.

Co-PI Uyeda is an Oahu County Extension Agent in the Department of Tropical Plant and Soil Sciences at UHM. He will lead outreach and the organization of field day events and workshops on Oahu, Maui, and Big Island.

Co-PI El-Kadi is a Professor of Hydrology in the Department of Earth Sciences and WRRC at UHM, with many years of experience in addressing water problems facing Hawaii. He will help the PI develop the advanced irrigation tools and publicize this project in the U.S. PIA through his strong connections with various scientists and some media outlets.

Co-PI Golabi is a Professor of Soil and Environmental Sciences at the University of Guam. He has been working with farmers and growers in Guam since 2001. He will implement and test Advanced CropManage in farmlands of Guam, and he will lead outreach and the organization of field day events and workshops.

Co-PI Bamba is an Extension Agent in Guam. He will coordinate with Golabi and Bateni to prepare field day events and workshops in Guam and help farmers with the application of advanced CropManage irrigation tool.

Co-PI Neale is a Professor of Agricultural Engineering, and also Director of Research for the Daugherty Water for Food Global Institute (DWFI) at UNL. He will significantly contribute to implementing and testing the irrigation scheduling in farmlands of Nebraska. He will lead outreach and the organization of field day events and workshops in Nebraska. Neale has successfully managed many federal funds.

Co-PI Yang is an Associate Professor/Extension Specialist of Soil Science and Irrigation Scheduling in the Department of Agronomy and Horticulture at UNL. He is the developer of CornSoyWater irrigation tool. He will assist the PI to compare irrigation schedulings in the farmlands of Nebraska based on the ET_o and rainfall forecasts, and CornSoyWater.

Co-PI Safa is a Postdoctoral Associate in the DWFI at UNL. He is interested in estimation and forecast of ET_o and rainfall using ANN approaches. He will help the PI forecast ET_o and rainfall in the farmlands of Nebraska.

Gary Maunakea-Forth (Managing Director of MA'O Organic Farm), **Alec Sou** (General Manager of Aloun), **Alika Napier** (Manager of Coretva Agriscience), **Roger Hirako** (Owner of Hirako Farm), **Justin Texeira** (Managing Director of Mahi Pono Farm)**, Bernard Watson** (Executive Director of Watson's Farm), **Mike Aguon** (Executive Director of MEDA Farm), **Ernest Wusstig** (Island View Farm), **Brandon Hunnicut** (Owner of Hunnicutt Farms), **Jerry Stahr** (Owner of Stahr Farm), **Richard Uhrenholdt** (Owner of Midplains Ag), and **Ted Tietjen** (Owner of LT Farm) are partners of our proposed project. The abovementioned partners in HI and GU provide land, labor, and materials for field trials of Advanced CropManage. The partners in NE assist the PI and Co-PIs in NE to trial and demonstrate the use of forecasted ET_o and rainfall in irrigation scheduling (Please see their letters of commitment).

Dr. Maria Wall (Director of Daniel K. Inouye U.S. Pacific Basin Agricultural Research Center) is collaborator of our proposed project. This project has also the endorsement of **Travis Thomason** (Director of NRCS-PIA). Please see their letters of support.

The experience of the research team is complementary and will guarantee success of the project, especially the implementation phase, including extension (training, consultation, etc.). Residence of members of the research group in different States/Territories facilitates the progress of the project and assures its success. The PI has strong partnerships will all the Co-PIs. Through collaboration with Prof. Michael Cahn (developer of CropManage) and the Co-PIs of this project in HI and GU, he successfully modified CropManage for use in the US Pacific Islands. In Summer 2017, the PI was invited by the DWFI at UNL to work with Co-PIs Neale and Safa on forecasting ET_o in farmlands of Nebraska.

The PI has efficiently used Zoom to communicate with the Co-PIs in previous projects, and will continue to take advantage of Zoom in this project. The Information Technology Services (ITS) center at UH has provided leading edge computational, analysis, and storage capabilities, which allow efficient retrieval, management and processing of all of the datasets collected in this project. The ITS center also has provided the "File Drop" service, which allows the PI to share files and data with the Co-PIs easily.

h. Project deliverables/products:

1. "Reference evapotranspiration (ET_o) and rainfall (R) forecasts respectively for 7 and 3 days ahead at the collaborating farmlands" will be generated in this project. We will collaborate with NRCS to upload these science data on its website. To increase the exposure of ET_o and R forecasts in the US PAI [Hawaii (Oahu, Maui, and Big Island), and Guam], and Nebraska, they will be posted respectively on the website of Water Resources Research Center (WRRC) at UHM and Daugherty Water for Food Institute (DWFI) at UNL.
2. ET_o and R forecasts in the farmlands of US PIA (Oahu, Maui, Big Island, and Guam) and NE will be saved on the UHM- and UNL-based servers, respectively.
3. Application Programming Interfaces (APIs) will be generated to pull out ET_o and R forecasts from the UHM server, and incorporate them into the CropManage web-based irrigation scheduling tool, ultimately developing the "Advanced CropManage" tool. The Advanced CropManage software will conserve water resources of Hawaii (Oahu, Maui, and Big Island), and Guam.
4. One weather station will be installed in the Island View Farm in Guam, and its weather data will be incorporated into Advanced CropManage. In addition, the crops and soil type of the Island View Farm will be added to Advanced CropManage. This allows Ernest Wusstig (owner of Island View Farm) to take advantage of Advanced CropManage.
5. Time-series of historical weather data (e.g., air temperature and humidity, wind speed, incoming solar radiation, and rainfall) and ET_o" at the investigated farmlands will be generated in this project. These science data will be added to the Weather Underground website (https://www.wunderground.com/). This will make the real-time weather data and ET_o to be easily available to the public.
6. Towards the end of the proposed project, we will have one extension article from each State/Territory, which summarizes findings in that State/Territory. Educational materials including extension publications, webpage materials, and educational videos will be available on the WRRC and DWFI websites.

i. Project evaluation:

In years 2 and 3 of the project, surveys will be conducted in workshops and field days at experimental sites to 1) recognize farmers who registered on the Advanced CropManage website to use these irrigation scheduling tools, and estimate acreage of their farmlands; 2) specify farmers' savings in dollars due to the reductions in their irrigation water, energy, labor, and fertilizer costs; 3) determine the seasons and crops for which farmers tend to make most use of Advanced CropManage; and 4) estimate the number of NRCS agents, extension agents, students, and urban gardeners that registered on the Advanced CropManage website. The web counters on the Advanced CropManage website allow the PI and Co-PIs to record the number of visitors of our advanced web-based smart irrigation scheduling tool, and the number of visitors that registered to use them.

To further evaluate the progress of our impacts, we will create survey questions that will allow us to assess the adoption rate of optimal irrigation scheduling through a transition index on a scale of 1-4:

1 = No transition (grower prior practices),
2 = Farmers are interested in learning about the advanced irrigation scheduling tools.
3 = Growers are eager to attend workshops and be an active part of this project.
4 = Growers irrigate their farms by using the advanced irrigation tools.

We will conduct the survey in Years 2 and 3 of the project. Assessing the transition index allows us to understand if farmers are willing to adopt the advanced irrigation tools in order to save water resources, and reduce their expenses.

j. Benefits or results expected and transferability:

This project will provide important achievements towards the ultimate goal of conserving valuable water resources in Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska through an advanced practical approach for irrigation scheduling. The expected outcomes and impacts include:

1. Significantly improving performance of a widely used web-based decision support tools (i.e., CropManage) for irrigation scheduling, and developing the so-called Advanced CropManage.
2. Empowering growers and extension faculty to make irrigation decisions/recommendations driven by an advanced field-validated model.
3. Increasing farmers' profitability and environmental stewardship through improved water use efficiency on intensive vegetation farms.
4. Increasing conservation of water resources of Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska.
5. Increasing resilience and sustainability of Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska agriculture in the face of a changing climate.
6. Implementing an outreach program to increase growers' awareness of an advanced weather-based irrigation scheduling that takes advantage of accurate ET_o and rainfall forecasts at their farms. The outreach program will consist of famer workshops (years 1-3), and field days (years 2-3). Annual workshops will be organized in each jurisdiction. In year 1, the workshops will focus on introducing the vital role of ET_o and rainfall forecasts in irrigation scheduling, and the components of web-based irrigation tools. In years 2 and 3, workshops will be devoted to disseminating and discussing the utility and performance of the advanced tools in the participating jurisdictions. Field days and software demonstration activities in years 2 and 3 will concentrate on the implementation phase of the advanced irrigation scheduling tools

with a focus on on-farm strip trials comparing smart irrigation using Advanced CropManage tool against famers' current practices. The workshops and field days will be conducted in Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska through close collaboration with the designated farmers, NRCS agents, and County Extension agents.

7. Sharing the outcomes of this project with on-going farmer education programs in Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska. The results of our proposed project will also be appeared in the News Articles published by the WRRC, U.S. Pacific Basin Agricultural Research Center, and DWFI.
8. Extending the results and benefits to other States/Territories via journal papers, bulletins, and conference meetings by using Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska as model systems. It is noteworthy that the PI has been in contact with the irrigation scheduling experts at different universities, and they all acknowledged the vital importance of accurate ET_o and rainfall forecasts at the farm level in improving irrigation scheduling. The PI will provide ANN-based MATLAB programming codes to irrigation scheduling experts upon requests.
9. Describing the use and benefits of the advanced irrigation scheduling software packages in layman terms to the public by preparing and uploading videos on YouTube. The will broaden public awareness and appreciation of the benefits of this project for the underserved US Pacific Islanders, and residents of NE.

All of the farmers and extension agents in Guam are historically underserved (Native Pacific Islanders). Also, the MA'O Farm in HI is owned and managed by Native Hawaiians. This project will directly benefit the historically underserved farmers in HI and GU by providing them advanced technologies that provide real-time data to enable better and faster water quantity decision. Hence, this project will embrace the priorities of CIG to benefit historically underserved producers through our outreach program.

We have received 10 letters of commitment from farmers in HI, GU, and NE for this proposal, which implies its great benefit for producers in NE, and historically underserved farmers in HI and GU. Our future goal is to continue partnership with NRCS state offices and Departments of Agriculture (DOA) in HI, GU, and NE to strengthen water resources conservation projects in these States/Territories beyond this project period.

k. Graphics: Not applicable.

l. References:

Ali, Z., Hussain, I., Faisal, M., Nazir, H. M., Hussain, T., Yousaf Shadm M., Shoukry, A. M., Gani, S. H. (2017), Forecasting drought using multilayer perceptron artificial neural network model, Advances in Meteorology, https://doi.org/10.1155/2017/5681308.

Allen, R. G., Pereira, L. S., Raes, D., Smith, M. (1998), Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56, FAO, Rome, 300.

Allen, R. G., Clemmends, A. J., Burt, C. M., Solomon, K., and O'Halloran, T. (2005), Prediction accuracy for project wide evapotranspiration using crop coefficients and reference evapotranspiration, Journal of Irrigation Drainage Engineering, 131(1), 24-36.

Allen, R. G., Pruitt, W. O., Wright, J. L., Howell, T. A, Ventura, F., Snyder, R., Itenfisu, D., Stedudo, P., Berengena, J., Yrisarry, J. B., Smith, M., Raes, D., Perrier, A., Alves, I., Walter, I., Elliot, R. (2006), A recommendation on standardized surface resistance for hourly calculation of reference ETo by the FAO 56 Penman-Monteith method, Agriculture Water Management, 81, 1–22.

Alves, W. B., Rolim, G. S., Aparecido, L. E. O. (2017), Reference evapotranspiration forecasting by artificial neural networks, Eng. Agric., 37, 1116-1125.

Bachour, R., Maslova, I., Ticlavilca, A. M., Walker, W. R., and McKee, M. (2015), Wavelet-multivariate relevance vector machine hybrid model for forecasting daily evapotranspiration. Stochastic Environmental Research and Risk Assessment, 30(1), 103-117.

Bateni, S. M., Borghei, S. M., and Jeng, D. S. (2007), Neural network and neuro-fuzzy assessments for scour depth around bridge piers, Engineering Applications of Artificial Intelligence, 20, 401-414.

Bateni, S. M., Afifi, A., Ek, M. (2019), Forecasting daily reference evapotranspiration using hybrid wavelet-neural network approaches, American Geophysical Union (AGU), San Francisco, CA.

Boussaada, Z., Curea, O., Remaci, A., Camblong, H., and Bellaaj, N. M. (2018), A nonlinear autoregressive exogeneous (NARS) neural network model for the prediction of the daily direct solar radiation, energies, 11, 620.

Cahn, M., Smith, R., and Hartz, T. K. (2013), CropManage: A web-based irrigation and nitrogen management tool, 2013 California Plant and Soil Conference Visalia, CA, 90-95.

Cai, J., and Mu, J., (2005), Estimation of daily reference evapotranspiration from weather forecast messages, ICID 21st European Conference 2005, Frankfurt and Slubice – Germany and Poland.

Cai, J., Liu,Y., Lei, T., and Pereira, L. (2007), Estimating reference evapotranspiration with the FAO Penman-Monteith equation using daily weather forecast message, Agricultural and Forest Meteorology, 145 (1-2), 22-35.

Cai, X., Hejazi, M. I., Wang, D. (2011), Value of probabilistic weather forecasts: Assessment by Real-Time Optimization of Irrigation Scheduling, Journal of Water Resources Planning and Management, 137 (5), 391- 403.

Chang, F.-J., Chang, L. C., Huang, C. W., Kao, I. F. (2016), Prediction of monthly regional groundwater levels though hybrid soft-computing techniques, Journal of Hydrology, 541, 965-976.

Chang, X., Wang, S., Gao, Z., Luo, Y., and Chen, H. (2019), Forecast of daily reference evapotranspiration using a modified Thornthwaite equation and temperature forecast, Irrigation and Drainage, 68(2), 297-317.

Chaovalit, P., Gangopadhyay, A., Karabatis, G., and Chen, Z. (2011), Discrete wavelet transform-based time series analysis and mining, ACM Computing Surveys (CSUR), 43(2), 6.

Charaniya, N. A., and Dudul, S. V. (2013), Design of neural network models for daily rainfall prediction, International Journal of Computer Applications, 61(14).

Chou, C. M., and Wang, R. Y. (2002), On-line estimation of unit hydrographs using the wavelet-based LMS algorithm, Hydrol. Sci, J. 47(5), 721-738.

Cobaner, M. (2013), Reference evapotranspiration based on Class A pan evaporation via wavelet regression technique. Irrigation Science, 31(2), 119-134.

Darji, M. P., Dabhi, V. K., and Prajapati, H. B. (2015), Rainfall forecasting using neural network: a survey, Proceedings of 2015 International Conference on Advances in Computer Engineering and Applications, Zhengzhou, China.

Devi, S. R., Arulmozhivarman, P., Venkatesh, C., Agarwal, P. (2016), Performance comparison of artificial neural network models for daily rainfall prediction, 13(5), 417-427.

Droogers, P., and Allen, R. G. (2002), Estimating reference evapotranspiration under inaccurate data conditions, Irrigation and Drainage Systems, 16(1), 33-45.

Garcia, M., Raes, D., Allen, R., and Herbas, C. (2004), Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano), Agricultural Forest and Meteorology, 125 (1-2), 67-82.

Gocic, M., Motamedi, S., Shamshirband, S., Petkovic, D., Ch, S., Hashim, R., and Arif, M. (2015), Soft computing approaches for forecasting reference evapotranspiration, Computers and Electronics in Agriculture, 113(C), 164-173.

Haylin, S. (1999), Neural networks: a comprehensive foundation, Prentice Hall International Inc, Hamilton, Ontario, Canada.

Hecht-Nielsen, R. (1989), Theory of the backpropagation neural network, In Proc. of the Int. Joint Conf. on Neural Networks, San Diego: SOS Printing, pages: 593-606.

Jabbari, A., and Bae, D.-H. (2018), Application of artificial neural networks for accuracy enhancements of real-time flood forecasting in the Imjin Basin, Water, 10, 1626.

Khan, Md. M. H., Muhammad, N. S., and El-Shafie, A. (2018), Wavelet-ANN versus ANN-Based Model for Hydrometeorological Drought Forecasting, Water, 10, 998.

Kisi, O. (2011a), Evapotranspiration modeling using wavelet regression model, Irrigation Science, 29, 241-252.

Kisi, O., (2011b), Wavelet regression model as an alternative to neural networks for river stage forecasting, Water Resources Management, 25, 579-600.

Koizumi, K. (1999), An objective method to modify numerical model forecasts with newly given weather data using an artificial neural network, Weather Forecast, 14, 109-118.

Kucuk, M., Kahaya, E., Cengiz, T. M., Karaca, M. (2009), North Atlantic oscillation influences on Turkish lake levels, Hydrology Process, 23(6), 893-906.

Labat, D. (2005), Recent advances in wavelet analyses: part 1. A review of concepts, Journal of Hydrology, 314 (1-4), 275-288.

Landeras, C., Ortiz-Barredo, A., Lopez, J. J. (2009), Forecasting weekly evapotranspiration with ARIMA and artificial neural network models, Journal of Irrigation Drainage Engineering, ASCE, 135(3), 323-334.

Londhe, S. N., and Narkhede, S. (2018), Forecasting stream flow using hybrid neuro-wavelet technique, ISH Journal of Hydraulic Engineering, 24(3), 275 – 284.

Lorite, I. J., Ramirez-Cuesta, J. M., Cruz-Blanco, M., and Santos, C. (2015), Using weather forecast data for irrigation scheduling under semi-arid conditions, Irrigation Science, 33, 411-427.

Luk, K. C., Ball, J. E., and Sharma, A. (2001), An application of artificial neural networks for rainfall forecasting, Mathematical and Computer Modeling, 33, 683-693.

Luo, Y., Seydou, T., Lyu, X., Wang, W. , Wang, Y., Xie, Y., Jiao, X., and Fipps, G. (2015), Medium range daily reference evapotranspiration forecasting by using ANN and public weather forecasts, Water Resources Management, 29(10). DOI: 10.1007/s11269-015-1033-8.

Manikumari, N., Murugappan, A., and Vinodhini, G. (2017), Time series forecasting of daily reference evapotranspiration by neural network ensemble learning for irrigation system, IOP Conf. Series: Earth and Environmental Science, 80, 012069.

Mishra, A., Siderius, C., Aberson, K., van der Ploeg, M., and Froebrich, J. (2013), Short-term rainfall forecasts as a soft adaptation to climate change in irrigation management in North-East India, Agricultural Water Management, 127, 97-106.

Mohammadpour, R., Asaie, Z., Shojaeian, M. R., and Sadeghzadeh, M. (2018), A hybrid of ANN and CLA to predict rainfall, Arabian Journal of Geoscience, 11, 553.

Monira, S. S., Faisal, Z. M., and Hirose, H., (2010), Comparison of artificially intelligent methods in short term rainfall forecast, 13th International Conference on Computer and Information Technology (ICCIT), DOI: 10.1109/ICCITECHN.2010.5723826.

Moreno, J. J. M., Palmer Pol, A., and Munoz Gracia, P. (2011), Artificial neural networks applied to forecasting time series, Psicothema, 23(2), 322-329.

Nanda, T., Sahoo, B., Beria, H., and Chatterjee, C. (2016), A wavelet-based non-linear autoregressive with exogenous inputs (WNARX) dynamic neural network model for real-time flood forecasting using satellite-based rainfall products, Journal of Hydrology, 539, 57-73.

Nayak, D. R., Mahapatra, A., Mishra, P., (2013), A survey on rainfall prediction using artificial neural network, International Journal of Computer Applications, 72(16).

Nourani, V., Baghanam, A. H., Adamowski, J., and Kisi, O. (2014a), Applications of hybrid wavelet-Artificial Intelligence models in hydrology: A review, Journal of Hydrology, 514, 358-377.

Nourani V, Baghanam AH, Yahyavi Rahimi A, et al. (2014b), Evaluation of wavelet-based de-noising approach in hydrological models linked to artificial neural networks. Computational Intelligence Techniques in Earth and Environmental Sciences, Springer Dordrecht Heidelberg New York London, 209–241.

Nury, A. H., Hasan, K., and Bin Alam, Md. J. (2017), Comparative study of wavelet-ARIMA and wavelet-ANN models for temperature time series data in northern Bangladesh, Journal of King Saud University – Science, 29 (1), 47-61.

Palmer, C., Osborne, H., Krone-Davis, P., Melton, F., and Hobbins, M., (2013), National Weather Service – Forecast Reference Evapotranspiration (FRET), American Meteorology Society, Austin, Texas.

Partal, T. (2009), Modelling evapotranspiration using discrete wavelet transform and neural networks, Hydrological Processes, 23(25), 3545–3555.

Perera, K. C., Westerm A. W., Nawarathna, B., and George, B. (2014), Forecasting daily reference evapotranspiration for Australia using numerical weather prediction outputs, Agricultural and Forest Meteorology, 194, 50-63.

Rani, B. K., and Govardhan (2014), Optimal kernel and wavelet coefficients to support vector regression model and wavelet neural network for time series rainfall prediction, International Journal of Applied Evolutionary Computation, 5(4), DOI: 10.4018/IJAEC.2014100101

Rumelhart, D. E., Hinton, G. E., and Williams, R. J., (1986), Learning internal representation by error propagation, Parallel Distributed Processing, MIT Press, Cambridge, MA, pp. 318-362.

Sachin, D. K., Ramana, R. V., and Jeyakanthan, V. S., (2018), Improved wavelet neural network modeling of daily rainfall forecast, International Journal of advance Research in Science and Engineering, 7(2), ISSN: 2319-8354.

Sheremetov, L., Cosultchi, A., Martinez-Munoz, J., Gonzalez-Sanchez, A., and Jimenez-Aquino, M. A. (2015), Data-driven forecasting of naturally fractured reservoirs based on nonlinear autoregressive neural networks with exogenous input, Journal of Petroleum Science and Engineering, 124, 106-119.

Subramanian, R., Venkatesh, C., Agarwal, P., and Pachiyappan, A., (2014), Daily rainfall forecasting using artificial neural networks for early warning of landslides, 2014 International Conference on Advances in Computing, Communications and Informatics (ICACCI), DOI: 10.1109/ICACCI.2014.6968566.

Sumi, S. M., Zaman, M. F., and Hirose, H., (2012), A rainfall forecasting method using machine learning models and its applications to the fukuoka city case, International Journal of Applied Mathematics Computing Science, 22(4), 841-854.

Tahir, S. A. (1998), Estimating potential evaporation using artificial neural network. The ICID 10th Afro-Asian Conference, Bali, Water and Land Resources Development and Management for Sustainable Use, p. 2.

Temesgen, B., Eching, S., Davidoff, B., and Frame, K. (2005), Comparison of some reference evapotranspiration equation for California, Journal of Irrigation Drainage Engineering, 131(1), 73-84.

Tian, Y., Xu, Y.-P., Yang, Z., Wang, G., and Zhu, Q. (2018), Integration of a parsimonious hydrological model with recurrent neural networks for improves streamflow forecasting, Water, 10(11), 1655.

Tiwari, M. K., and Chatterjee, C. (2010), Development of an accurate and reliable hourly flood forecasting model using wavelet-bootstrap-ANN (WBANN) hybrid approach, Journal of Hydrology, 394, 458-470.

Toth, E., Montanari, A., and Brath, A. (2000), Comparison of short-term rainfall prediction model for real-time flood forecasting, Journal of Hydrology, 239, 132-147.

Trajkovic, S., Todorovic, B., and Stankovic, M., (2003), Forecasting of reference evapotranspiration by artificial neural networks, Journal of Irrigation Drainage Engineering, 129 (6), 454–457.

Traore, S., Luo, Y., and Fipps, G. (2016), Deployment of artificial neural network for short-term forecasting of evapotranspiration using public weather forecast restricted messages, Agriculture Water Management, 163(C), 363-379.

UN-Water (2006), Coping with Water Scarcity, A Strategic Issue and Priority for System-Wide Action, UN-Water Thematic Initiatives.

UNEP (2007), Global Environment Outlook (GEO-4), United Nations Environment Programme Nairobi, Kenya.

Unnikrishnan, P., and Jothiprakash, V. (2017), Data-driven multi-time-step ahead daily rainfall forecasting using singular spectrum analysis-based data pre-processing, Journal of Hydroinformatics, 20(3), 645-667.

Uysal, G., and Sorman, U. A. (2017), Monthly streamflow estimation using wavelet-artificial neural network model: A case study on Camlidere dam basin, Turkey, Precedia Computer Science, 120, 237-244.

Vaz, A. G. R., Elsinga, B., van Sark, W. G. J. H. M., and Brito, M. C. (2016), An artificial neural network to assess the impact of neighboring photovoltaic systems in power forecasting in Utrecht, the Netherlands, Renewable Energy, 85, 631 – 641.

Wang, W. G., and Luo, Y. F. (2007), Wavelet network model for reference crop evapotranspiration forecasting. In: Wavelet analysis and pattern recognition (ICWAPR 07), 2, 751-755.

Wang, D., and Cai, X. (2009). Irrigation scheduling - Role of weather forecasting and farmers' behavior, Journal of Water Resources Planning and Management, 135(5), 364-372. https://doi.org/10.1061/(ASCE)0733-9496(2009)135:5(364)

Detailed Budget Narrative:

A. PERSONNEL: Total $411,978

A.1. PI (Bateni) Summer Overload: **Total $73,674**

The PI receives a regular 9-month salary from the University of Hawaii and is allowed to receive summer overload up to 3 months each year. Dr. Bateni (PI) will work full time on the proposed project during each summer and also mentors the field technician, postdoc, and graduate students. He requests 2 months' compensation for the project during summer of Year 1, 2, and 3. The salary numbers quoted are based on this pay rate. In addition, a 2.12% fringe benefit is required by UH for faculty working on projects in the summer.

A.2. One Field Technician in Hawaii: **Total $90,000**

In Year 2 and 3, a field technician is required to conduct field demonstration trials of the Advanced CropManage in the designated farms of Oahu, Maui, and Big Island. The field technician will work with Bateni, Deenik, and Uyeda in Hawaii. We requested a salary of 45,000/yr for the field technician.

A.3. One Post-doctorate Fellow in Hawaii: **Total $200,400**

One Post-doctorate fellow is needed in Year 1-3 to involve in activities related to creating MATLAB codes for forecasting reference evapotranspiration and rainfall in the farmlands of Hawaii (Oahu, Maui, and Big Island), Guam, and Nebraska. The Post-doctorate fellow will also help the PI save the reference evapotranspiration and rainfall forecasts in the farmlands of Hawaii/Guam and Nebraska on the UHM- and UNL-based servers, respectively. Moreover, the Post-doctorate fellow will assist the PI to generate Application Programming Interfaces (API) codes for pulling out data from the UHM-based server and incorporating them into the "CropManage" irrigation tool, ultimately developing "Advanced CropManage". The postdoc's activities/trainees will be under Dr. Bateni's supervision. A stipend of 66,800/yr is requested for the postdoc in Year 1-3.

A.4. One Research Assistant in Hawaii: **Total 47,904**

One graduate student will work with the postdoc in Year 1 and 2. He/She will download historical time-series of daily micrometeorological variables (i.e., air temperature, humidity, incoming solar radiation, and wind speed) from weather stations in the farmlands of Hawaii, Guam, and Mariana Islands. He/She will use the downloaded micrometeorological variables and the Food and Agriculture Organization-Penman Monteith (FAO-PM) equation to calculate historical time-series of daily reference evapotranspiration. Finally, the graduate student will use the MATLAB codes generated by the postdoc to forecast reference evapotranspiration at each farm for the next 7 days. The graduate student will also download historical time-series of daily rainfall from weather stations in the farmlands of Hawaii, Guam, and Mariana Islands. He/She will use the MATLAB codes generated by the postdoc to forecast rainfall at each farm for the next 3 days.

The graduate students will work under Bateni's supervision. Their appointments will be half-time (20 hr/week) at the standard UH RA pay rate of $23,952 per 11 months for Years 1-2. The University of Hawaii at Manoa also requires a 14.09% fringe benefit for research assistants.

B. FRINGE BENEFIT: Total $64,555

Rate for Summer Overload is 2.12%, Field Technician is 62.49%, Post-doctorate Researcher is 0%, and Graduate Assistant is 14.09%.

C. TRAVEL: Total 31,410

Year 1 – $5,500

PI (Baten) will travel to Nebraska in Year 1 to work with Co-PI Neale on machine learning algorithms to forecast evapotranspiration and rainfall in Nebraksa.

For Nebraska: Airfare = $1000; car rental = $50/day × 2 days = $100; lodging = $40/day × 14 days = $560; per diem = $60/day × 14 days = $840 => $2,500

An estimate cost of $3000 domestic travel to mainland for New Awardee Orientation.

Year 2 – $14,870

PI (Baten) will travel to Nebraska in Year 2 to work with Co-PI Neale on machine learning algorithms to forecast evapotranspiration and rainfall in Nebraksa. PI (Bateni) will also travel to Guam, Maui, and Big Island in Year 2 to participate in one of the workshops and/or field days in these Islands. During these workshops/field days, the PI and Co-PIs will explain the critical role of reference evapotranspiration and rainfall forecasts in irrigation scheduling to farmers. In these workshops/field days, the PI will motivate farmers in Guam, Maui, and Big Island to adopt the Advanced CropManage irrigation tool.

For Nebraska: Airfare = $1000; car rental = $50/day × 2 days = $100; lodging = $40/day × 14 days = $560; per diem = $60/day × 14 days = $840 => Total = $2,500

For Guam: Airfare = $2,300; car rental = $60/day × 2 days = $120; lodging = $150/day × 2 days = $300; per diem = $60/day × 2 days = $120 => Total = $2,840

For Maui: Airfare = $200; car rental = $60/day × 2 day = $120; lodging = $150/day × 2 days = $300; per diem = $50/day × 2 days = $100 => Total = $720

For Big Island: Airfare = $250; car rental = $60/day × 2 day = $120; lodging = $150/day × 2 days = $300; per diem = $50/day × 2 days = $100 => Total = $770

The field technician will travel from Oahu to Maui and Big Island 12 times (once every month) in Year 2 to conduct field demonstration trials.

For Maui: Airfare = $200; car rental = $60/day × 1 day = $60; per diem = $50/day × 1 day = $50 => $310/trip. Total = $310/trip × 12 (trips) = $3,720.

For Big Island: Airfare = $250; car rental = $60/day × 1 day = $60; per diem = $50/day × 1 day = $50 => $360/trip. Total = $360/trip × 12 (trips) = $4,320.

Year 3 – $11,040
An estimate cost of $3000 domestic travel to mainland for NRCS designated events.

The field technician will travel from Oahu to Maui and Big Island 12 times in Year 3 to conduct field demonstration trials.

For Maui: Airfare = $200; car rental = $60/day × 1 day = $60; per diem = $50/day × 1 day = $50 => $310/trip. Total = $310/trip × 12 (trips) = $3,720.

For Big Island: Airfare = $250; car rental = $60/day × 1 day = $60; per diem = $50/day × 1 day = $50 => $360/trip. Total = $360/trip × 12 (trips) = $4,320.

D. EQUIPMENT: NA

E. SUPPLIES: Total $30,142
$2000 is requested in Year 1 to cover the cost for purchasing two computers and two external hard drives.

Data plan for each weather station costs $200 per year. Currently, nine weather stations at nine farms (three on Oahu, three on Maui, and three on Big Island) are connected to the CropManage. Three weather stations at three farms in Guam are connected to CropManage. Overall, there are 9+3=12 weather station. The annual budget of 12 × $200 = $2,400 is requested for data plan of the nine weather stations in Hawaii.

$2,000/year in Year 2 and 3 for irrigation supplies, seeds, and fertilizer will be needed to compensate collaborating farmers.

In Year 1, 5 flowmeters are required for the nine farms in Hawaii to measure irrigation water and send those measurements to the Advanced CropManage irrigation tool. Each flowmeter costs $700.

$500 will be used annually for printing educational materials.

$8,000 is requested in Year 1 for the Amazon Web Service and store (retrieve) the reference evapotranspiration and rainfall forecasts at the farmlands of Hawaii, Guam, and Marians Islands on (from) its cloud.

The budget of $470 in Year 2 and $472 in Year 3 will cover the cost of truck rental fees, gas, and mileage for use of personal vehicle at 0.485/mile. This budget is required for transportation among farmlands to conduct demonstration trials of the Advanced CropManage irrigation scheduling tool.

A contingency fee of $1000 is requested each year for replacing sensors on the weather stations in the farmlands of Oahu, Maui, and Big Island if they are damaged.

F. CONTRACTUAL: Total $40,000

2.5 months of software consultant time from Breyta Inc. to incorporate the reference evapotranspiration and rainfall forecasts into the CropManage. Breyta will also add new algorithms to CropManage to check the accuracy of reference evapotranspiration and rainfall forecasts. Finally, Breyta Inc. will add the new farm on Guam (i.e., Island View Farm) to the CropManage software in Year 1 (400 hours @ $100 per hour).

G. SUBCONTRACT: Total $212,406

G.1. Subcontract ($104,406) to University of Guam

Statement of work: This subcontract supports Co-PIs Mohammd Golabi (0.4 FTE) and Jesse Bamba (0.4 FTE) to extend the application of the Advanced CropManage tool to farmlands of Guam. In Year 2 and 3, a field technician will work with Co-PIs Golabi and Bamba to conduct field trials to validate the capability of Advanced CropManage tool in improving water use efficiency at the cooperating farms on Guam. During the workshops and/or field days, Co-PIs Golabi and Bamba will explain the benefits (e.g., saving water, energy, fertilizer, etc.) of using reference evapotranspiration and rainfall forecasts in irrigation scheduling to a wide network of farmers in Guam, and motivate them to adopt the Advanced CropManage.

The Co-PIs Golabi and Bamba already installed two weather stations in the MEDA and Watson's Farms on Guam. Micrometeorological data from these two weather stations were already incorporated to the CropManage irrigation tool, allowing the MEDA and Watson's farms to use CropManage. In this project, the Co-PIs Golabi and Bamba will additionally install one weather station in the Island View Farms. Thereafter, PI Bateni will work with the Breyta Inc. to add this weather station to Advanced CropManage.

Budget narrative: Please refer to page 5.

G. 2. Subcontract ($108,000) to University of Nebraska-Lincoln (UNL)

Statement of work: This subcontract supports Co-PIs Christopher Neale, Haishun Yang, and Babak Safa to forecast reference evapotranspiration and rainfall in farmlands of Nebraska. During the workshops and/or field days, Co-PIs Neale and Yang will explain the vital importance of reference evapotranspiration and rainfall forecasts in real-time decisions on irrigation scheduling to a wide network of farmers in Nebraska, and motivate them to adopt CornSoyWater. Co-PI Yang also will help the PI in saving the reference evapotranspiration and rainfall forecasts at farms of Nebraska on a UNL-based server.

Budget narrative: Please refer to page 6.

Cost share agreements from participating farmers totaled $228,000 are listed in the budget table. All cost share agreement with farmers are confirmed by their letters of commitment attached.

In addition, cost share commitment letter are attached for the following PIs: Bateni, El-Kadi, Golabi, Bamba, Neale, Yang, and Safa and total $707,581.

Total Matching commitment from all sources = $228,000 + $707,581 = $935,581

G. CONSTRUCTION: NA

H. OTHER. NA

I. TOTAL DIRECT CHARGES: $790,491 (total of all direct cost including subcontract to University of Guam (UOG) and University of Nebraska-Lincoln (UNL)).

J. TOTAL INDIRECT CHARGES: $109,509 (Preexist federally approved indirect cost rate of 26% for off campus sponsored activities is used for budget calculation. Please see attachment).

K. TOTALS (Direct and Indirect): **$900,000**

Budget Narrative for Subcontract to University of Guam

A. PERSONNEL: Total $60,000

A field technician is required to conduct field demonstration trials at the cooperating farms during years 2 and 3. We requested a salary of 40,000/yr for the field technician.

B. FRINGE BENEFIT: Total $6,906

A 11.51% fringe benefit is required by the University of Guam for field technicians.

C. TRAVEL: Total $2,000

$2000 is requested to attend one professional conference in year 3.

D. SUPPLIES: Total: $23,500

$1000 is requested to purchase a computer.

One HOBO RX3000 weather station will be installed at the Island View Farms. Each HOBO RX3000 weather station and its shipping to Guam cost $3,600. Two weather stations were already installed at the other two participating farms (i.e., MEDA Farm and Watson's Farm).

A contingency fee of $500 is requested each year for replacing sensors on the weather stations if they are damaged.

The annual budget of $3,000 (during years 2 and 3) for irrigation supplies, seeds, and fertilizer will be needed to compensate collaborating farmers.

Educational materials for workshops on the Advanced CropManage irrigation tool during years 2 and 3 ($1000 per year).

Three Flowmeters for the three participating farms are required. Each flowmeter costs $800.

The annual budget of $2000 (during years 2 and 3) will cover the cost of truck rental fees and gas. This budget is required for transportation among farmlands to conduct field demonstration trials.

E. TOTAL DIRECT CHARES: $92,406

F. TOTAL INDIRECT CHARGES: $12,000 (Preexist federally approved indirect cost rate of 20% for off campus sponsored activities is used for budget calculation)

G. TOTALS (Direct and Indirect): $104,406

Budget Narrative for Subcontract to University of Nebraska-Lincoln (UNL)

Personnel

Dr. Neale, PI, (effort = as matching funds 0.20 calendar months, in year 1, 0.10 calendar months in year 2, and 0.00 calendar months in year 3) will be responsible for the overall project management as well as experiment development, data analysis and reporting to the sponsor.

Dr. Yang, Co-I, (effort = as matching funds 0.5 calendar months each year) will be responsible for incorporating the improved forecasts reference evapotranspiration and rainfall into the current CornSoyWater, testing the new program in the field trials, and organizing workshops/field days to demonstrate the benefits of the Advanced CornSoyWater for improved irrigation management and crop water use efficiency.

Dr. Safa, Co-I, (effort = as matching funds 1.00 calendar months each year) will utilize artificial neural network (ANN) approaches to forecast ETo and rainfall at the cooperative farms NE, assessing the performance of the two wavelet-ANN approaches in the designated farms against daily ETo estimates from the FAO-PM equation and rainfall measurements, and help choose the best approach in each climatic condition.

TBD, Technician, (effort = 1.5 calendar months in year 1, 3.25 calendar months in year 2, and 2.86 calendar months in year 3) will be responsible for engaging new producers in the project, and working with new and participating farmers to conduct field trials, taking samples and measurements, data analysis, and coordinating workshops and field demonstrations.
A 2% cost of living increase has been applied to all salaries in years 2 and 3.

Benefits

Personnel benefits are estimated at the rates shown below. The actual cost of benefits for each person will be charged to the project.

Fringe Benefit Estimates				
Base Salary >$70,000	30%		Graduate Students	40%
Base Salary $40,000 - $70,000	40%		Part-Time Employees (less than 0.5 FTE)	8%
Base Salary <$40,000	50%		Undergraduate Students (Full Time)	0%

*GRA benefits include tuition remission estimated at 40% of salary plus health benefits estimates at $2,423 in year 1; $2,714 in year 2; and $3,040 in year 3.

Travel

The PI and one Co-PI will travel to a required sponsor meeting in year 1 in coordination with NRCS.

Domestic

Travel expenses to TBD estimated at $1,500 per person
Airfare: Lincoln, NE to TBD $700
Hotel (4 nights) $480
Meal Allowance $240
Ground Transportation $80
The PI or Co-I will travel to a conference in year 2 to share the project results.

Travel expenses to TBD estimated at $1,500 per person

Airfare: Lincoln, NE to TBD	$700
Hotel (4 nights)	$480
Meal Allowance	$240
Ground Transportation	$80

The PI and one Co-I will travel to a meeting in year 3 to share their project results and benefit from peer-to-peer technology transfer opportunities identified in coordination with the NRCS National Technical Contact for the project.

Travel expenses to TBD estimated at $1,500 per person

Airfare: Lincoln, NE to TBD	$700
Hotel (4 nights)	$480
Meal Allowance	$240
Ground Transportation	$80

Field visits

In years 2-3 a Field Technician and GRA will travel to work with participating farmers in order to conduct field trials, scout the crop, take soil and plant samples, and make on-site measurements. Estimated expenses for transportation, mileage, lodging and meals each year is $3,000.

4 producers x 2 trips/year x $375 per trip = $3,000.

Participant Support Costs

$5,000 is budgeted for 4 producers in years 2 & 3 as compensation for allowing access to their fields for this study, extra management care and possible yield loss.

Hardware and Supplies

Costs are estimated at $17,000 for three years to purchase soil moisture sensors, data loggers, telemetry service. Another $2,900 for three years is for consumable materials and supplies for the proposed experiments, workshop, and field demonstrations.

Publications

Costs of $1,000 per year in years 2 and 3 is budgeted to cover the cost of publishing project results.

Computer Services

$2,000 is requested each year to cover the user fees in the core facilities at the Holland Computing Center at UNL during the course of the project period.

Facilities & Administrative Cost
26% MTDC has been applied to the request portion of this budget.

Matching funds
A total of $108,068 is being offered as match:

- Dr. Christopher Neale, salary/benefits for 0.20 calendar months in year1; 0.10 calendar months in years 2 and 0.00 calendar months in 3, for a total of $7,756 in salary/benefits.
- Dr. Yang, salary/benefits for 0.50 calendar months each year 1, for a total of $21,400 in salary/benefits.
- Dr. Safa, salary/benefits for 1.00 calendar months each year 1, for a total of $20,313.
- Third-party cost share is being offered in the amount of $14,000 in the form of staff time and fringe benefits from Hunnicutt Farms ($4,000), Stahr Farms ($4,000), Tietjen Farms (2,000), and Uhrenholdt Farms ($4,000).

Additionally, to meet the full 1:1 match ratio, 30% TFFA has been included in the amount of $27,202, as well as $17,397 in unrecovered F&A.

TOTAL DIRECT CHARES: $87,778
TOTAL INDIRECT CHARGES: $20,222
TOTALS (Direct and Indirect): $108,000

Indirect Costs

All proposed budgets for extramurally funded awards must include the approved Facilities and Administrative (F&A) rate. F&A rates are indicated in the table below.

- Implementation of New FY18-FY23 F&A Agreement memo
- New F&A Rate Agreement Implementation FAQ (May 2019)
- Official Rate Agreement
- Prior Rate Agreement

Current F&A Rates (Updated May 24, 2019)

Rate	Campus	FY2018-FY2019	FY2020	FY2021	FY2022	FY2023	7/1/23 - Until Amended (Provisional)	Base[4]
Research, On-Campus[1]	All, except Kakaako	41.50%	43.00%	44.50%	45.00%	45.50%	45.50%	MTDC
Research, On Campus Kakaako [2]	Kakaako	54.00%	55.00%	55.50%	56.00%	56.50%	56.50%	MTDC
Research, Off-Campus[7]	All	24.00%	26.00%	26.00%	26.00%	26.00%	26.00%	MTDC
Instruction, On-Campus	All	40.00%	45.00%	45.00%	45.00%	45.00%	45.00%	MTDC
Instruction, Off-Campus[7]	All	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%	MTDC

Other Sponsored Activities, On-Campus[3, 8]	All	32.00%	36.50%	36.50%	36.50%	36.50%	36.50%	MTDC
Other Sponsored Activities, Off-Campus[3, 7]	All	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%	MTDC
Intergovernmental Personnel Act (IPA), Off-campus[6]	All	4.30%	1.80%	1.80%	1.80%	1.80%	1.80%	MTDC

1. Applies to research conducted predominantly on any of the ten campuses in the UH system. Includes the following sites: Agricultural Experiment Stations (Hawaii, Kauai, Maui, & Oahu); Hawaii Institute of Marine Biology (Coconut Island); Institute for Astronomy (Woodlawn; Hilo; 88” Telescope; Advanced Technology Research Center); Kewalo Marine Laboratory; Lyon Arboretum; Makai Research Pier; and Marine Expeditionary Center. Also includes research conducted predominantly in hospital space leased by UH entities such as the School of Medicine and not paid with grant funds at Kapiolani, Kuakini, Leahi, and Queen’s Medical Center.

2. Applies to research conducted predominantly at the Kakaako Campus (Ilalo Street). Includes research conducted predominantly in space leased by UH entities such as the School of Medicine or Cancer Center and not paid with grant funds in the Gold Bond Building (677 Ala Moana Boulevard).

3. Applies to projects that are not classified as research or training such as clinical trial agreements; evaluations of a sponsor's programs or operations; performances and exhibitions; workshops and conferences; and operations of health clinics or small business development centers. NOTE: Federally funded clinical trial agreements should use an MTDC cost base; non-federally funded clinical trial agreements should use a TDC (total direct cost) cost base.

4. Modified Total Direct Costs (MTDC) consists of all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel, and the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). MTDC excludes equipment, capital expenditures, charges for patient care, tuition remission, rental costs of off-site facilities, scholarships and fellowships, participant support costs, the portion of each subaward in excess of $25,000, and specialized service facility charges.

5. Specialized service facility (SSF) charges refer to charges from the following SSF's: IFA Job Order Services; IFA Mauna Kea Midlevel Facility; SOEST Computing Facility; SOEST Engineering Facility; and SOEST Ship Operations.

6. For Intergovernmental Personnel Act (IPA) agreements.

7. Off-campus rates shall apply to activities performed in facilities not owned by the University and to which either rent is directly allocated to the project(s), or activities are conducted in third party space rent free, the off-campus rate will apply. Actual costs will be apportioned between on-campus and off-campus components. Each portion will bear the appropriate rate according to location and purpose. In the case that one rate is required by the sponsor, if more than 50% of a project is performed off-campus the off-campus rate will apply.

UH has defined performance to mean work that is conducted by UH employees or employees hired through RCUH to work on the project.

8. Industry sponsored clinical trials should use the Other Sponsored Activities (OSA) rate. Federally funded clinical trials should use the applicable negotiated research F&A rate. The OSA

rate may be used as the minimum accepted rate for federally funded clinical trials if the federal sponsor is prohibited from using the negotiated research F&A rate.

Office of Research Services
Physical Address: 2425 Campus Road, Room 1, Honolulu, HI 96822-2247
Mailing Address: 2440 Campus Road, Box 368, Honolulu, HI 96822-2234

UNIVERSITY
OF GUAM

College of Natural and Applied Sciences

Unibetsedåt
GUAHAN

Office of the Dean/Director

February 10, 2020

Dr. Sayed Bateni
Department of Civil and Environmental Engineering &
Water Resources Research Center
University of Hawaii at Manoa
2540 Dole Street, Holmes 243
Honolulu, Hawaii 96822

Dear Dr. Bateni:

The University of Guam, College of Natural and Applied Sciences, is pleased to support your proposed project, "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture", being submitted for funding to the U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS).

If the USDA-NRCS funds this proposal, the University of Guam, College of Natural and Applied Sciences, as a subcontractor, is committed: 1) to extend the application of the Advanced CropManage irrigation tool to farmlands of Guam; 2) to conduct field demonstration trials to validate the capability of Advanced CropManage irrigation tool in improving water use efficiency at the cooperative farms in Guam; and, 3) to organize workshops and/or field days for a wide network of farmers in Guam and explain the benefits (e.g., saving water, energy, fertilizer, etc.) of using reference evapotranspiration and rainfall forecasts in irrigation scheduling, finally encouraging them to adopt the Advanced CropManage irrigation tool.

The value of subcontract is $104,406. The indirect rate at the University of Guam is 20%

The University of Guam, College of Natural and Applied Sciences agrees with the subcontract scope and budget.

Sincerely,

LEE S. YUDIN, Ph.D.
Dean/Director

UOG Station, Mangilao, Guam 96923
Telephone: (671) 735-2001/2 Fax: (671) 734-4600

January 21, 2020

Dr. Sayed Bateni
Department of Civil and Environmental Engineering & Water Resources Research Center
University of Hawaii at Manoa
2540 Dole Street, Holmes 243
Honolulu, HI, 96822
Phone: (808) 956-4249/Cell: (617) 913-9702/Email: smbateni@hawaii.edu

Dear Dr. Bateni:

The University of Nebraska-Lincoln, and Daugherty Water for Food Global Institute-University of Nebraska (DWFI) is pleased to support your proposed project "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture" being submitted for funding to the U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS).

Statement of Work: If the USDA-NRCS funds this proposal, DWFI is committed 1) to work with the PI (Dr. Bateni) to evaluate the reference evapotranspiration and rainfall forecasts at the farmlands of Nebraska and their future use in the CornSoyWater irrigation tool, 2) to conduct field demonstration trials to validate the capability of CornSoyWater irrigation tool for improving water use efficiency at the cooperative farms in Nebraska, and 3) to organize workshops and/or field days for a wide network of farmers in Nebraska and explain the benefits (e.g., saving water, energy, fertilizer, etc.) of using reference evapotranspiration and rainfall forecasts in irrigation scheduling. The value of subcontract is $ 108,000.

Description of cash contribution: The University of Nebraska-Lincoln is committing $108,068 in cash support to this project. Funds will be used for the following project budget elements 1) salary and benefits, and 2) unrecovered indirect costs. The indirect rate at the University of Nebraska-Lincoln is 48.5%.

5) Pledge Statement: The University of Nebraska-Lincoln pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as cash match to USDA NRCS CIG grant funds. The University of Nebraska-Lincoln and DWFI agrees with the subcontract scope and budget.

Sincerely,

Christopher Neale, Director of Research

Suzan G. Lund, Associate Director
Office of Sponsored Programs

UNIVERSITY of HAWAI'I® MĀNOA

College of Engineering
Civil Engineering

Febraury 6, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen:

This letter commits the University of Hawaii, College of Engineering to designate up to 30% of Dr. Sayed Bateni's time in each year of the project entitled "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture" to cover, in part, the 1:1 cost sharing requirement for the National Conservation Innovation Grants (CIG) Program. Fringe benefit for Dr. Bateni from the University of Hawaii at Manoa is 62.49%. The estimted value of this in-kind contribution is therefore $153,139.00.

The Principal Investigator (PI) of this three year project (2020-2023) is Dr. Sayed Bateni from the University of Hawaii at Manoa.

Sincerely,

Panos Prevedorous
Chair, Department of Civi and Environmental Engineering

Brennon Morioka
Dean, College of Engineering

2540 Dole Street, Holmes Hall 383
Honolulu Hawaii, 96822

UNIVERSITY of HAWAI'I MĀNOA

Water Resources Research Center

July 11, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen:

Dr. Aly El-Kadi is jointly appointed with the Department of Earth Sciences and the Water Resources Reserach Center, University of Hawaii at Manoa, at 50% each. This letter commits the two units to designate up to 30% of Dr. El-Kadi's time in each year of the project entitled "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture" to cover, in part, the 1:1 cost sharing requirement for the National Conservation Innovation Grants (CIG) Program. Fringe benefit for Dr. El-Kadi from the University of Hawaii at Manoa is 62.49%. The estimted value of this in-kind contribution is therefore $79,443.96 per year (a total of $238,331.88 for three years.)

The Principal Investigator (PI) of this three year project (2020-2023) is Dr. Sayed Bateni from the University of Hawaii at Manoa.

Sincerely,

Paul Wessel, Professor and Chair
Department of Earth Sciences

Darren Lerner, Interim Director
Water Resources Reserach Center

2540 Dole Street, Holmes Hall 283
Honolulu Hawaii, 96822

UNIVERSITY
OF GUAM

College of Natural and Applied Sciences

Unibetsedåt
GUAHAN

Office of the Dean/Director

February 11, 2020

Mr. Kari Cohen, Director
Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250

Dear Mr. Cohen:

This letter commits the University of Guam, Western Pacific Tropical Research Center to designate up to 30% of Dr. Mohammad Golabi's time in each year of the project entitled, "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture", to cover in part, the 1:1 cost-sharing requirement for the National Conservation Innovation Grants (CIG) Program. Fringe benefit for Dr. Golabi from the University of Guam is 29.6%. The estimated value of this in-kind contribution is $144,778.00.

The Principal Investigator (PI) of this three-year project (2020-2023) is Dr. Sayed Bateni from the University of Hawaii at Manoa.

Sincerely,

Lee S. Yudin, Ph.D.
Dean/Director

cc: Christine Visosky

UOG Station, Mangilao, Guam 96923
Telephone: (671) 735-2001/2 Fax: (671) 734-4600

UNIVERSITY
OF GUAM

College of Natural and Applied Sciences

Unibetsedåt
GUAHAN

Office of the Dean/Director

February 11, 2020

Mr. Kari Cohen, Director
Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250

Dear Mr. Cohen:

This letter commits the University of Guam, Western Pacific Tropical Research Center to designate up to 30% of Jesse Bamba's time in each year of the project entitled, "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture", to cover in part, the 1:1 cost-sharing requirement for the National Conservation Innovation Grants (CIG) Program. Fringe benefit for Jesse Bamba from the University of Guam is 29.6%. The estimated value of this in-kind contribution is $63,265.00.

The Principal Investigator (PI) of this three-year project (2020-2023) is Dr. Sayed Bateni from the University of Hawaii at Manoa.

Sincerely,

Lee S. Yudin, Ph.D.
Dean/Director

cc: Christine Visosky

UOG Station, Mangilao, Guam 96923
Telephone: (671) 735-2001/2 Fax: (671) 734-4600

List of Letters of Commitment

1) **MA'O Organic Farms (Hawaii)**, PO Box 441, Waianae, HI, 96792, Phone: 808 696 5569. MA`O will contribute labor, materials, and land to assist with this project at an estimate value of $10,000 per year over the 3 years of the project duration (in-kind commitment).

2) **Aloun Farm (Hawaii)**, 91-1440 Farrington Hwy, Kapolei, HI, 96707, Phone: 808 677 9412. Aloun Farm will contribute labor, materials, and land to assist with this project at an estimated value of $20,000 per year over the 3 years of the project duration (in-kind commitment).

3) **Corteva Agriscience (Hawaii)**, Waialua Parent Seed, 67-172 Farrington Hwy, PO Box 520, Waialua, HI, 96791. Corteva Agriscience Farm will provide labor and materials, and allocate some areas of its farm for our field measurements at an estimated value of $10,000 per year over the 3 years of the project duration (in-kind commitment).

4) **MEDA Farm (Guam)**, 3283 Hagatna, Guam 96932, Phone: 671 482 1753. MEDA Farm will contribute labor, materials, and land to assist with this project at an estimated value of $5,000 per year over the 3 years of the project duration (in-kind commitment).

5) **Watson's Farm (Guam)**, PO Box 20487, GMF 96921, Phone: 671 687 2139. MEDA Farm will contribute labor, materials, and land to assist with this project at an estimated value of $5,000 per year over the 3 years of the project duration (in-kind commitment).

6) **Island View Farms (Guam),** PO Box 20876, GMF 9692, Phone: 617 483 5699. Island View Farms will contribute labor, materials, and land to assist with this project at an estimated value of $5,000 per year over the 3 years of the project duration (in-kind commitment).

7) **Hunnicutt Farms (Nebraska)**, 609 South G Road, Giltner, NE, 68841, Phone: 402 – 604 - 9199. Hunnicutt Farms will contribute labor, materials, and land to assist with this project at an estimated value of $5,000 per year over the 3 years of the project duration (in-kind commitment).

8) **Stahr Farm (Nebraska)**, 1701 Road 14, York, NE, 68467. Stahr Farm will contribute labor, materials, and land to assist with this project at an estimated value of $5,000 per year over the 3 years of the project duration (in-kind commitment).

9) **Midplains Ag Services (Nebraska)**, 51556 836 Rd, Elgin, NE, 68636, Phone: 402-843-5342. Midplains Ag Services will contribute labor, materials, and land to assist with this project at an estimated value of $6,666.67 per year over the 3 years of the project duration (in-kind commitment).

10) **LT farm (Nebraska)**, 32726 Hwy 23, Grant, NE 69140, Phone number: 308 – 289 – 5740. LT farm will contribute labor, materials, and land to assist with this project at an estimated value of $4,333.33 per year over the 3 years of the project duration (in-kind commitment).

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** MA'O Organic Farms, PO Box 441, Waianae 96792, HI, 808 696 5569

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)

4) **Description of in-kind contribution**: MA'O Organic Farms is committing $30,000 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $ 15,000
- Fringe Benefits: $4,500
- Indirect costs: $10,500

5) **Pledge Statement:** The [MA`O Organic Famrs (a dba of the Wai`anae Community Re-development Corporation pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized
Representative: Gary Maunakea-Forth, Co-Founder/Managing Director

Signature of Applicant (PI) Organization Authorized
Representative:

S M Bateni 7/18/2019

91-1440 Farrington Hwy, Kapolei, HI 96707 Phone: (808) 677-9516 Fax: (808) 677-9412

MEMORANDUM
DATE: 7/15/19

In-Kind Contribution Commitment Letter
Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Aloun Farms, 91-1440 Farrington Hwy, Kapolei HI 96707

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)

4) **Description of in-kind contribution**: Aloun Farms is committing $60,000 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $20,000
- Fringe Benefits: $20,000
- Indirect costs: $20,000

5) **Pledge Statement:** Aloun Farms pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized Representative:

Alec Sou,
President & General Manager

Signature of Applicant (PI) Organization Authorized Representative

S M Bateni 7/18/2019

Waialua Parent Seed
67-172 Farrington Hwy.
PO Box 520
Waialua, HI 96791

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Corteva Agriscience, 67-172 Farrington Highway, Waialua HI 96791

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)

4) **Description of in-kind contribution**: Corteva Agriscience is committing $30,000 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $10,000
- Fringe Benefits: $10,000
- Indirect costs: $10,000

5) **Pledge Statement:** Corteva Agriscience pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Alika Napier Production Location Manager Coretva Agriscience:

7/15/19

Signature of Applicant (PI) Organization Authorized Representative:

S M Bateni
7/18/2019

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Bernard Watson, Watson's Farm, P. O. Box 20487, GMF 96921, Phone: 671-687-2139

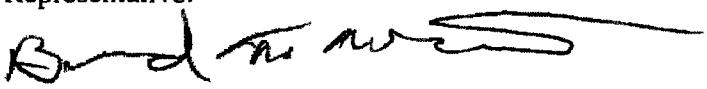
2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)
Co-PIs: Mohammad Golabi and Jesse Bamba (University of Guam)

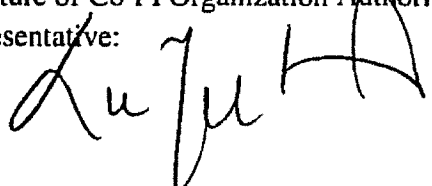
4) **Description of in-kind contribution**: The Watson's Farm is committing $15,000.0 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $15,000.0
- Fringe Benefits: $0.0
- Indirect costs: $0.0

5) **Pledge Statement:** The Watson's Farm pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

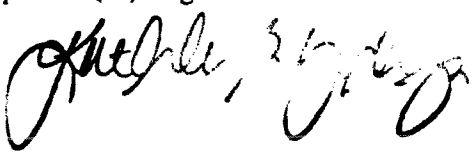
Signature of Donor Organization Authorized Representative:



Signature of Co-PI Organization Authorized Representative:



Signature of Applicant (PI) Organization Authorized Representative:



In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Mike Aguon, MEDA Farm, 3283 Hagatna, Guam, 96932, Phone: 671-482-1753

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)
Co-PIs: Mohammad Golabi and Jesse Bamba (University of Guam)

4) **Description of in-kind contribution**: The MEDA Farm is committing $15,000.0 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $15,000.0
- Fringe Benefits: $0.0
- Indirect costs: $0.0

5) **Pledge Statement:** The MEDA Farm pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized Representative:

7/5/19

Signature of Co-PI Organization Authorized Representative:

Signature of Applicant (PI) Organization Authorized Representative:

S M Bateni
7/18/2019

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Ernest Wusstig, Island View Farms, P. O. Box 20876, GMF 96921, Phone: 671-483-5699

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)
Co-PIs: Mohammad Golabi and Jesse Bamba (University of Guam)

4) **Description of in-kind contribution**: The Island View Farms is committing $15,000.0 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $15,000.0
- Fringe Benefits: $0.0
- Indirect costs: $0.0

5) **Pledge Statement:** The Island View Farms pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized Representative:

Signature of Co-PI Organization Authorized Representative:

Signature of Applicant (PI) Organization Authorized Representative:

S M Bateni 7/18/2019

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Brandon Hunnicutt, Hunnicutt Farms, 609 South G Road Giltner NE 68841 402.604.9199

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)
Co-PIs: Christopher Neale, Haishun Yang, and Babak Safa (University of Nebraska-Lincoln)

4) **Description of in-kind contribution**: Hunnicutt Farms is committing $15,000 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $15,000
- Fringe Benefits: $0
- Indirect costs: $0

5) **Pledge Statement:** Hunnicutt Farms pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized Representative:

Signature of Co-PIs Organization Authorized Representative:

7/19/2019

Signature of Applicant (PI) Organization Authorized Representative:

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Jerry Stahr, Stahr Farm, 1701 road 14, York, NE. 68467

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)
Co-PIs: Christopher Neale, Haishun Yang, and Babak Safa (University of Nebraska-Lincoln)

4) **Description of in-kind contribution**: Stahr Farm is committing [$15,000] in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:

- Personnel: $15,000
- Fringe Benefits: $0
- Indirect costs: $0

5) **Pledge Statement:** The [Stahr Farm] pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized Representative:

Jerry L. Stahr

Signature of Co-PIs Organization Authorized Representative:

Jeanne Wicks

7/19/2019

Signature of Applicant (PI) Organization Authorized Representative:

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization: Ted Tietjen**
   32726 Hwy 23, Grant, NE 69140
   308-289-5740 Cell; bigbyron@gpcom.net

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
   PI: Sayed Bateni (University of Hawaii at Manoa)
   Co-PIs: Christopher Neale, Haishun Yang, and Babak Safa (University of Nebraska-Lincoln)

4) **Description of in-kind contribution**: LT Farm is committing 200 hrs. at$65.00/hr.= $13,000 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $13,000
- Fringe Benefits: $0
- Indirect costs: $0

5) **Pledge Statement:** The LT Farm pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized Representative:

Ted Tietjen

Signature of Co-PIs Organization Authorized Representative:

Jeanne Wicks

S M Bateni 7/19/2019

Signature of Applicant (PI) Organization Authorized Representative:

In-Kind Contribution Commitment Letter

Pledge Agreement
Applicant In-Kind Contribution

1) **Donor Organization:** Richard Uhrenholdt, 51556 836 Rd, Elgin, NE 68636, Phone number: 402 – 843 – 5342.

2) **Applicant Organization:** University of Hawaii at Manoa

3) **Project Title:** *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*
PI: Sayed Bateni (University of Hawaii at Manoa)
Co-PIs: Christopher Neale, Haishun Yang, and Babak Safa (University of Nebraska-Lincoln)

4) **Description of in-kind contribution**: MIDPLAINS AG SERVICES is committing $20,000 in an in-kind contribution of staff time, fringe benefits, and indirect costs to this project:
- Personnel: $15,000
- Fringe Benefits: $3,000
- Indirect costs: $2,000

5) **Pledge Statement:** The MIDPLAINS AG SERVICES pledges to make this contribution over the USDA NRCS 2019 Conservation Innovation Grants funding period as an in-kind match to USDA NRCS CIG grant funds awarded to the University of Hawaii at Manoa for Innovative Conservation project, *Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*

Signature of Donor Organization Authorized Representative:

Signature of Co-PIs Organization Authorized Representative:

Jeanne Wicks

Signature of Applicant (PI) Organization Authorized Representative:

S M Bateni 7/19/2019

Assessment of Environmental Impacts:

Our field demonstration trials will be conducted on existing farmable land in commercial fields, which are not placed on wetlands and do not have protected endangered species. These farms also are not located in historical sites, and our activities will not impact cultural resources. Our field tests will be implemented by collaborating farmers using their current management practices [i.e., irrigation based on both CropManage using long-term reference evapotranspiration (rainfall) average as the reference evapotranspiration (rainfall) forecast, and growers' observation (in Hawaii and Guam); and irrigation based on both CornSoyWater utilizing NOAA reference evapotranspiration and rainfall forecasts, and growers' observation (in Nebraska)] and best management practices [i.e., irrigation based on Advanced CropManage (in Guam and Hawaii) and accurate reference evapotranspiration/rainfall forecasts (in Nebraska) as proposed in this project]. Our project collaborators cover a wide range of farm sizes including medium (e.g., MA'O Farm, Island View Farm, Watson's Farm, and MEDA Farm), and large (e.g., Corteva Agriscience Farm, Aloun Farm, Stahr Farm, and Hunnicutt Farm) farms.

During the project period, we will record detailed information on the costs of irrigation, pumping energy, labor, and fertilizers in cooperative commercial fields. Yield data will be converted to prevailing market prices. Collected data will then be used to calculate net farm profit by subtracting production costs from gross farm revenues. We will conduct strip trials in farms to compare water, energy, and fertilizer consumptions, and crop yields. We will finally compare the net benefits based on the growers' current irrigation management (mentioned above for each State/Territory) versus the optimal irrigation scheduling using the Advanced CropManage irrigation tool. The increase in the net benefit will enable us to quantify the role of reference evapotranspiration and rainfall forecasts in weather-based irrigation scheduling.

As indicated in Figure 1 and Table 1 in the proposal narrative, the accurate reference evapotranspiration and rainfall forecasts from this project significantly improve performance of the existing CropManage irrigation tool. The irrigation scheduling based on the accurate reference evapotranspiration and rainfall forecasts yield numerous positive environmental and social impacts such as 1) lowering farmers' cost of water and labor through fewer irrigation, 2) allowing farmers to schedule watering to minimize crop water stress and maximize yield, thereby conserving vital water resources, 3) reducing fertilizer costs and adverse impacts on groundwater by minimizing deep percolation (leaching), and 4) increasing farmers' profit by increasing crop yields and quality. This project also helps historically underserved producers in the Pacific Islands save costs by decreasing management and production expenses and preserve or even improve crop yields. Farmers can readily and inexpensively adopt Advanced CropManage irrigation tool by using their computers or smart phones.

Through collaborations with extension agents and specialists in Hawaii (Co-PIs Deenik and Uyeda), Guam (Co-PI Bamba), and Nebraska (Co-PI Yang), we will implement an outreach program to enhance farmer awareness and adoption of improved water management strategies. The outreach program will consist of field demonstrations, farmer workshops, training of farmers on how to use the online Advanced CropManage tool, and the development of multi-media extension materials.

Our project directly target historically underserved producers on Guam. In Hawaii, our outreach efforts will include the historically underserved native Hawaiian community of small farmers. The primary social impact of this project will be: 1) increasing growers' knowledge on the importance of utilizing accurate reference evapotranspiration and rainfall forecasts in irrigation scheduling for water conservation in agriculture, and 2) protecting critical water

resources increasingly threatened by the effects of climate change. We will quantify changes in farmers' attitudes towards irrigation management and water conservation by using pre- and post-project surveys. Our evaluation program will also assess the adoption rate of the Advanced CropManage irrigation tool based on a transition scale explained in the Project.

Declaration of previous CIG projects involvement and past performance

a. Previously received, and successfully managed NRCS CIG by PI

Project Tile: Real-time Optimization of Irrigation Scheduling for Farmlands in Hawaii, Guam, and American Samoa

CIG agreement number: 69-3A75-17-54

Award funding amount: $979,927

Year of Award: 2016

In the project listed above, the PI successfully modified the CropManage database system and associated algorithms to match site-specific weather, soil, and crop data for Hawaii, Guam, and American Samoa. All progress reports have been filed semiannually on time, and completed successfully within the time lines. In the above-listed project, the PI tested the modified CropManage tool in several farmlands of Hawaii and found it would conserve water resources. Currently, the PI is testing this online tool at other cooperating farms in Hawaii, Guam, and American Samoa. *It is found that the performance of CropManage is significantly dependent on the daily reference evapotranspiration and rainfall forecasts (the focus of the proposed project).* The results of the above project were presented in the 74th Soil and Water Conservation Society (SWCS) International Annual Conference (July 28-31, 2019 – Pittsburgh, Pennsylvania).

b. Five other federal assistant agreements received in the last 5 years.

1. Bateni, S. M. (PI), 2019-2022, Real-time Monitoring of Bridge Scour and Estimation of Scour Depth, DOT, $495,000.

2. Bateni, S. M (Co-PI), 2018-2020, Improving Snowpack Estimation through Advanced Snow Emissivity Modeling and Multivariate Data Assimilation, NASA, $456,418.

3. Bateni, S. M. (PI), 2018-2020, Characterizing the impact of Advection on Evapotranspiration in American Samoa, USGS, $51,584

4. Bateni, S. M. (PI), 2016-2018, Irrigation Management for Farmlands in American Samoa, USGS, $42,208.

5. Bateni, S. M. (PI), 2015-2016, A Novel Approach for Estimation of Evapotranspiration, USGS, $94,578

Projects 1, 2, and 3 are in progress, and progress reports are filed timely. Project 4 and 5 are complete and final reports were filed as planned. The PI managed to execute the project and expenditure as budgeted.

Declaration of Historically Underserved and veteran farmers or ranchers:

The PI (Dr. Sayed Bateni) and his Historically Underserved partners wish to compete in the set aside funding pool for Historically Underserved producers. Our proposed project will directly serve Historically Underserved producers in Guam and Mariana Islands, as well as Native Hawaiian producers.

List of Historically Underserved and Native Hawaiian producers

1. MA'O Organic Farm (Hawaii)
2. Watson's Farm (Guam)
3. MEDA Farm (Guam)
4. Island View Farms (Guam)

Their letters of self-certification are attached herein.

List of Community-Based Organization Comprised of or Representing Historically Underserved producers

1. Wai'anae Community Re-Development Corporation (Representing MA'O Farm).
2. Farmers' Cooperative Association of Guam (Representing Watson's Farm, MEDA Farm, and Island View Farm).

Their letters are attached herein.

MA`O ORGANIC FARMS

a non-profit `aina-based project of the Wai'anae Community Re-Development Corporation
P.O. Box 441, Wai'anae, Hawai'i 96792 • Tel/Fax. 808-696-5569
info@maoorganicfarms.org • www.maoorganicfarms.org

June 9, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen,

I qualify as a Historically Underserved (Native Hawaiians) producer and wish to compete in the set-aside funding pool.

Sincerely yours,

Gary Maunakea-Forth
Co-Founder/Managing Director

Mr. Bernard Watson; Watson's Farm; P. O. Box 20487; GMF 96921; Phone: 671-687-2139

July 3, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen,

I qualify as a Historically Underserved producer and wish to compete in the set-aside funding pool.

Sincerely yours,

Bernard Watson  Date 7-3-19

Mr. Mike Aguon, MEDA Farm, 3283 Hagatna, Guam, 96932, Phone: 671-482-1753

July 3, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen,

I qualify as a Historically Underserved producer and wish to compete in the set-aside funding pool.

Sincerely yours,

Mike Aguon MSD Date 7/5/19

Mr. Ernest Wusstig, Island View Farms, P. O. Box 20876, GMF 96921, Phone: 671-483-5699

July 3, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen,

I qualify as a Historically Underserved producer and wish to compete in the set-aside funding pool.

Sincerely yours,

Ernest Wusstig  Date 7/3/19

WAI'ANAE COMMUNITY RE-DEVELOPMENT CORPORATION
Mala 'Ai 'Opio (MA'O) Community Food Systems Initiative
P.O. Box 441, Wai'anae, Hawai'i 96792 ~ Office Tel/Fax. 808-696-5569
Email: info@maoorganicfarms.org, www.maoorganicfarms.org

Mr. Kari Cohen, Director
Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

June 4, 2019

Dear Mr. Cohen,

This is to confirm that the Wai'anae Community Re-Development Corporation (WCRC) represents, supports, and services the MA'O Organic Farm through the project "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture". MA'O Organic Farms (280-acres) is located in the arid Lualualei Valley and consists of a clay-rich Vertisol (Lualualei series, fine, smectitic, isohyperthermnic, Typic, Gypsytorrerts). Its crops are kale, lettuce, eggplant, carrot, beets, parsley, onion, lemon, and lime. **Through MA'O, WCRC strongly supports the project.**

For your information, the WCRC is a native controlled 501c3 nonprofit organization located in the moku of Wai'anae on O'ahu. WCRC created the MA'O Organic Farms, and the MA'O Community Food Systems Initiative to empower our youth, families, and community to work toward a just, healthy, self-reliant, sustainable and resilient food system for Hawaii. MA'O is the acronym for *mala 'ai 'opio*, which translates as 'the youth food garden', a movement to develop a comprehensive and living local food system-educating youth, fighting hunger, improving health and nutrition, growing the organic agriculture industry – to empower our community to move towards self-determination and self-sufficiently.

Please feel free to contact me if you have questions.

Sincerely yours,

Gary Maunakea-Forth
Co-Founder, Managing Director
WCRC, MA'O Organic Farms

Farmers' Cooperative Association of Guam
144 Santa Monica Ave. Dededo, Guam 96923
FCAG@gmail.com
671-989-3276

July 10, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen,

The "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture" proposed project is a needed tool not just for the Coop members but also for the whole agriculture industry on Guam. I write this letter to confirm that the Farmer's Cooperative Association of Guam has represented, supported, and serviced the following Historically Underserved producers.

1) Watson's farm (30 acre) is in northern Guam in the Village of Yigo. The soil on his farm is made of typical Guam northern cobbly clay loam, very shallow, well drained, nearly level to moderately sloping soils. His crops are bittermelon, banana, eggplant, cherry tomato and bell pepper.

2) MEDA farm (30 acre) is in the southern part of Guam in the village of Inarajan. MEDA has a mixture of northern and southern Guam soils. It sits on top of limestone but has deep pockets of southern soils (Pulantat clay) that are shallow, well drained, gently sloping to extremely steep slopes. His crops are eggplant, hot pepper, cucumber, cherry tomato, and watermelon.

3) Ernest Wusstigs farm (60 acre) is in northern Guam in the village of Dededo. The soils on his farm is made up of typical Guam northern soils which are very shallow, well drained, nearly level to moderately sloping. His main crops are sweet corn, pechay, cherry tomatoes, pole beans, watermelon, citrus and bananas.

The Farmer's Association of Guam strongly supports the above mentioned historically underserved producers in this project. Our organization over the years has provided help to past and present Coop members such as Watson's farm, Island View Farms and MEDA farms since 2007 and we will continue to do so with the hope of strengthening our local agriculture producers. We also look forward to future collaborations with our Guam farmers and the USDA /NRCS Conservation Innovation Team.

Farmers' Cooperative Association of Guam
144 Santa Monica Ave. Dededo, Guam 96923
FCAG@gmail.com
671-989-3276

Sincerely yours,

Thomas Tanaka Jr.

Thomas V. Tanaka Jr.
Digitally signed by Thomas V. Tanaka Jr.
DN: cn=Thomas V. Tanaka Jr., o=CATCON, ou, email=tomtanakajr@guam.net, c=US
Date: 2019.07.11 17:52:01 +10'00'

President chairman Farmers' Cooperative Association of Guam

List of Letters of Support

1) **Dr. Marisa Wall** (Director of Daniel K. Inouye U.S. Pacific Basin Agricultural Research Center), 64 Nowelo Street, Hilo, Hawaii 96720, Phone: 808 - 959 - 4343. The proposed project will support collaborative efforts between the University of Hawaii and the U.S. Pacific Basin Agricultural Research Center aimed at sustaining food production in the U.S. Pacific Basin in a changing climate. This project complements the mission of the Daniel K. Inouye U.S. Pacific Basin Agricultural Research Center to conduct research for the development of diverse, sustainable agricultural systems in support of Hawaii, the Pacific Basin, and U.S. agriculture. Dr. Wall will provide expertise in vegetable crop management, yield and quality assessments, and outreach to stakeholders.

2) **Travis L. Thomason** (Director of the NRCS-Pacific Islands Area), Prince Kuhio Federal Building, 300 Ala Moana Boulevard, Room 4-118, Honolulu, Hawaii. Mr. Thomason will provide any necessary data or tools for our project.

Letters of support from Dr. Wall and Mr. Thomason are attached herein.

United States Department of Agriculture

Research, Education, and Economics
Agricultural Research Service

July 19, 2019

Mr. Kari Cohen
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250
Phone: (202) 720-6037 / (202) 720-4265
Email: Kari.cohen@wdc.usda.gov

Dear Mr. Cohen,

I am writing to express my support of the proposed project "*Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture*" in Hawaii, Guam, and the Mariana Islands. The project is led by Dr. Sayed Bateni of the University of Hawaii at Manoa, with co-PIs from the University of Guam and Northern Marianas College. The collaborative project addresses the needs of underserved farmers in the U.S. Pacific Basin and provides practical tools to guide their irrigation management and water conservation efforts. Recently, Dr. Bateni modified CropManage software for use in Pacific islands. Growers in the U.S. Pacific Basin require current information management systems to meet the demands of the marketplace. Irrigation tools such as CropManage are rapidly becoming essential for growers, and require refinement as new information is available. This project will refine CropManage by incorporating accurate forecasts of daily reference evapotranspiration and rainfall into the system. This innovation will:

1) Significantly improve management guidance offered by CropManage to optimize water use efficiency and conserve water resources in Hawaii, Guam, and the Mariana Islands.
2) Reduce nitrogen leaching and ground water contamination.
3) Increase farmers' profit by enhancing crop yields and quality, maximizing fertilizer use efficiency, and optimize energy and labor use in irrigation.

This project is of high relevance and practical value, and successful implementation will benefit the diverse farmers in the U.S. Pacific Basin. The project complements the mission of the Daniel K. Inouye U.S. Pacific Basin Agricultural Research Center to conduct research for development of diverse, sustainable agricultural systems in support of Hawaii, the Pacific Basin, and U.S. agriculture.

Sincerely,

Marisa M. Wall

Marisa M. Wall, Ph.D.
Center Director

Daniel K. Inouye U.S. Pacific Basin Agricultural Research Center
64 Nowelo Street, Hilo, HI 96720
Voice 808.959.4343 Fax 808.959.5470 Cell 808.313.0620 E-mail marisa.wall@usda.gov

USDA

United States Department of Agriculture

July 2, 2019

Mr. Kari Cohen,
Director, Conservation Innovation Team
USDA Natural Resources Conservation Service
14th and Independence SW, Room 5239-S
Washington, DC 20250

Dear Mr. Cohen,

This is to confirm that the USDA-Natural Resources Conservation Service-Pacific Islands Area (NRCS-PIA) supports the project "Forecasting daily reference evapotranspiration and rainfall for water resources conservation and sustainable agriculture" in Hawaii, Guam, and Mariana Islands. This project is highly beneficial for PIA because it 1) conserves water resources, 2) lowers farmers' cost of water and labor through fewer irrigation events, 3) allows farmers to schedule watering to minimize crop water stress and maximize yields, 4) reduces fertilizer costs by minimizing deep percolation (leaching), and 5) increases farmers' profit by enhancing crop yields and quality.

This is a collaborative effort in the Pacific Islands Area for this project. We will provide any necessary data, review or tools that the sponsor needs.

Sincerely,

TRAVIS L. THOMASON
Director
Pacific Islands Area

Natural Resources Conservation Service
Pacific Islands Area
P.O. Box 50004 Rm. 4-118
Honolulu, HI 96850-0050
808-600-2911