SMART CONTROL OF RURAL RENEWABLE ENERGY RESOURCES

PROJECT REPORT
April 2018

1. THE SCORRES PROPOSAL

1.1 Summary of Approach to Smart Precision Irrigation

Heriot Watt University is the Lead for the SCORRES project, working in collaboration with Auraventi, Findhorn Foundation College, Scene Connect (UK), Auroville Consulting and the Centre for Scientific Research in Auroville. A main objective of SCORRES (Smart Control of Rural Renewable Energy & Storage) is the development of financially viable, robust, location specific irrigation systems for the Indian agricultural sector. The systems will be optimally sized to deliver 'right-time, right-volume' irrigation to farms, reducing water & energy consumption, increasing crop yields & food nutrient content and improving soil condition. The "smart" part of the system is ICT software which designs, forecasts and controls the crop-specific irrigation. A water balance model uses crop information combined with highly accurate weather forecasting to control solenoid valves, which activate the irrigation. The weather forecasting includes rain, solar radiation, wind and temperature feeding information to the water balance model. Self learning algorithms improve the irrigation forecasts to respond to crops need. The ICT system also optimises the solar PVs and batteries to energise solar pumps and irrigation delivery, when applicable.

The project develops clean technology that addresses the soil-water-energy-food nexus with reduced water and energy consumption of up to 80%. Indian agriculture is currently responsible for 22% and 85% of India's total electricity and water consumption respectively[1]. Recent federal initiatives to boost investment in the sector include £10.5bn over the period to 2022 to increase uptake of micro-irrigation systems and a replacement program to install 3.9 million solar water pumps over the same time frame.

Provision of water and energy are significant infrastructure challenges in India. Using subsidised electricity, farmers pump groundwater at will, drawing up more annually than China and America combined. A recent report states that "54% of India Faces High to Extremely High Water Stress" and almost 600 million people are at high risk of surface-water supply disruptions. In the Union Budget 2017-18, the Finance Minister announced an ambitious target of replacing 15% of all irrigation pumps with solar pumps[2]. The Union Budget also signaled an increased commitment to the National Bank for Agriculture and Rural Development (NABARD), with the budget allocation for micro-irrigation being increased from INR 20,000 Crore to INR 40,000 Crore (£4.7 billion). In June 2017, the Union Government launched Pradhan Mantri Krishi Sinchai Yojana (PMKSY). This scheme has a major objective of achieving convergence of investments in irrigation at the field level, expanding cultivable area under assured irrigation, improving on-farm water use efficiency to reduce wastage and enhancing the adoption of precision irrigation and other water-saving technologies ("more crop per drop"). Over 5 years, INR 50,000 Crore (£5.8 billion) from the central Budget will be utilised for PMKSY[3].

In summary, these Government initiatives will see a rapid increase in the deployment of solar pumps and micro-irrigation systems over the next 5 years. A key development need is reliable and optimally sized and controlled irrigation, preferably solar powered with intelligent local management of water and energy resources, allowing agricultural communities to prosper. The approach is low carbon with strong sustainability credentials. Improved soils sequester more carbon as do increased crop yields. The preferred energy is solar with storage batteries. Less direct benefits for the farming community are reduced stress on aquifers and contribution to higher electricity grid stability.

1.2 Buddha Garden

A field trial has been established in this 10-acre vegetable farm. This location was selected because the farm is research oriented, has some existing solar pumping with battery storage and is keen to tailor irrigation to particular crops. SCORRES has extended the solar-PV and electrical storage capacity of the farm and installed controls for the existing micro-irrigation equipment. Solenoid valves on water supplies enable accurate irrigation flows to the research vegetable beds. The function of the Pilot has been to schedule precision irrigation based on a Water Balance Model with Penman Monteith formulae as the basis, crop coefficients supplied by Anna University in Chennai and informed by accurate local weather forecasts through Auraventi. The latest version of Auraventi's software enables farmer interaction with the system, by providing the farmer with the ability to increase or reduce forecasted irrigation. Machine learning can then provide tailored irrigation controls based on the farmer interactions for future crop cycles.

1.3 Auroville Library

A field trial was developed in the library area of Auroville to provide supply-demand management of a PV array and attendant electrical load. This load comprised a library building that serviced the Auroville community, a water treatment facility that trested waste water from the library and 7 dimmable street lights on the street outside the library. The energy system comprises a PV array, a Li-ion battery energy system and attendant communications and controls. Systems were procured and installed during the first two quarters of the project and control systems instituted and trial monitoring proceeded during the second two quarters. The aim was to explore the nature of an energy system that would provide ride through capability for energy systems subject to significant outage risk.

1.4 Deliverables

The main deliverables are software and hardware providing precision irrigation, which:

- Delivers healthy abundant crops with high human nutritional value;
- Reduces the amount of water and energy used;
- Enables farmer intervention, adjusting irrigation through experience;
- Increases crop yields;
- Reduces farm labour through automation;
- Reduces compost additions because of less leaching of nutrients;
- Improves soil health as part of a whole ecological approach;
- Increases the opportunity for increased farm revenues and reduced costs.

2. KEY RESULTS AND FEATURES FROM BUDDHA GARDEN

2.1 BG Trials on okra, lettuce, rucola & long beans.

The trials involved three areas of the farm, each providing a research bed, with irrigation controlled by a solenoid valve and activated by the software through a site communication system. A manually irrigated bed was planted with the same crop at the same time. Comparisons were then made of crops between "electronic" and manual beds. The opportunity has been taken of using the same system in each of the three areas, with staggering of planting times. Water volume to the research beds was measured accurately with a non-intrusive ultrasonic meter. Water volume to the manually irrigated beds was determined by a combination of timing of known flows and electrical paddle wheel meters.

2.2 Description of the WBM

Irrigation scheduling using water balance modelling is a well-researched pathway that has been adopted globally. Commercial and open source software packages have been developed and are available (e.g. Cropwat developed by the FAO[1] is perhaps the most widely known - http://www.fao.org/land-water/databases-and-software/cropwat/en/). The modelling approach has been subject to standardised approaches that allow output to be compared between different trials, geographies and time periods. The water balance model outputs an irrigation schedule for a reference crop that varies based on the time period studied, the location, the soil type and the weather data used. This is then translated to a candidate crop using generic, crop specific coefficients. Typically, average climate data (wind speed, temperature, humidity and irradiance) is used, based on historical data for the candidate location. This approach carries risk in an Indian context where the actual weather conditions can vary considerably from historical averages. Accessing localised, actual data has generally not been possible either because of a lack of reliable weather stations or because of cost limitations in accessing available datasets. Similarly, generic crop coefficients can also introduce errors into computational processes as they may not be relevant for specific local conditions.

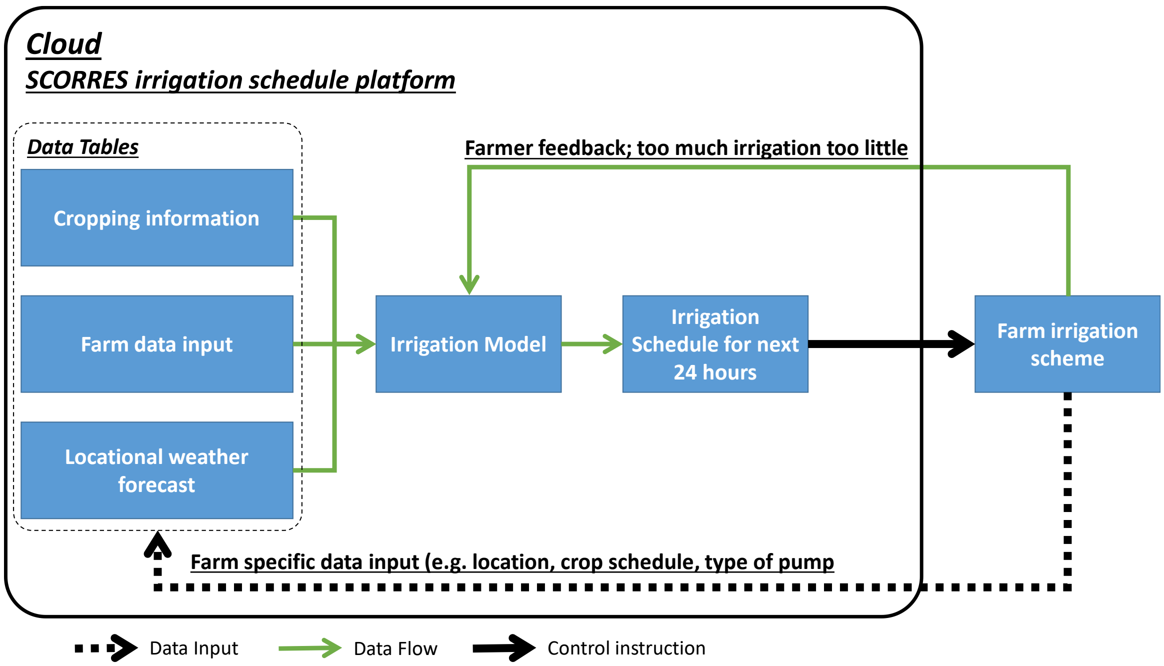
The SCORRES approach seeks to overcome these limitations by combining a) highly localised, accurate weather forecasting approach developed by Auraventi, b) a bespoke water balance modelling approach developed for this project based on the ASCE[2] standardised reference evapotranspiration equation and c) a farmer feedback feature that allows the farmer to tailor computational output to marry with their specific irrigation knowledge. A flowchart outlining the computational approach is shown in Figure 1. A machine learning environment is used that incorporates the farmer feedback and actual weather observations where available. Output from the model has been compared to published evapotranspiration data for Tamil Nadu and found to be equivalent.

[1] Food and Agricultural Organisation of the United Nations, http://www.fao.org/home/en/, accessed March 2018

[2] American Society of Civil Engineers

The output of the SCORRES approach is a dynamic, irrigation scheduling platform which is bespoke for the farm, tuned to the irrigation knowledge held by the farmer. This approach of developing systems with the farmer rather than imposing technology on the farmer is central to the overarching SCORRES approach.

Figure 1: Computational approach used by the SCORRES water balance approach



Status of the SCORRES WBM

The dynamic irrigation schedule platform has been converted into robust, commercialised code by the Auraventi team (see associated deliverable for more detail). This includes data schema requirements for the micro-controller and the user interface. The platform shadowed the lettuce crop grown using pre-determined schedules, grown in Jan/Feb 2018 to ensure that its output was credible. It is currently being used to create daily schedules for three long bean crops that are being grown in Buddha Garden. These are approximately one month into a 90 day crop cycle and water consumption of c50% of pre-determined and c80% of manual schedules has been achieved with no impact on vegetative growth.

The SCORRES team have been successful in securing funding beyond the Energy catalyst grant to extend the functionality of the platform. This will include research into predicting electricity outages and developing methods for managing multi-cropping irrigation scheduling.

3. KEY RESULTS AND FEATURES OF AUROVILLE LIBRARY

3.1 Solar Village concept

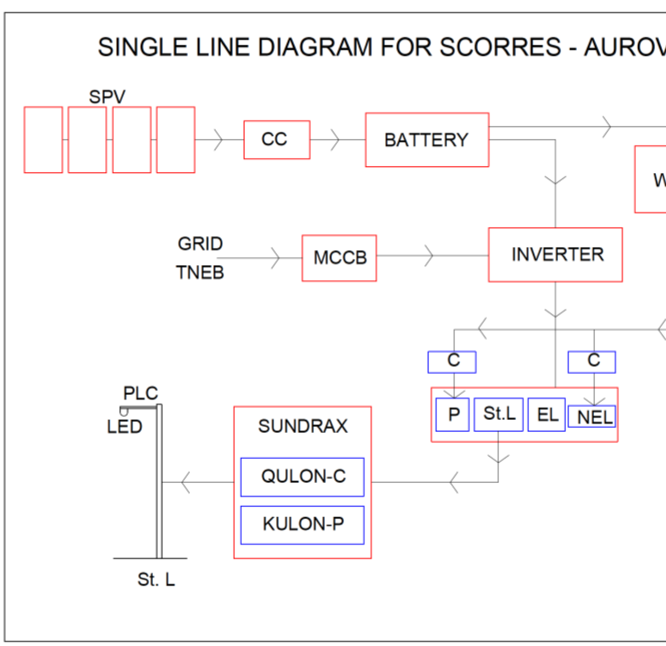
One of the two field trials on smart demand side response component including street light and water pumps was initially intended to take place at the Solar Village pilot project at Irumbai Village. Due to delays in the implementation of the Solar Village pilot project this SCORRES field trial had to be implemented at a different location. A public building, the Auroville Library, was identified for this purpose.

The Solar Village pilot project at Irumbai is a joint research project by Tamil Nadu Energy Development Agency and by the State Utility (TANGEDCO). The project aims at making the village a prosumer, the village will, on an annual basis, produce more electricity (from solar) than it consumes. All solar energy produced by the Solar Village will be exported to the grid and sold to the state utility. The solar energy generators will be connected to the village level electrical infrastructure. The village will receive a revenue share from the sale of electricity.

3.2 Demand side response

The Auroville Library, a public facility, is prominently located along the Auroville Crown Road. The electrical circuit of the Auroville Library was separated into two circuits; one electrical circuit for the essential load and one electrical circuit for the non-essential load of the building. This separation into two circuits is meant to support the supply demand side responsiveness of the library. 7 (nos) smart streetlights (dimmable, 25 W LED) were installed and added to the essential load. A Solar PV system of 1,2 kWp along with 5.2 kWh of lithium ion battery storage was installed. Using hybrid inverter with a grid export function and a battery charge controller the solar PV system is capable of exporting surplus energy once the battery is fully charged.

Figure 2 SCORRES Single Line Diagram - Auroville Library



INVERTER	MultiPlus 48/5000/70-100 230V VE.Bus
BATTERY	Panasonic 48V/2.6kWh Lithium battery (2 No.s)
SPV	Solar panel 315W (4 No.s)
CC (Charge Controller)	Bluesolar MPPT150/35
WATTMON	Wattmon Pro- Data logger and controller
QULON-C	Sundrax QULON-C QUL-C-EXT-203
KULON-P	Sundrax QULON Simpline QUL-P-EXT-PWR
PLC	Simpline Node QUL-PLC-T-PWM-XXX X
LED	25W with dimmable driver
Grid TNEB	Tamil Nadu Electricity Department
MCCB	Molded Case Circuit Breaker
P	Pump
St.L	Street Light
EL	Essential Load
NEL	Non Essential Load
C	Contactor

3.3 Automated control functions under SCORRES are:

- Streetlights On/Off based on forecast of sunset/sunrise
- Streetlights at 60% brightness for the first 30 min
- Dimming at 11:30 PM to 60 % brightness using power line communication;
- Non-essential load is switched off at 60% of battery charge
- 1,5 HP pump for waste water treatment is being automatically operated from 3:00 PM to 4:00 PM and 4:00 AM to 5:00 AM
- In the case of power outages and a lack electricity on the battery bank light output of street lights are be dimmed down further to a level that guarantees operation of the streetlights for the entire night.

3.4 Implications from lower electrical storage costs & future timing

In the case of future price drop for both solar PV and storage technology, a smart energy system equal or similar to the one tested at the Auroville Library will become a financially viable alternative, especially for the higher consumer tariff categories such as industrial, commercial and street lighting and water supply tariffs.

3.5 Acknowledgment:

From 24th to 25th January 2018 Auroville witnessed two days of power outage. The Auroville Library and the associated streetlights were the only public services in Auroville that were fully operational. This highlights the contribution that distributed generation in combination with storage and smart control system is able to make to a more resilient and robust community energy system.

Figure 3 Public Acknowledgement by Auroville Library. News & Notes Auroville from 16th March 2018

A message from the Library

The Auroville Library has been gifted two major development projects over the last few months.

A new hall has been built to expand the collection by an additional 4000-5000 books. This has been made possible thanks to SAIIER, Suhasini as the architect, and Vinayagam as the contractor. It is open since a few weeks.

As part of a UK sponsored research initiative Auroville Consulting installed a solar system at the Library, which is now running only on solar energy since the last eight months. The system supplies the energy demand for the building, the pump for the waste-water treatment, and seven street lights. Having a battery storage and the option to draw electricity from the grid, if and when required, the system has proven to be a guarantee for uninterrupted power supply. Despite regular power cuts in Auroville, recently even for two days, the Auroville Library and the street lights remained operational.

We would like to express our profound gratitude to everyone who has made these developments possible.

The Auroville Library

The Auroville Town Development Council recently commissioned 3 street light clusters that adapted the SCORRES approach. A total of 87 streetlights with solar PV, lithium-ion storage and smart control will be installed during May 2018.

4. DETAILED REPORTS

4.1 Crop Reports

Appendix 1 is a detailed description of the trials and the results. This is the main SCORRES report and covers the technology at this point. Highlights from this report are provided below.

- Crop yield improvement caused by SCORRES compared to the incumbent irrigation schedule approach used in the farm was found to be 15% and 22% for the okra and lettuce crops. This represented an increase of 43% and 203% compared to the Indian averages published for 2016 by FAO for okra and lettuce respectively.

- For lettuce crop, the water use efficiency was found to be 164m^3/T compared to 204.8 and 536.5m^3/T for the incumbent approach and Indian average respectively. The SCORRES approach produced lettuce with global average water use efficiency.

- The energy consumption of a 3 acre candidate farm that used the SCORRES approach was estimated to be between 3.5 and 6.3MWh depending on the extent of farmer feedback in modifying the dynamic irrigation schedule. This compares with an estimate of 13.1MWh for the incumbent irrigation approach.

- This resulted in CO_2 emissions of 2.8-5.1TCO_2 pa for the SCORRES approach compared to 10.7TCO_2 pa for the incumbent approach assuming a grid connected pump.

- The size of PV array that would be required to provide water pumping that would cover 90% of the year was also calculated and found to be 9kW for the incumbent approach and between 3 and 4kW for the SCORRES approach.

4.2 Measuring nutrition

At the start of the project, it was believed that a simple way of measuring the human nutritional value of crops might be found. Our initial approach was a Brix meter, which measures sugar content. However after consultation with a plant chemist in Auroville and the James Hutton Institute in Dundee, Scotland a report on measuring of nutrition was prepared by the project agronomist and is included as Appendix 2.

4.3 Soil and nutrient composition testing

The main objective of SCORRES was to develop a system to deliver an irrigation schedule to a number of different vegetable crops. As part of this system, our hypothesis was that a range of inputs to vegetable production (good compost, smart irrigation, temperature and sunshine) would have an influence on human nutrition. As such, we carried out a brief review of the literature to identify the primary drivers of good human nutrition in India and the nutrients, which should be measured in the vegetables in order to detect changes in composition at various stages of plant growth (please see report on Annex 2).

The findings of this research work showed that the primary way to measure horticultural plant quality was through a measurement of sweetness. This was not considered appropriate for the kind of vegetables in our trials (mainly green leafy vegetables), nor for the Indian context, where malnutrition remains a significant challenge, with stunting for children under 5 years around 39 per cent and anaemia among women at 48 per cent[3]. We consulted with experts from The James Hutton Institute in Scotland, who confirmed that the main nutrients to measure from a human health perspective are the minerals that tend to be deficient in humans, the four key ones being iron, zinc, calcium and magnesium. A protocol was then drawn up to outline the procedure for soil and crop nutrient testing of these nutrients for the second round of crops (see Annex 3). This protocol was continued in the 3rd cycle of crops.

Please refer to the Lettuce Crop Report (Annex 1) for the main results of the soil and nutrient tests.

Our recommendations for future nutrition and soils testing include the following:

- To continue to test the full range of elements in the soil test and the 4 elements identified in the nutrition test
- To carry out more comprehensive testing, with larger sample sizes for nutrition testing and more systematic (synchronized with nutrition testing) and regular soil sampling.
- To include testing of different parts of the crop, in addition to the main edible part, for instance the leaves and roots, to track the pattern of uptake of nutrients by the plants
- To carry out a statistical comparison of plant growth against nutrient uptake and soil fertility, to give a more complete picture of how the SCORRES system effects rate of plant growth and maturation, nutritional quality of edible parts and the relationship with soil fertility.
- To establish a working relationship with a qualified research institution in India, such as the Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore, to design and analyze data collection.

4.4 Methodology – Soil and nutrient composition testing

Nutrition and soil testing was carried out in each of the 3 arrays where the SCORRES irrigation system was being trialed. See Figure 1, below, for the testing schedule.

All soil and nutrition samples were taken to Environmental Monitoring Service Laboratory, Auroville for testing. The laboratory has expertise in water, soil and food analysis since 1993.

a) **Soil testing.** Soil samples were collected around two main periods: at the time of transplanting the new crop and after the crop had been harvested. Not all beds were sampled at each period, due to budget constraints. Where samples were taken, they were obtained from 3 parts of each bed – the front, middle and back. The soil from each part was then mixed together so that one sample for each bed was submitted to the laboratory. Initially, the first soil test was conducted for 7 elements (pH, Electrical Conductivity, Organic Carbon, Organic Matter, available

3 Sonne, L. (2017) Policy Environment for Food, Agriculture and Nutrition in India: Taking Stock and Looking Forward. LANSA Working Paper Series Volume 2017 No 15. Leveraging Agriculture for Nutrition in South Asia

nitrogen, phosphorous and potassium). The test was subsequently expanded to include available calcium, magnesium, zinc, copper, iron, manganese and boron. The methodology utilized by the laboratory to test each element is listed in the table below (Table 1).

Table 1. EMS Laboratory method of analysis – Soil test

	Nutrients	Method	Reference
1	pH	Potentiometrical Method	International Standard number 10390
2	Electrical Conductivity	Potentiometrical Method	Indian standard number 14767 - 2000 (Bureau of Indian Standards)
3	Organic Carbon	Wet combustion method	Indian standard number 2720 (part 22) – 1972 (Bureau of Indian Standards)
4	Organic Matter	Calculation method from OC by factor 1.78	-
5	Available Nitrogen	Alkaline permanganate Method	Tandon (2005) [4]
6	Available Phosphorous	Olsen's Method (Olsen et al 1954)	FAO Fifth Edition 1995
7	Available Potassium	Neutral Normal Ammonium Acetate (N NH4OAc) Extraction Method	Tandon (2005)
8	Available Calcium, Magnesium	Neutral Normal Ammonium Acetate (N NH4OAc) Extraction (EDTA Titration Method	Tandon (2005)
9	Available Zn, Cu, Fe, Mn	DTPA Extract, AAS Method	Tandon (2005)
10	Available Boron	(Azomethine H)Spectrophotmeter Method	Tandon (2005)

b) N**utrient composition testing.** Crop nutrition samples were collected once for each crop tested, which was at the time of the first harvest (some crops were only harvested once e.g. lettuce, while others were harvested several times e.g. Lady's Finger). The part of the crop that was tested, was the part to be used for human consumption, for instance, the Lady's Finger fruit, rather than the leaf.

Not all beds were sampled at each period, due to budget constraints. Where samples were taken, they were obtained from 3 parts of each bed – the front, middle and back. Each sample was tested individually, and the samples were not mixed together, in order to maximize the sample size from each bed.

The number of samples tested per crop cycle are shown in Table 2.

[4] Methods of Analysis of Soils, Plants, Waters and Fertilizers. Edited by HLS Tandon (2005). Fertilizer Development and Consultation Organisation, New Delhi, India

Table 2. Sampling of crops for nutrient testing

Crop Cycle	Crop	Number of samples taken per bed	Number of beds tested	Total number of samples tested
2	Lady's finger	5 fruits	2	10
3	Lettuce (array 1)	12 leaves (1 each from 12 different plants)	2	24
3	Lettuce (array 2)	12 leaves (1 each from 12 different plants)	2	24
3	Rucola	9 leaves (from 9 different plants)	2	18

The test focused on the levels of calcium, magnesium, zinc and iron present in each sample. The methodology utilized by the laboratory to test each element is listed in the table below (Table 1).

Table 3. Method of analysis - Nutrition testing

	Parameters	Method	Reference
1	Moisture	Oven dry method	Tandon (2005)
2	Ca, Mg	Di- Acid Digestion EDTA Titration method	Tandon (2005)
3	Zn, Fe	Di- Acid Digestion AAS method	Tandon (2005)

The laboratory supplied a 'required' value for each element, which served as a benchmark figure of the nutritional quality of each crop.

5. BUSINESS PLAN

5.1 Other research funding secured

An EPSRC Impact acceleration award of approx. £35K has been awarded to finalise the software and hardware prototypes. Scene Connect has also successfully applied for an ETP voucher to work with Heriot Watt to expand the dynamic irrigation platform to work with a variety of crops. We are also looking at securing Datalab funding to further investigate the potential for forecasting power outages.

5.2 Formation of Farm-Hand Ltd

A company called Farm-Hand Ltd has been incorporated in Scotland in March 2018 to commercialise the smart irrigation system. All Partners (Auraventi, Scene, FFC and AVC with the exception of HWU, which is already a shareholder in Auraventi) will be shareholders in this new company. Farm-Hand has been awarded a Climate KIC award to get the company started. Funding applications have been made to Scotedge, Converge Challenge and in India through AVC to the Swiss Re-Source Foundation, NABARD and WABARG. We have reached the final of the ScotEdge 'Wild-Edge' competition where our team will be pitching for a £15,000 prize.

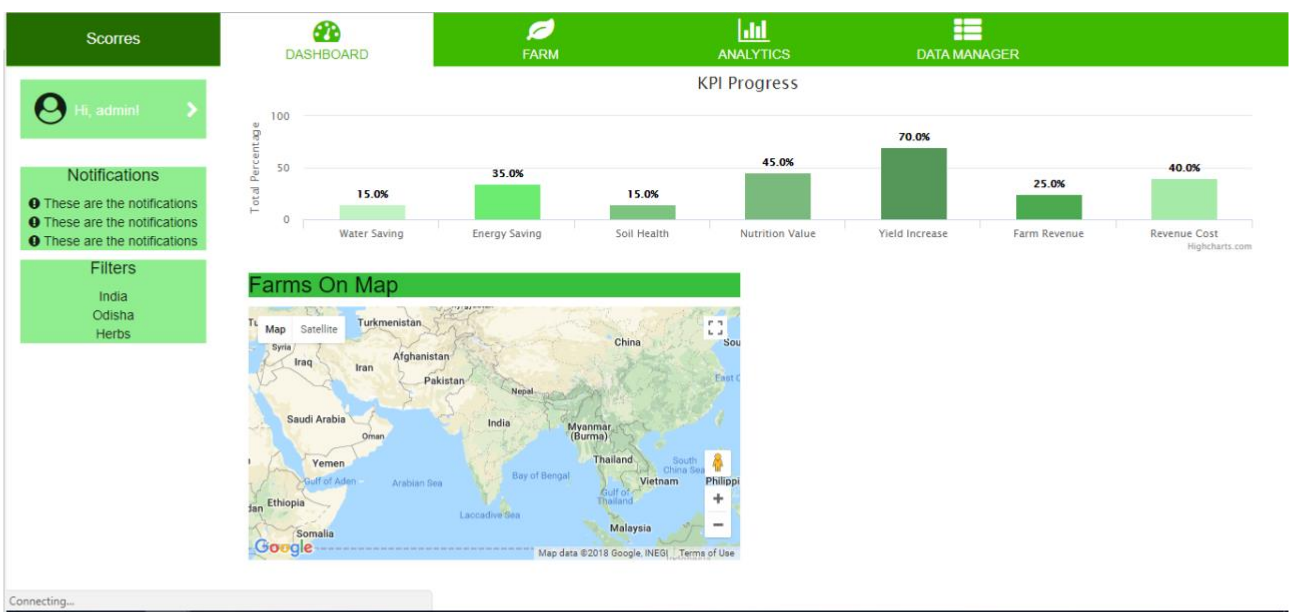
5.3 Low CAPEX of the SCORRES product

The CAPEX strategy is to keep the hardware costs low and deliver as much as possible through software. The product is cost sensitive. For example costly moisture probes have been installed in Buddha Garden, which have produced interesting, often erratic data and are now considered non-essential. The Farm-Hand objective is to limit hardware to solenoid valves, robust microcontrollers, irrigation water flow indicators (not measurement) and on-site communications to allow data to be sent to and received from the “Cloud”. An important consideration is how much farmers are willing to pay for the product, followed by the consideration of novel routes to market and the structures and delivery around these factors.

Following much research into potential Water Balance Models, the current controls meet the research specifications and the data and controls make sense on an ongoing basis. Control strategies include the farmer’s crop irrigation schedule as a starting point, the water balance model with ongoing farmer adjustments, with machine learning applied to the data streams. In time, irrigation systems bespoke to a farm are delivered. The ongoing OPEX includes communication systems costs and maintenance of the limited hardware of solenoid valves, site electronic controls, water flow indicators and rain gauge. Localised weather forecasting is a clear market advantage. It is improved by having local observations, including those in the latest microcontroller model with temperature and humidity located outside the housing on the bottom of the casing.

5.4 App development and user interface

A web-application was designed and developed for SCORRES. The design process included a feedback workshop with farmers in Auroville in December 2017. The strategy for this work was to develop a system which could then be turned into a mobile app as part of the commercialisation journey. This is due to the fact that the eventual end users of the system will largely not own computers and therefore require a system with equivalent functionality to the web-app but with a mobile app or SMS based interface. A screenshot of the web app is shown below. Workshops were undertaken at the end of March 2018 in which ~20 farmers spent 2 days with the team helping us to design a user interface which is fit for our target user group. This SMS and mobile app will be developed by July 2018.



5.5 Business and Market Development

The route to market strategy appraisal carried out by the SCORRES team, shows that achieving the scale and usage believed to be possible requires innovative business models and strategies, even with the relative advanced state of micro-irrigation products in India, as the take up rate is still modest.

Discussions were held with the Sustainable Livelihoods Institute (SLI), Auroville, to understand better the farming culture in Tamil Nadu as well as the wider farming sector needs across the State. While there is a lack of coordination between the agricultural sector and financial organizations that could provide finance, the sector is moving to be more technologically-based and there is a growing trend towards aggregation of farmers into farmer groups. FPOs (Farmer Producer Organisations) provide a potential route to market for the SCORRES product.

A recent government initiative has established around 200 FPOs, supported by the National Bank for Agriculture and Rural Development (NABARD) and the Small Farmers' Agri-Business Consortium. The industry-wide workshop held by the SCORRES team in December 2017, highlighted the need for farmer cooperatives to be strengthened by enabling organisations (technically, administratively, managerially etc.). Further research is needed to identify the status of FPOs across the State.

SLI has proposed a joint-collaboration with Farm-Hand to carry out a survey of FPOs in each of the agro-climatic zones of the state and to identify the kind of system support that these groups require to function effectively, for instance, access to finance. The findings will be presented to a multi-sector stakeholder group in order to identify areas of convergence, particularly around how to take products to market and collaboration within the wider farming sector. Finally, a conference will be held to market tools that can provide potential support to farmer cooperatives.

In addition to this work, Farm-Hand will carry out a review of the irrigation sector in Tamil Nadu, to identify potential partners.

5.6 Finance – Raising capital and start-up operating expenses including working capital

A plan is in place to take SCORRES from a promising R&D and pilot study to a commercial operation. A business plan and commercialisation plan have been developed. The business plan is still in flux, pending results of ongoing pilot trials – the intention is to finalise the business plan by the end of May 2018 and seek commercialisation funding thereafter. Some funding is in place to take product and commercial development to end of September 2018, though the team is actively seeking additional funds to support the team during this time. Funding will be sought from a range of avenues, including grants and competitions as well as early stage private finance, either from angel investors or early-stage venture funds such as Sustainable Ventures and Bethnal Green Ventures.

6. DISSEMINATION AND FUTURE PILOTS

6.1 New Pilots

Identification and applications for potential sources of future funding is ongoing, particularly from NABARD (National Bank for Agriculture and Rural Development) and WABARG for additional pilots in Tamil Nadu. An accelerator grant through HWU, called Rosii, is enabling further hardware development and continuation of the field trials in Buddha Garden for the rest of 2018. Laboratory testing of plant and soil samples is continuing, allowing an understanding to be attained of the impact on crops and soils from various irrigation strategies, adopted by new pilots. AVC, CSR & HWU are Partners with the James Hutton Institute as Lead in a proposal for the H2020 SC5-12-2018 call – EU India water cooperation. The learnings from precision irrigation work from SCORRES are included in the proposal, which carries the name ALLSTAR, and involves research in the use of treated sewage effluent in smart irrigation systems.

The energy demand led management trial at the Auroville Library and nearby streetlights has been completed successfully and has demonstrated good hardware and software solutions for future systems. AVC has been asked to quote for a significant extension of the street lighting system in Auroville. During a recent two day electricity outage, the Library was one of a very few buildings in Auroville that had no energy disruption. AVC will continue to work on similar “Solar Village” projects. The Auroville Library project has also been successful in showing the potential for energy demand management systems in India.

7. CONCLUSIONS

7.1 SCORRES is becoming known.

Working with Auroville International, SCORRES has enabled a display to be installed in SOAS (School of African and Oriental Studies) in London for the week commencing May 14 2018. Presentations have been given this year by SCORRES to the British Business Group in Chennai, the Environment and Water Resources Department of Civil Engineering of the Indian Institute of Technology Madras (IITM) and briefly to the Commissioner of the State of Tamil Nadu (the most senior Tamil Nadu Government civil servant. In addition presentations have been given for landscape irrigation projects in Tamil Nadu to Tata Consulting Services, Chennai Corporation, Chennai River Restoration Trust, Environmentalists of India, Matrimandir water management in Auroville and for a new 25-acre irrigated landscape funded from Delhi.

7.2 Next Steps

While SCORRES has had its technical challenges, particularly with engineered electronic communications, hardware and software systems perform well every day, while improvements remain a focus. New pilots and substantially sized irrigation opportunities will enable a design freeze on the product, while concentration moves to marketing and delivering on the Business Plan.

CONTENTS

Introduction

The SCORRES irrigation system comprises an irrigation scheduling platform and a controllable irrigation system that delivers the schedule to the designated crop. Irrigation of the crops described in this report was carried out using two different approaches.

a) Pre-determined schedules

These were developed by Buddha Garden Farmers and were made up of a series of irrigation episodes distributed throughout the day and included modification based on the growth stage of the crop. No modification was made for weather variations other than for determination of effective rainfall with this been made by the Buddha Garden Farmers.

b) Manual Irrigation

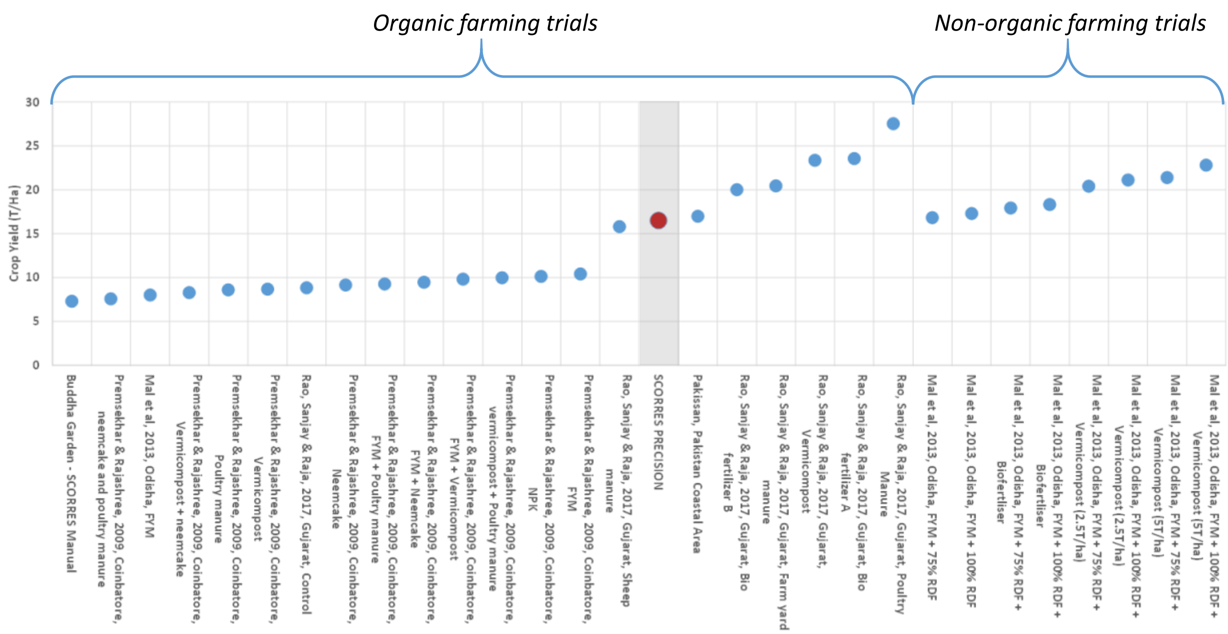
A manual approach is the incumbent method of irrigation followed at Buddha Garden. Irrigation duration is defined as a single time block, typically in the early morning. A farm volunteer then turns on the irrigation system for the defined period.
A dynamic irrigation schedule platform has been developed by SCORRES that uses a water balance model (WBM) approach to create daily irrigation schedules. These vary based on forecasted weather variables (temperature, cloud cover and humidity) delivered by Auraventi Ltd – a SCORRES project partner. The water balance model shadowed the crops described here and the irrigation schedules it would have mandated were collated and compared to both the pre-determined and manual schedules.

1 OKRA REPORT

1.1 Crop Yield

The crop yield of the SCORRES okra crop was 16.5 T/Ha. This compares favourably to the Indian average of 11.35 T/Ha reported by the FAO. It also compares favourably to a range of published, controlled research trials, both organic and non-organic (Figure 1-1).

Figure 1-1: Comparison between SCORRES Crop Yield and those from published trials



Estimation of water consumption from the okra trial was not possible as a consequence of failures in the impeller based flow meters initially used in the trial. Moving forward the objective is to limit hardware to solenoid valves, robust microcontrollers, irrigation water flow indicators (not measurement) and on-site communications to allow data to be sent to and received from the "Cloud". Keeping hardware requirements to a minimum and making sure any hardware used is robust is key to making the system affordable and of interest to the farmer.

2. Lettuce Report

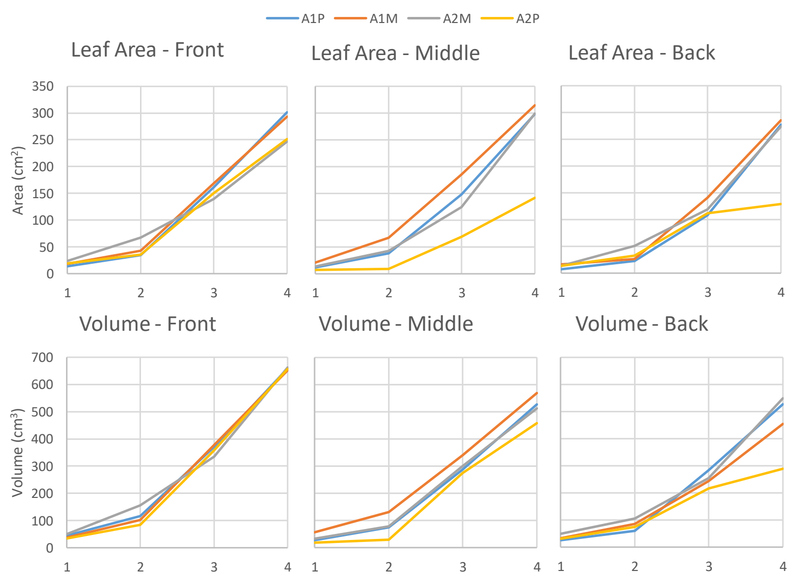
2.1 Scope of experiment

Four lettuce crops were grown in four individual beds in Array's 1 &2 in January/February. Two of these were irrigated using pre-determined schedules and two using the incumbent manual approach. The water consumption of each irrigation approach was determined to be broadly similar so that the singular effect of switching from a single to multiple irrigation episodes could be assessed.

2.2 Vegetative Growth

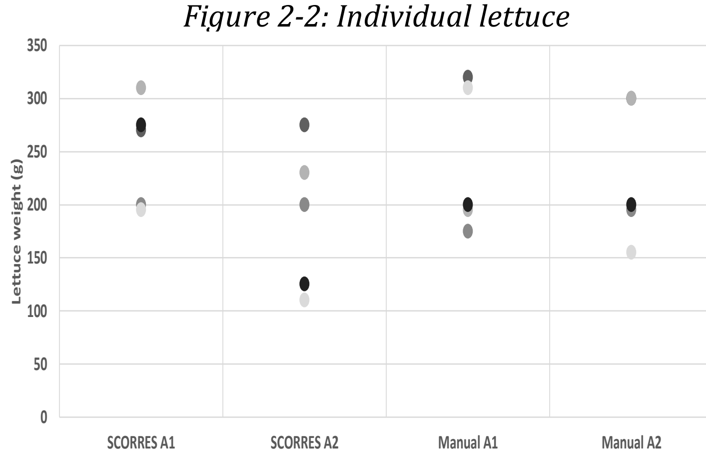
The vegetative growth was measured at the end of each week after seedlings had been planted (4 weeks in total). Five measurements were made from three different places in the bed, the front, middle and back. The leaf length and width and the lettuce height and width were measured. These allowed leaf area and lettuce volume to be calculated (Figure 2-1).

Figure 2-1: Vegetative growth of the SCORRES lettuce crop



A clear anomaly can be detected in the vegetative growth measurements associated with the progression of crop growth in SCORRES A2 (denoted A2P on Figure 2-1). Leaf growth seems to have been stunted in the middle and back and lettuce volume in the back of the bed. Issues with this bed were confirmed by the Buddha Garden farmers. Irrigation to the bed was interrupted during the first week after planting as a consequence of communications errors with the bed never recovering. The causes of these errors have been diagnosed and corrective action taken in the manufacture of the second version of the SCORRES micro-controller. The overall impact of the crop growth can also be seen in the

Figure 2-2: Individual lettuce



measured weights of the harvested crops (Figure 2-2). Two of the weights recorded in the SCORRES A2 bed were below 150g with all other lettuce weights between 150g and 320g across the other three beds.

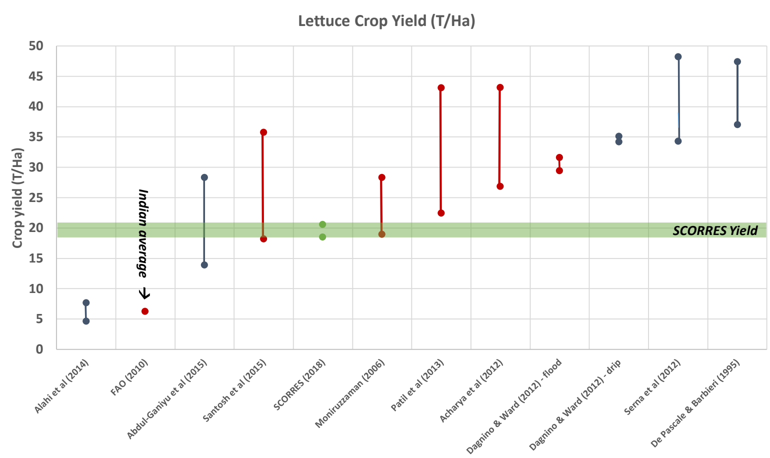
2.3 Crop Yield

The crop yield in each array was split between Grade 1 and Grade 2 produce. Results for each grade, total and the crop yield (T/Ha) are shown in Table 2.1. The beds controlled using the SCORRES approach showed a significant improvement in yield over the manually irrigated beds of 15.4 in Array 1.

Parameter	Array 1	
	Manual	SCORRES
Yield Grade 1 (kg)	58.2	67.9
Yield Grade 2 (kg)	3.8	2.6
Total Yield (kg)	62	70.5
Cultivated area (m^2)	36.36	36.26
Crop Yield (T/ha) (Total Yield)	**17.1**	**19.74**

Table 2-1: Crop Yield

Figure 2-3: Crop yield of SCORRES lettuce crops compared to other published research and benchmarks



A range of controlled experimental trials, investigating different aspects of farming practice on the cultivation of lettuce crops have been reported over the last two decades. A number of these trials reported crop yield information (Figure 2-3). This, together with data regarding Indian average crop yield for lettuce was used in a benchmarking exercise to understand the context of the Buddha Garden trial results. The crop yields from all beds in Buddha Garden compare favourably with the average lettuce crop yield of 6.35T/Ha reported for India in 2016 (FAO, 2017). The reported studies that were located in India or Bangladesh are marked in red in Figure 1. The crop yield achieved using the pre-determined schedule in Array 1 at Buddha Garden is circa 3 times the Indian average. It also achieved a 15% higher crop yield compared to the manual irrigation approach. That the crop yields are in the lower percentiles of the published research trials is not unsurprising as Buddha Garden is a working farm, rather than the highly controlled research facilities that were typically used to carry out these trials.

2.4 Anecdotal Farmer Feedback

The Buddha Garden farmers also observed that the crop from SCORRES A1 was denser than that from the manual beds. Two lettuces from each bed were placed in a fridge to observe how long the crop stayed fresh. The crop from SCORRES A1 was found to stay fresher for longer compared to the crop from the manual beds. These qualitative assessments may also indicate important properties for these friable crops. The ability of the harvested crop to retain freshness is critically important in ensuring they reach market in prime condition. Any increase in freshness period may also be useful in allowing some level of market arbitrage to take place.

2.5 Conclusions on Crop Yield & Vegetative Growth

The results from SCORRES A1 will be used in the following sections to calculate water foot-printing compared to Buddha Garden manual beds and State and National benchmarks.

2.6 Irrigation water consumption

The irrigation schedule for the lettuce crop, delivered by the SCORRES system varied depending on the post-nursery growth stage (Table 2-2). Schedules that spilt the daily requirement into as many as eight irrigation episodes were envisaged to optimise water delivery to the crop.
The irrigation schedule was 45, 50 and 47 minutes per day in growth stages 1, 2 & 3 respectively. The transplanting date in Array 1 was 5th January and the harvest date the 5th February. It was assumed that the first day of automatic irrigation was the 6th January and the last irrigation day was the 4th February.
Water delivery to the beds irrigated using the pre-determined schedules was measured using an ABB Doppler Flow Meter with minutely temporal precision. This data was used to calculate an irrigation flow rate for the bed. This flow rate was then applied to the pre-determined schedule to provide an estimate of irrigation water consumed during the cropping period.

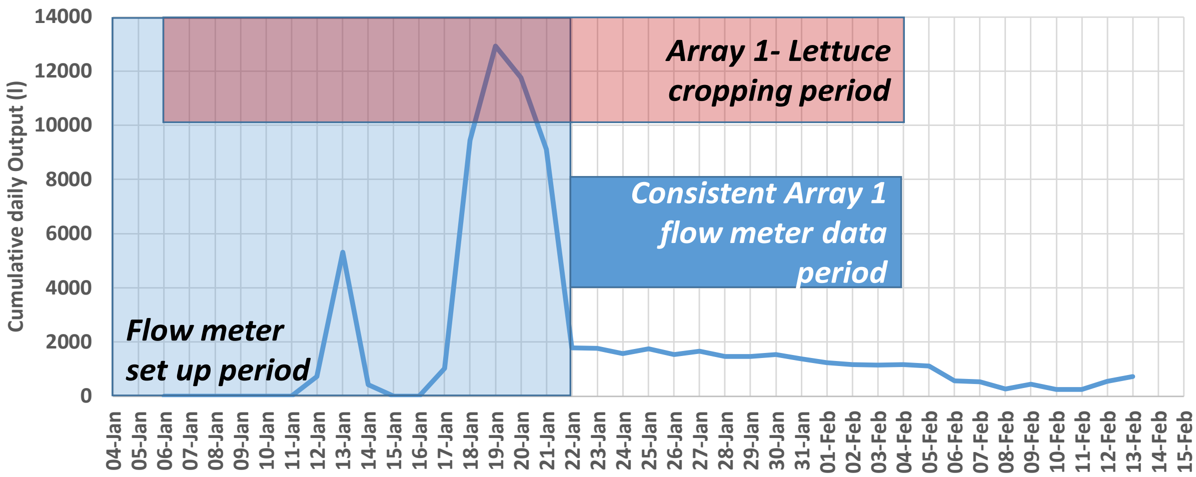
Time	Growth stage 1 irrigation duration (min)	Growth stage 2 irrigation duration (min)	Growth stage 3 irrigation duration (min)
2:00 AM	7	7	5
4:00 AM	7	7	8
5:00 AM	5	5	4
6:00 AM	10	15	10
9:00 AM			10
10:00 AM			6
8:00 AM	5	5	
9:00 AM	2	5	
3:00 PM	2	3	
5:00 PM	7	3	
6:00 PM			4
Total (min per day)	45	50	47
Number of days	10	15	5

Table 2-2: Pre-determined irrigation schedule for the lettuce crop

2.7 Measured irrigation – average irrigation flow rate

The flow meter was installed in the feed pipe from the water tank to the electronic beds such that consistent output was available from the 22nd January (Figure 2-4). As such, the period of output from the flow meter that was relevant to the Lettuce trial was from the 22nd January to the 5th February.

Figure 2-4: Output from the ABB Flow Meter



The ABB flow meter measured cumulative irrigation consumption for the three arrays controlled by the SCORRES irrigation system. The timing of irrigation to each of the three arrays was staggered such that the irrigation being supplied to each array was isolated.
The staggering of irrigation timing for each of the irrigation episodes scheduled on the 22nd January is shown in Figure 2-5. Lettuce in growth stage 2 was in arrays 1&2 and Rucola in growth stage 2 was in array 3. The number of irrigation episodes in the original Buddha Garden schedules was eight in each case.

The measured irrigation duration (based on flow meter data) is slightly longer than scheduled episode duration as a consequence of gravitational flow occurring beyond the period where the solenoid valve has been opened (Figure 2-6). This effect is more pronounced in Array 1 than 2 as a consequence of it being further away from the storage tank.

Figure 2-5: Flow meter data for 23rd January 2018 showing the irrigation episodes

Figure 2-6: Scheduled and recorded, average irrigation episode duration

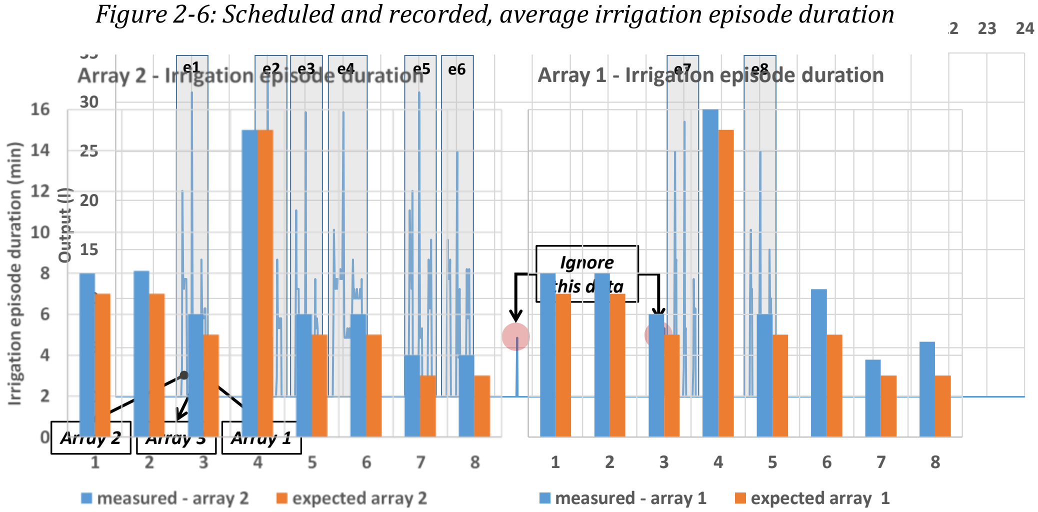
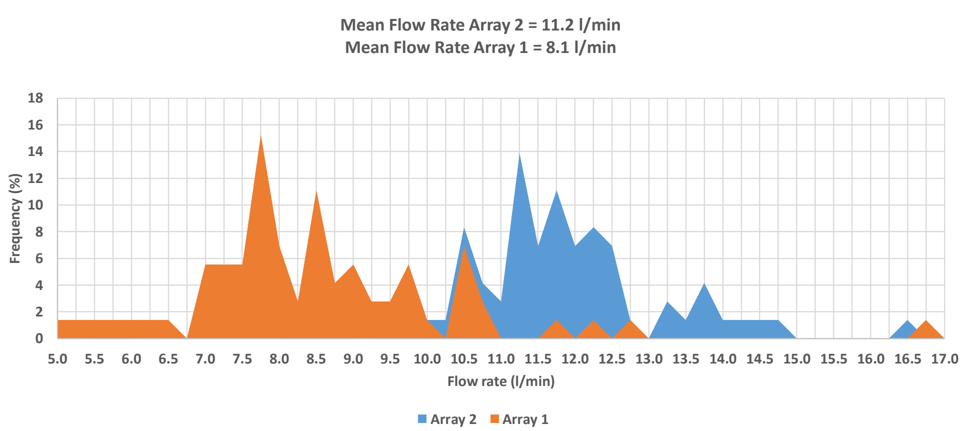


Figure 2-7: Frequency of flow rate and average flow rate achieved in each array



The frequency distributions of flow rates (l/min) achieved in each array for the irrigation episodes that occurred between 22nd January and 4th February is shown in Figure 2-7. The data was used to calculate the mean flow rate achieved by the irrigation system in each array.

2.8 Calculating total water consumed in each array

The flow rates calculated above between 22nd January and the 4th February can be applied to the irrigation schedules to estimate total water consumed in each SCORRES controlled array over the duration of the lettuce crop.

- **<u>Total water consumed SCORRES bed in Array 1 = 11.622m^3</u>**
- **<u>Total water consumed SCORRES bed in Array 2 = 16.062m^3</u>**

The volume of water delivered to the manually irrigated beds was not measured but has been estimated based on historical farm records. The irrigation volume for lettuce crop was estimated to be 400-500l/day. If we assume 500l per day, then 1000l per day was supplied to the two manual beds. Scheduling in the manual beds is carried out by instructing farm volunteers to irrigate for specific time periods. It was assumed that the disparity in flow rate to Array's 1&2 that was calculated using the flow meter were also apparent in the manual beds. This would result in the irrigation volume of 1000l per day being split 42:58 between Arrays 1 & 2.

- **<u>Total water consumed manual bed in Array 1 = 12.600m^3</u>**
- **<u>Total water consumed manual bed in Array 2 = 17.400m^3</u>**

2.9 Water Foot-printing

Two different methods were used to here to foot-print the water used to irrigate the lettuce crop; namely Water Use Efficiency (WUE) and Relative Irrigation Supply (RIS).

2.9.1 Water Use Efficiency

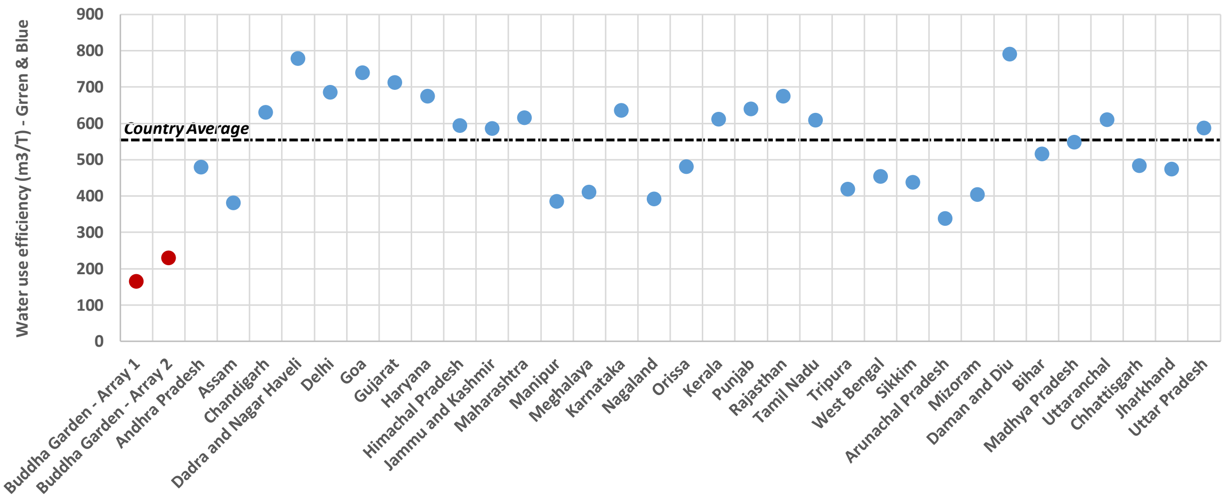
Calculating the water-use efficiency of crops typically proceeds by computing Blue, Green and Grey water requirement per tonne of crop produced. Blue, Green and Grey water definitions are shown in Table 2-3. Only the green and blue components of the water footprint were considered here as these were directly measured in the trial. It should be noted that any reduction in Blue water consumption is likely to reduce Grey water footprint due to the reduction in irrigation water run-off.

Water type	Description
Blue	The amount of surface water and groundwater required (evaporated or used directly) to produce a tonne of crop
Green	The amount of rainwater used (evaporated or used directly) to produce a tonne of crop
Grey	The amount of freshwater required to dilute the wastewater generated in manufacturing, in order to maintain water quality , as determined by state and local standards for each tonne of crop produced

Table 2-3: Water footprint descriptions

The WUE of the lettuce crop was calculated and compared to State level benchmarks produced for lettuce crop (Mekonnen & Hoekstra, 2011). WUE of the Buddha Garden lettuce crop was calculated to be 164.8 m^3/T in Array 1. The Tamil Nadu, Indian and Tamil Nadu average WUE were reported as being 607.8, 536.5 and 161 m^3/T.

Figure 2-8: Comparison of SCORRES pre-determined Blue & Green WUE compared with Indian State Benchmarks for Lettuce



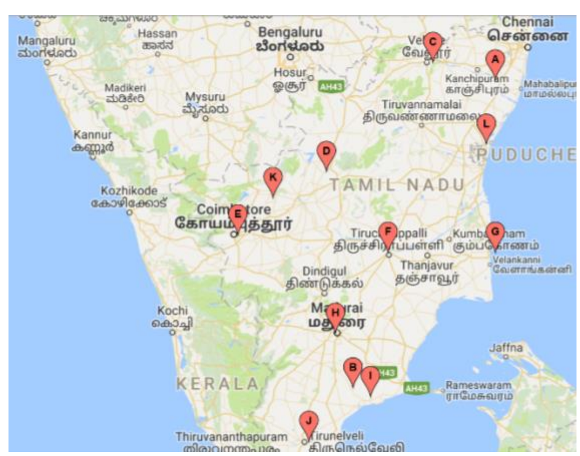
2.9.2 Relative Irrigation Supply

Relative irrigation supply (RIS) is calculated as the ratio of total irrigation supply to irrigation demand. Irrigation demand is defined as the crop evapotranspiration value. The SCORRES project developed a water balance model for calculating daily evapotranspiration values using the ASCE Standardized Reference Evapotranspiration Equation (Allen et al., 2005).

Evapotranspiration modelling

The water balance model produced forecasted daily crop evapotranspiration values for the period 9th January to 4th February. Historical reference evapotranspiration values have been published for twelve different locations in Tamil Nadu. The data is contained in the District Level Database Documentation which was collated as part of the Village Dynamics in South Asia (VDSA) project. Those candidate stations that were in closest geographical proximity to Auroville were North Arcot (C), Chengalpattu (A), Thanjavur (G), Tiruchirapally (F) and Salem (D) (Figure X)..

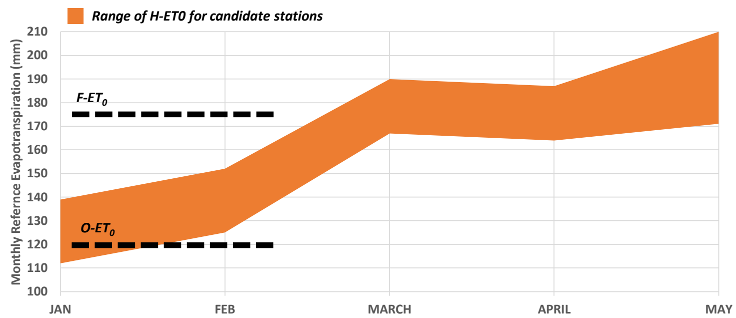
Figure 2-9: Location of published H-ET0 values for Tamil Nadu



The forecasted daily reference evapotranspiration value (F-ET_0) from the SCORRES WBM was compared to (i) the value calculated by the SCORRES WBM using weather observations rather than forecasts (O-ET_0) and (ii) historical data published for a range of Tamil Nadu stations (H-ET_0) (Figure 2-10).

The SCORRES forecast over-estimated the evapotranspiration values. In particular, the model over-estimated solar irradiance, the weather parameter which has the most significant influence on the calculation process. The trial period predominantly occurred in January. The ET_o value calculate using observed weather data was within the range of the published historical values for the candidate stations for January.

Figure 2-10: Comparison between SCORRES ETO values (forecasted and observed and H-ET_0 values

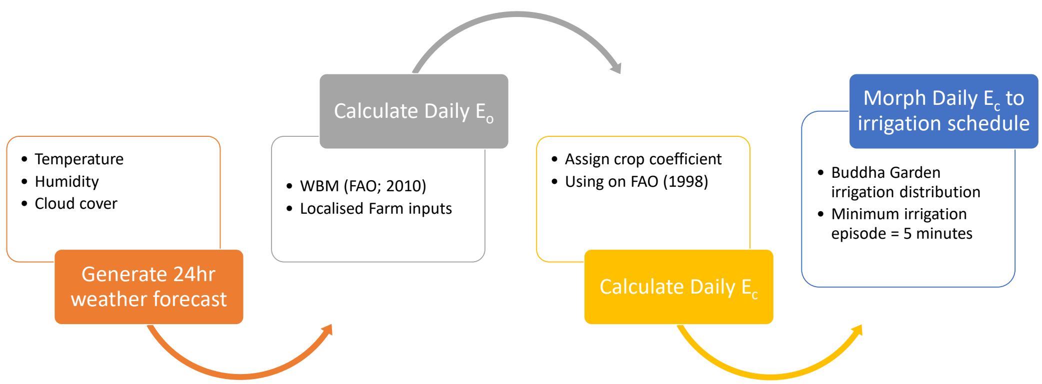


Calculating an Irrigation Schedule

The procedure for creating an irrigation schedule using a daily reference evapotranspiration (Eo) calculation is described in Figure 2-11.

The input data shown in Table 2-4 are required to translate F-ET_0 into an irrigation schedule. A number of Farm-Hand developmental issues are highlighted that will need to be solved in order to create a widely applicable irrigation scheduling platform. Based on these inputs, the calculation procedure followed is described in figure 2-11

Figure 2-11: Procedure used to calculate an irrigation schedule using the SCORRES WBM



Nº	Input	Unit	Description/Commentary
1	Crop coefficient, K_c		SCORRES are currently using Kc values from FAO 1998 document. K_c values vary with crop growth stage.
2	Standardised Distributed Irrigation requirement (DIR)	Minutes of irrigation in each time slot	Buddha Garden have provided SCORRES with DIR for eight different crops. DIR varies with crop growth stage.
3	Irrigation flow rate	Litres/min	SCORRES computed this using the ABB flow meter
4	Area to be irrigated	m^2	
5	Minimum Irrigation Episode (MIE)	min	This is the minimum irrigation episode for a farm or area of the farm being irrigated. It reflects the time it takes for water to travel from the pump or tank to the area

Table 2-4: Parameters used to compute an irrigation schedule using the procedure defined in Figure 2-11

Irrigation schedule for Array 1 – 9th Jan to 4th Feb

The DIR for the Buddha Garden lettuce crop is shown in Table 2-5. Three growth stages are defined, each with a K_c value that is used to calculate the daily irrigation requirement from the forecasted E_o. The fraction of this daily irrigation requirement that is to be supplied in each time slot is defined in the *Lettuce DIR* columns. These are based on the pre-determined irrigation schedules provided by Buddha Garden farm.

Growth stage	Crop day start	Crop day end	Kc	Lettuce DIR																							
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	10	0.70		0.23		0.23		0.32											0.23							
2	11	25	0.95		0.21		0.21		0.44			0.14															
3	26	30	1.00		0.22		0.35					0.43															

Table 2-5: DIR for the Buddha Garden Lettuce Crop

The irrigated area constants for Array 1 & 2 in Buddha Garden are described in Table 2-6. These are used to calculate the distributed irrigation schedule for the lettuce crop for this Array.

Constant	Array 1	Array 2	Comment
Irrigated area	36.36m^2	34.08m^2	This is the total planting area.
Irrigation Flow rate	8.10 l/min	11.19 l/min	This was calculated using ABB flow meter data.
Minimum irrigation episode	2 min	2 min	This is based on trial observations
Irrigation volume per unit of F-ET$_c$ per m^2 irrigated area	1 litre	1litre	

Table 2-6: Farm constants for Array 1&2 at Buddha Garden

A daily irrigation requirement (F-ETc) was calculated for Array 1&2 using output from the SCORRES WBM; this was then translated into an irrigation schedule using the Lettuce DIR and the minimum irrigation episode constant. The idealised schedule cannot be delivered as a consequence of the minimum irrigation episode duration. The idealised, constrained, pre-determined & manual irrigation schedules can be compared to the calculated irrigation schedule derived from the WBM using the observed weather data for the period where forecasted data was being produced (9th January to 4th February) (Figure 2-12). This displays the forecast error associated with the SCORRES WBM on a daily basis. The extent of this error is dwarfed by the extent to which both the pre-determined and manual irrigation schedules exceed the calculated evapotranspiration level. This data was used to calculate the Relative Irrigation Supply for each irrigation schedule (Figure 2-13). There was no effective rainfall during the lettuce cropping period (based on Maitreye weather station observations). The RIS is therefore equivalent to the Relative Water Supply (RWS) value.

Figure 2-12: Comparison between manual, pre-determined, idealised F-ET$_c$, constrained F-ET$_c$ and calculated O-ET$_c$

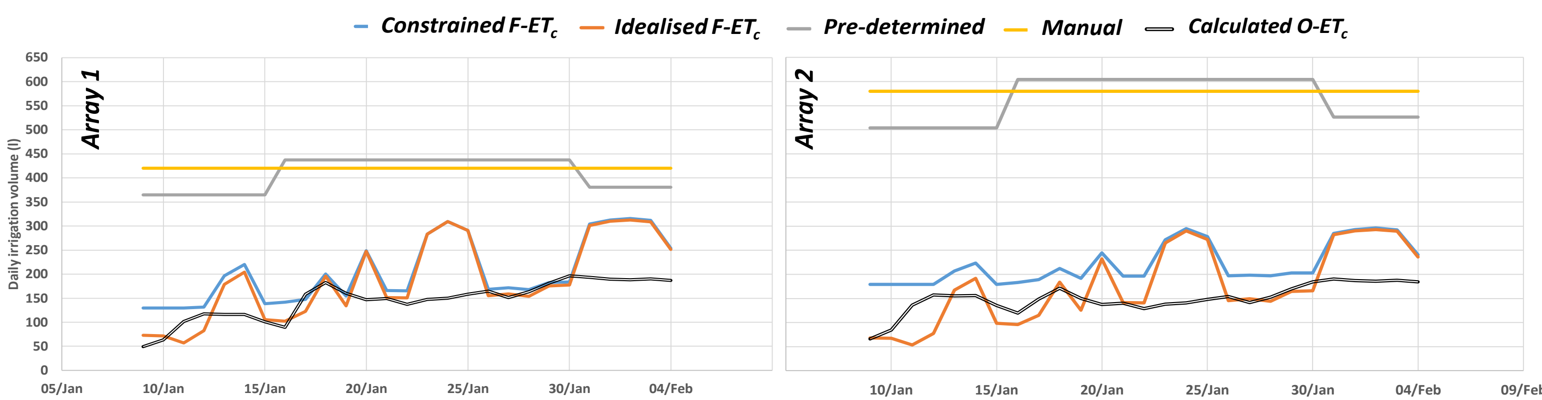
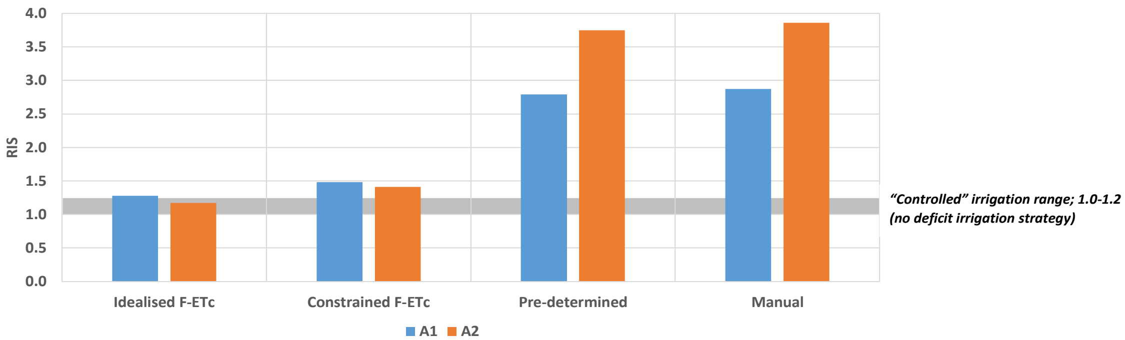


Figure 2-13: Relative Irrigation Supply (RIS) of Manual, pre-determined, idealised F-ET$_c$ and constrained F-ET$_c$



2.10 Crop Nutrition

Twelve samples taken from different Lettuce plants harvested in each bed were analysed for the parameters Water Content, Calcium, Magnesium, Ifron and Zinc. The results are shown on Pages 12-14. Analysis of variance (ANOVA) at 95% CI was used to determine the significance of any variation between beds found for each parameter.

A relatively consistent pattern was found in 4 out of the 5 parameters measured. For Water content, Ca, Mg and Zn, the parameter level in the SCORRES beds was found to be higher than that found in the manual beds. These findings were statistically significant with values >>2.0 returned for the F-test. The results for Zn were anomalous compared to this pattern with the value for the SCORRES A1 bed found to be lower than that returned for the other three beds. The difference was significant with respect to the F-test but less so than in the other 4 parameters.

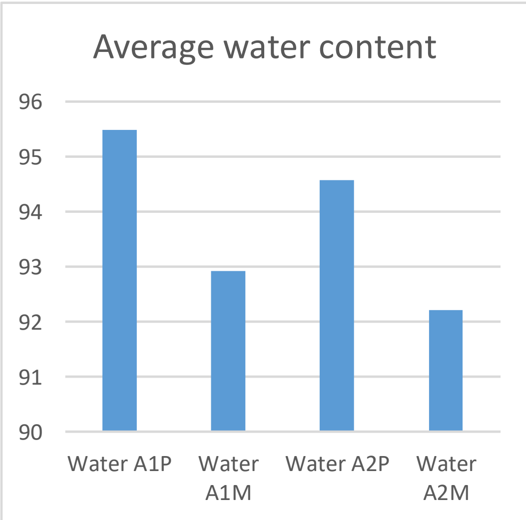
Anova: Single Factor

SUMMARY

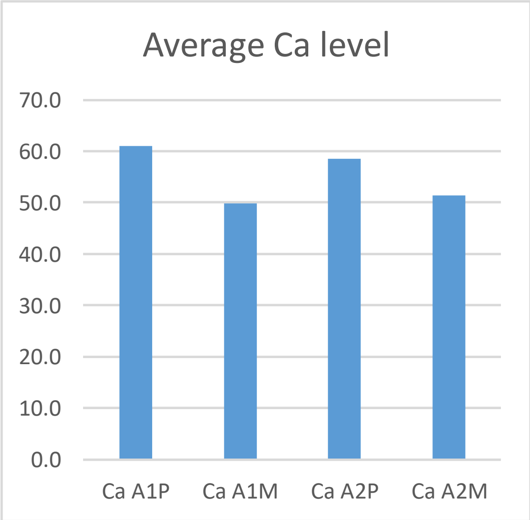
Groups	*Count*	*Sum*	*Average*	*Variance*
Water A1P	12	1145.8	95.48	0.55
Water A1M	12	1115	92.92	0.60
Water A2P	12	1134.9	94.58	0.85
Water A2M	12	1106.5	92.21	0.42

ANOVA

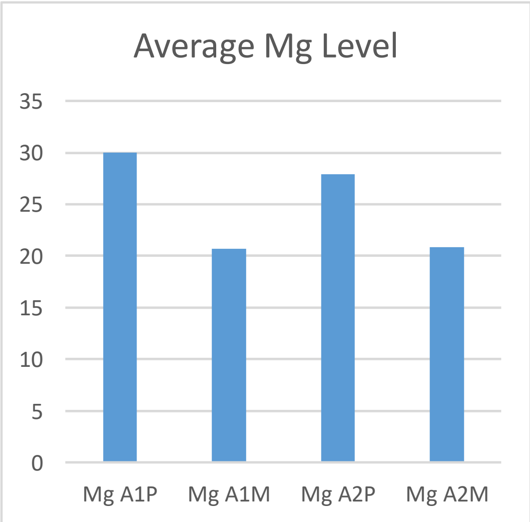
Source	*SS*	*Df*	*MS*	*F-test*
Between Groups	81.0	3	27.0	44.8
Within Groups	26.5	44	0.60	
				P-value
Total	107.5	47		0.00



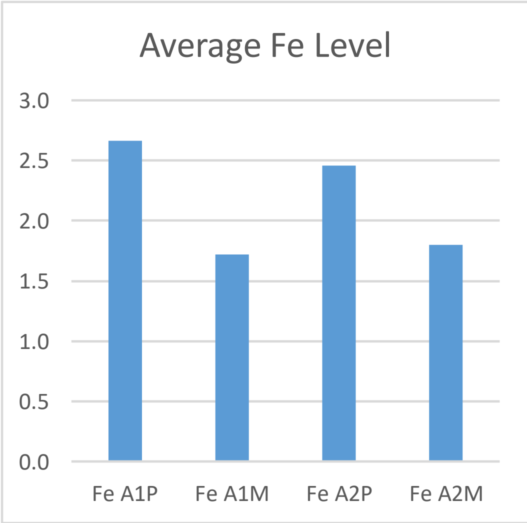
Anova: Single Factor				
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Ca A1P	12	731.4	61.0	47.8
Ca A1M	12	598.8	49.9	42.2
Ca A2P	12	703.2	58.6	44.4
Ca A2M	12	617	51.4	29.7
ANOVA				
Source	*SS*	*Df*	*MS*	*F-test*
Between Groups	1044.3	3	348.1	8.5
Within Groups	1805.5	44	41.0	
				P-value
Total	2849.8	47		0.00



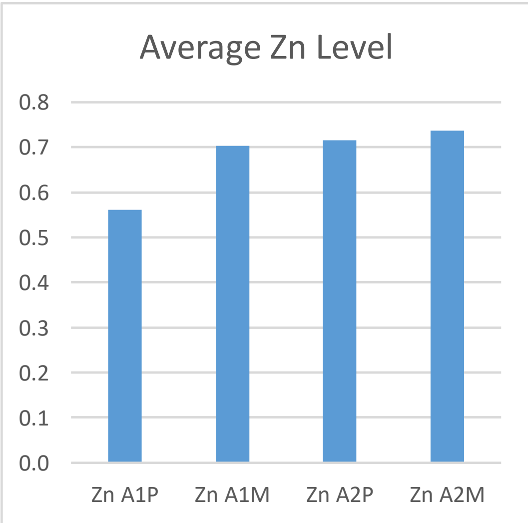
Anova: Single Factor				
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Mg A1P	12	360.5	30.04	12.46
Mg A1M	12	248.4	20.70	5.09
Mg A2P	12	334.6	27.88	9.33
Mg A2M	12	250.5	20.88	4.09
ANOVA				
Source	*SS*	*Df*	*MS*	*F-test*
Between Groups	830.1	3	276.7	35.7
Within Groups	340.6	44	7.74	
				P-value
Total	1170.7	47		0.00



Anova: Single Factor				
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Fe A1P	12	32.01	2.67	0.44
Fe A1M	12	20.62	1.72	0.13
Fe A2P	12	29.54	2.46	0.12
Fe A2M	12	21.6	1.80	0.09
ANOVA				
Source	*SS*	*Df*	*MS*	*F-test*
Between Groups	8.08	3	2.7	13.7
Within Groups	8.62	44	0.2	
				P-value
Total	16.70	47		0.000



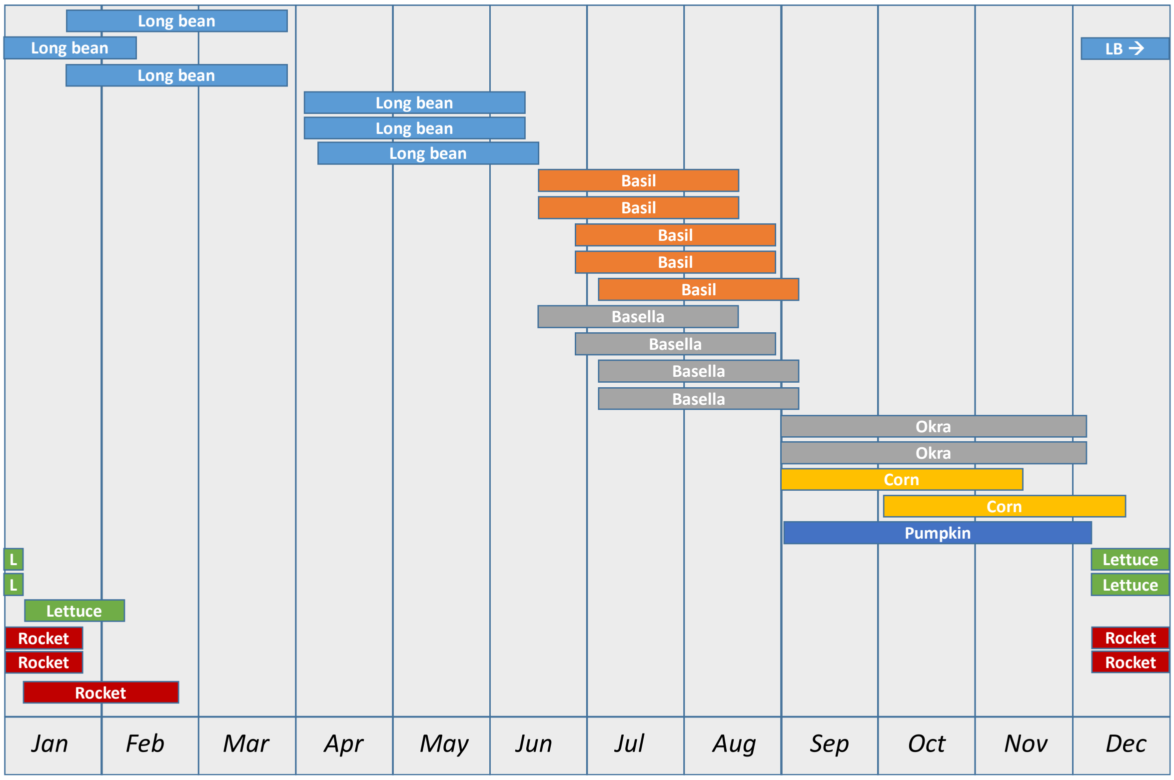
Anova: Single Factor				
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Zn A1P	12	6.73	0.561	0.009
Zn A1M	12	8.43	0.703	0.045
Zn A2P	12	8.59	0.716	0.009
Zn A2M	12	8.85	0.738	0.014
ANOVA				
Source	*SS*	*Df*	*MS*	*F-test*
Between Groups	0.23	3	0.077	4.0
Within Groups	0.85	44	0.019	
				P-value
Total	1.08	47		0.01



3 Impact on Energy Systems

3.1 Solar-PV System sizing

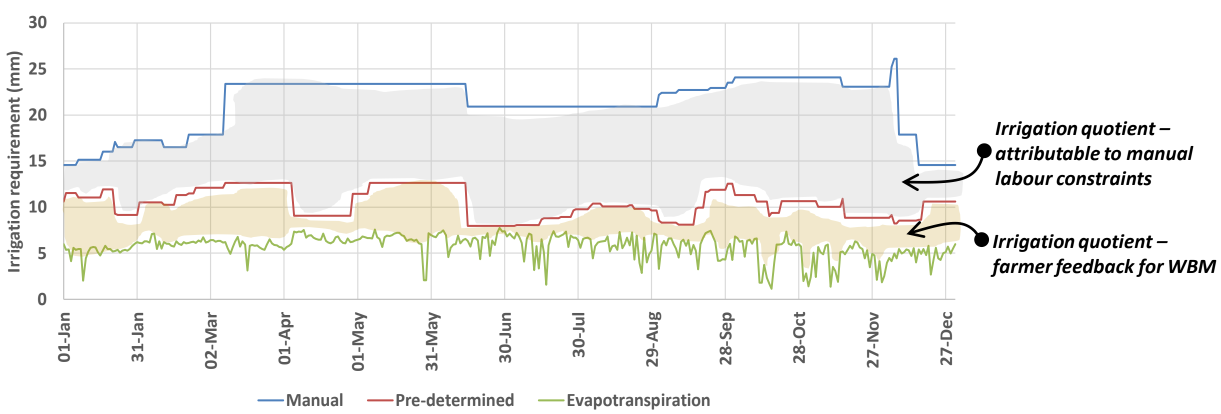
Figure 3-1: Cropping schedule used to estimate impact of precision irrigation on Solar-PV sizing



1. Assume the cropping schedule described in Figure 3-1

2. This creates the water consumption requirement described in Figure 3-2

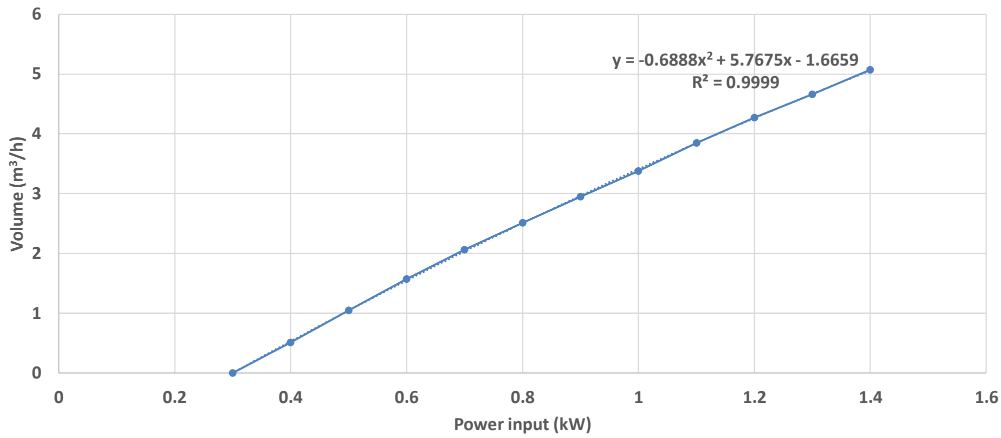
Figure 3-2: Irrigation requirement



The manual and pre-determined schedules are predicated on the cropping schedule and the requirements of the crop. The evapotranspiration line described the requirement of the reference crop and is not scaled to account for crop coefficients specific to each crop being grown. It can therefore be viewed as indicative of climate driven irrigation using observed weather parameters from the weather station local to Buddha Garden farm.

3. These irrigation schedules were scaled for a 3 acre farm (approximate average for India), assuming a cultivated area ratio of 46% (equivalent to Buddha Garden Organic Farm). The cultivated area was therefore 5585m^2.
4. The energy consumption attributable to the water pumping was computed using the the power to volume curve for a Grundfos Sqflex 5a-7 (2hp) AC/DC. Pump head was assumed

Figure 3-3: Power-Volume curve for the candidate water pump with head height of 45m



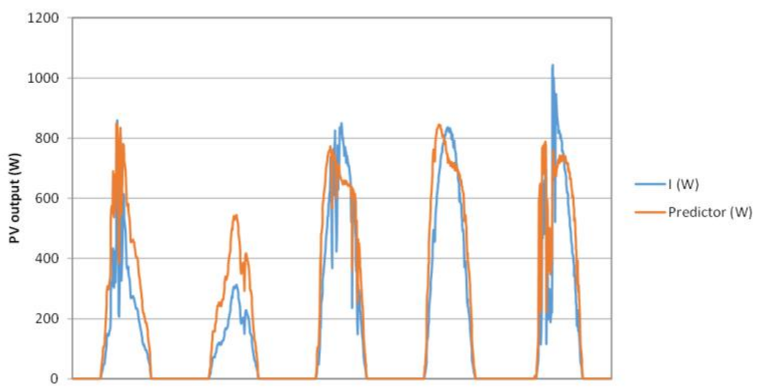
to be 45m (Figure 3-3).

5. PV output was estimated using the PVUSA model developed by Dows and Gough (1995) reported in Pepe et al (2017).

$$P = \mu_1 I + \mu_2 I^2 + \mu_3 IT \qquad (1)$$

Where P = Power output from PV array (kW); I = Global Irradiance (W/m^2) and T = air temperature (°C) and μ_1, μ_2, and μ_3 are regression coefficients.

Figure 3-4: Modelled and actual output of the Buddha Garden PV array

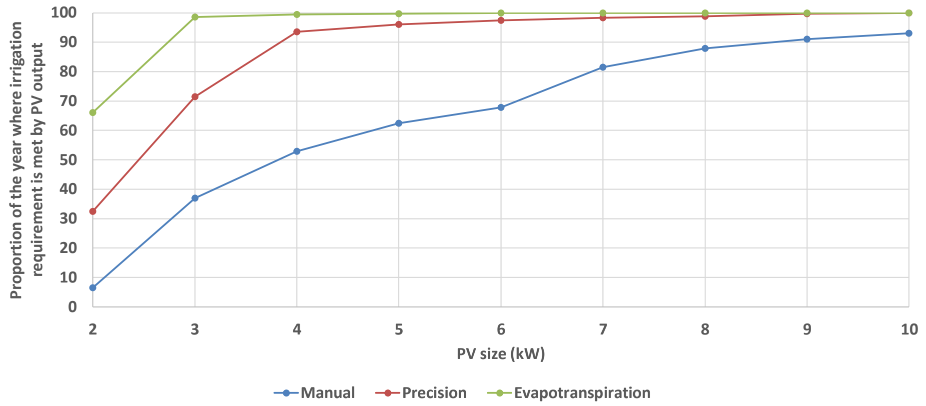


This was applied to the monitored output for the Buddha Garden 3.9kW PV array and to the weather data from the Local Weather Station for October 2017 (temporal precision of 5 minutes). The comparison between the predictor and monitored data is shown for a 5 day period in Figure 3-4 and provides an adequate estimating for sizing the PV system.

6. It was assumed that a PV system had to be capable of providing the required daily water consumption for a minimum 90% of the year, i.e. this would mean that there was unlikely to be a requirement for storage or reliance on grid electricity for back-up power.

The impact of changing the irrigation scheduling from manual to pre-determined and then to evapotranspiration based is shown in Figure 3-5. To the nearest kWp, PV system size was found to be 9kW, 4kW and 3kW for manual, pre-determined and evapotranspiration irrigation schedules respectively for the candidate 3 acre farm.

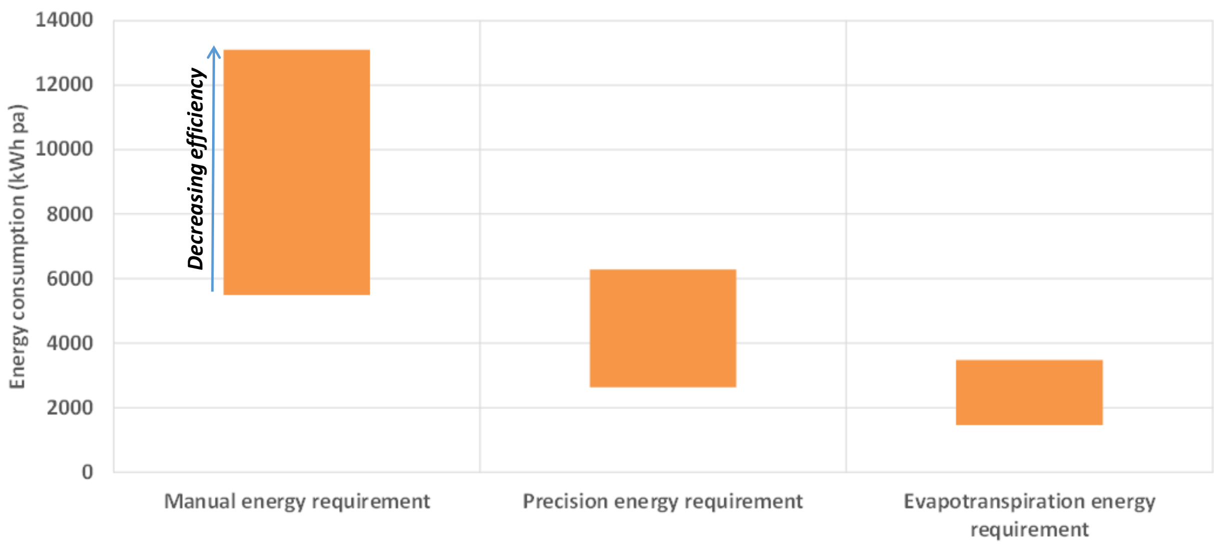
Figure 3-5: Impact of changing the irrigation schedule on PV system sizing



3.1 Energy consumption and CO_2 emissions

Energy consumption attributable to water pumping is a function of irrigation schedule and pump efficiency. The efficiency of the Grundfos pump was found to be circa 50% compared to stated averages for the Indian agricultural sector of 21%. The range in consumption for each irrigation schedule shown in Figure 3-6 reflects these two efficiency points.

Figure 3-6: Energy consumption of water pumping for the 3 acre farm for different irrigation

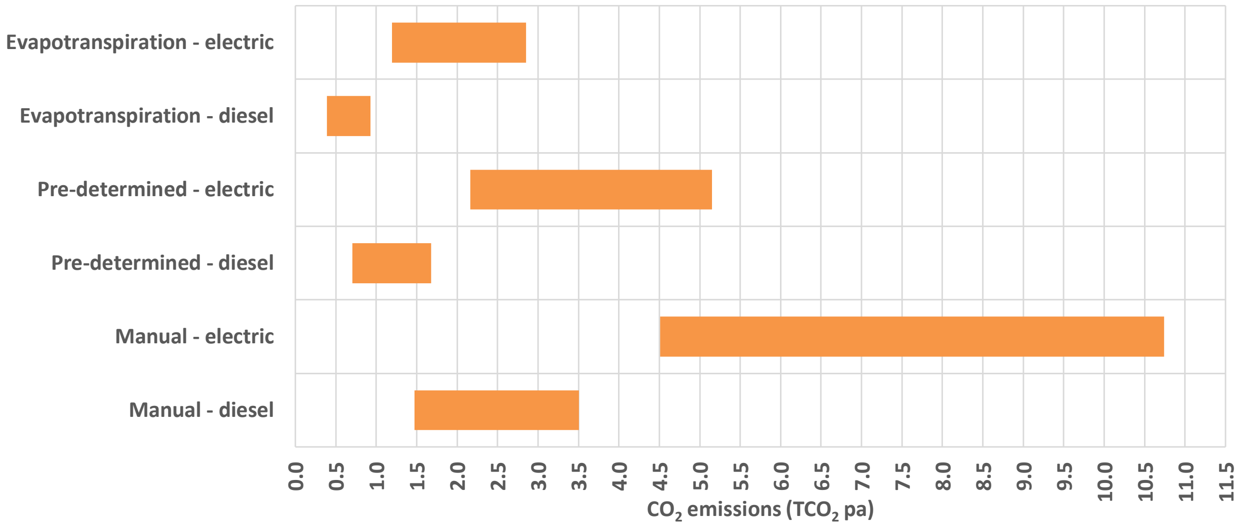


The energy consumption was found to be {5.5 to 13.1MWh}, {2.6 to 6.3MWhnd {1.5 to 3.5MWh} pa for the manual, pre-determined and evapotranspiration schedules respectively where the first number is for the Grundfos pump @ 50% efficiency and the latter for the 21% average.

The CO_2 emissions arising from these levels of consumption depend on whether grid electric or diesel pumps are used. The annual average grid emission factor for grid electricity in India in 2016 was 0.82kgCO_2/kWh. The emission factor used here for diesel is 0.268 kgCO_2e per kWh (100% mineral diesel; net CV). Diesel pumps result is substantially lower CO_2 emissions than grid electric pumps (Figure 3-7; table 3-1). This will be the case until systematic decarbonisation of the Indian grid is completed. Diesel pumping creates additional environmental hazards which should not be overlooked, associated with fuel spillage risk causing bore-well contamination.

The candidate 3 acre farm, irrigated using manual schedules and an average efficiency, grid electric pump emits 10.74TCO_2 pa, equivalent to the emission attributable to electricity consumption from c12 average Indian dwellings. This could be reduced by more than 50% of SCORRES irrigation systems were employed and by almost 80% if these were accompanied by high efficiency, grid connected pump sets.

Figure 3-7: CO_2 emissions attributable to water pumping for the 3 acre farm for different irrigation systems



Irrigation description	Emissions - high efficient pump (TCO_2)	Emissions - average efficient pump (TCO_2)
Manual – diesel	1.47	3.5
Manual – electric	4.51	10.74
Pre-determined – diesel	0.71	1.68
Pre-determined – electric	2.16	5.15
Evapotranspiration – diesel	0.39	0.53
Evapotranspiration – electric	1.20	2.85

Table 3-1 CO_2 emission attributable to irrigation of a candidate 3 acre farm

SCORRES – Measurement of nutritional composition in vegetables

Appendix 2

What tools are available that provide an accurate measurement of nutritional composition in vegetables?

1. Background

An established consortium comprising Heriot Watt University, Findhorn College (Scotland), Auroville Consulting (India) and private sector companies are working to implement a UK-DFID funded project, 'Smart Control of Rural Renewable Energy & Storage' (SCORRES) in India. The main objective of the project is the development of financially viable, robust, location specific irrigation systems for the Indian agricultural sector. The systems will be optimally sized to deliver 'right-time, right-volume' irrigation to farms, reducing water & energy consumption, increasing crop yields & nutrient content and improving soil condition. The "smart" part of the system is ICT software which designs, forecasts and controls the crop-specific irrigation.

2. Understanding improved nutrient content of horticultural plants

Although SCORRES is focusing on energy reduction and optimization of water availability, the consortium is aware that a range of inputs to vegetable production (good compost, smart irrigation, temperature and sunshine) are likely to drive good human nutrition. The project would like to better understand i) the drivers of good human nutrition, as well as ii) to determine what nutrients should be measured in the vegetables in order to detect changes in composition at various stages of plant growth.

An online Google search was carried out on these two questions. The first question can be further disaggregated into two parts: i) good human nutrition, ii) better agricultural practices. The search revealed that each part had its own area of research and there were not necessarily linkages being made between them. The main findings were:

- **The human nutritional value of food -** this issue tends to be couched in terms of deterioration of nutritional value as a result of industrial agricultural practices[i], rather than the potential for improving quality through better farming methods and inputs.

- **Ecological agricultural practices and inputs[5] that influence nutritional quality -** in the online literature, farming practices such as regenerative agriculture[ii] tend to be adopted and implemented in response to declining soil fertility, rather than an explicit effort to influence human health through improved nutritional composition.

- **The benefits of organic vegetable production for human nutrition** – these tend to be viewed through the lens of the organic vs non-organic debate, which is not a key part of our research.

3. Measurement of plant nutrient composition

In light of the challenges faced above, a search was carried out on the issue of measurement of nutritional composition of plants. No literature was found on measuring changes in vegetable

[5] This study focuses on ecological practices rather than industrial farming practices

quality as a result of improved ecological agricultural practices. Therefore the question was divided into several parts, as follows:

- **What is meant by vegetable quality?** - Nutritional value is only one indicator of quality and tends not to be the one of primary concern. Measurement in vegetable quality tends to include i) colour and appearance, ii) flavour (taste and aroma), iii) texture and iv) nutritional value, in that order (see consumer preferences below).

- **What kind of measurements are used around nutritional quality of vegetables?** – there are journals, such as Journal of Plant Science and Journal of Plant Nutrition and Soil Science, which are devoted to the measurement of various aspects of plant nutrition. The research tends to be very specific and is not broad enough for our purposes.

  However, it is possible to conclude that the measurement of nutrient quality is geared towards consumer preferences – initial purchases often based on external attributes such as appearance, colour, shape and size and subsequent purchases is dependent upon consumer satisfaction based on flavour and internal quality, which are related to soluble solids content (SSC) (mainly sugars), titratable acidity (TA), soluble solids to acid (SSC/TA) ratio and texture. With improvement in living standards and income, sensory (taste) quality and sugar content have become significant quality parameters in consumer perception of quality and value of fresh and processed horticultural food products. As such, the determination and quantification of sugars and sweetness is of great importance in many fields of plant food sciences research.

  A thorough review[iii] of the analytical methods for determination of sugars and sweetness of horticultural products has been carried out by the University of KwaZulu Natal and University of Stellenbosch in South Africa. The paper provides a thorough overview of indices used to characterize sugar content as well as a range of measurement methods, categorized according to whether they are destructive or non-destructive (based on the necessity for sample preparation before analysis). These are summarized briefly below:

  A. The indices used to characterize sugar content and sweetness of horticultural products

  i) **Total soluble solids (TSS) and soluble solids content (SSC) (BRIX)** – the sugars and acids, , together with small amounts of dissolved vitamins, fructans, proteins, pigments, phenolics, and minerals, are commonly referred to as soluble solids. SSC and TSS are the most important quality parameters used to indicate sweetness of fresh and processed horticultural food products, in laboratories for research and by industry to determine marketing standards. TSS can be measured using either a Brix scale hydrometer or a refractometer (see below) and reported as "degrees Brix" (◦Brix) which is equivalent to percentage. In principle, the unit ◦Brix represents the dry substance content of solutions containing mainly sucrose.

     There is quite a bit of information available online around the use of Brix as a measurement tool of long standing (over 40 years), including from Ohio State University. There are no brix standards per se, but reference values are available in government and scientific reports and other documents. However, ultimately, the most important values for most vegetable growers, buyers, and handlers may be the 'bank' of numbers they develop in their own operation over time through consistent measurement. Brix is widely used, particularly in the wine industry. It does appear to be reliable but it could be rather a simplistic tool (for instance, battery acid will raise brix).

ii) **Alternatives to Brix** - In 2001, a new sweetness (or maturity) index was developed called BrimA (pronounced bree-mah) as alternative to brix/acid ratio. BrimA (an abbreviation for Brix minus Acid) measures the balance between Brix (sweetness) and acidity (sourness). Research has shown that BrimA is a consistently better indicator of consumer liking than other commercial maturity standards (e.g. TSS, TA, and brix-to-acid ratio) and its future adoption by horticultural industries in different countries is promising.

B. Methods to measure sweetness in horticultural products

a. Destructive methods

i. **Sensory evaluation** – determining the taste of fruit and vegetables

ii. **Hydrometer** – a simple instrument that measures the density of liquids and usually calibrated using a standard liquid. A Brix hydrometer measures specific gravity and is calibrated to read directly in units of sugar concentration (degrees Brix) at room temperature. The hydrometer is a common technique for quantify Brix but is inadequate and inaccurate because of manual operating and reading errors.

iii. **Refractometer** – optically measures the refractive index of juice. Is the standard method used to measure TSS and SSC of fruit and vegetables. The Brix refractometer has advantages over other methods of estimating SSC concentration because it is inexpensive, readily available, less fragile and less sensitive to variation in sample temperature and ambient temperature, season of the year and other factors.

iv. **High performance liquid chromatography (HPLC)** – is the most effective technique for separating naturally occurring compounds and has been widely accepted as the most effective and innovative method for carbohydrate analysis. There are numerous HPLC procedures and the evaporative light scattering detector (ELSD) is probably the most widely used for sugars in horticultural produce. Pulsed amperometric detector (PAD) is considered as the most highly sensitive and reliable detection method for all carbohydrates[6].

v. **Electronic tongues** – an instrument that closely mimics the organization of human sense of taste. It is widely used for analysis of horticultural food products such as fruit, juices and vegetable oil.

Destructive methods are widely used but one of the drawbacks is that the results only reflect the properties of the specific produce being evaluated. The high variability in quality attributes of fruit and vegetable batches, coupled with industry demand for innovative tools for quality measurements have spurred considerable interest to search for non-destructive alternatives.

b. Non-destructive methods

[6] I assume the advantage of the Brix is that it measures total sugars, whereas the HPLC procedures measure individual compounds.

i. **Visible to near infrared spectroscopy** – an optical technique, which has been extensively investigated on multiple horticultural products. Among many non-destructive sensing techniques that have been developed, it shows great potential for sorting and grading fresh produce for internal quality.

ii. **Hyperspectral and multispectral imaging** - images are made to evaluate and predict parameters such as SSC and TSS of fruit and vegetables. Can map sugar distribution at different stages of maturity to assess ripeness.

In conclusion, the methods for quantifying sugars are constantly evolving. Techniques such as nuclear magnetic resonance (MNR) spectroscopy has been developed to estimate the SSC of whole fruits, but the equipment is currently too delicate and expensive for commercial use. Even equipment for the HPLC is too sophisticated and precise for wide use, although it is commonly used for identification and quantification of individual sugars. While refractometry is the most invasive and time consuming method, the handheld refractometer remains the most commonly used tool due to its simplicity and low cost.

In addition there is an overreliance on TSS for assessing quality and data on fructose, glucose and sucrose levels should be included to provide a more accurate description of biochemical changes.

- **Standards in measurement of vegetable quality** - Standards don't tend to exist around quality (which perhaps why poor quality is so common), except for international/regional trade. Trade standards tend to focus on appearance and presence of disease rather than nutritional quality.

Who are the experts in the field?

Most of the info available online indicates that there are few experts who are looking at the question as a whole. There tends to be different experts looking at different parts of the puzzle:

- There are experts looking at vegetable quality, not linked to agricultural practices, for example, Department of Food Science & Technology University of California
- Some are linking vegetable quality with human health, although still not linked to agricultural practices, for example Children's Nutrition Research Center, Houston, Texas
- There are a whole range of experts looking at renegerative agricultural practices, as you know, for instance the Rodale Institute, USA
- There are a few linking regenerative agricultural practices to nutritional quality of vegetables
  - Most of it is through anecdotal evidence
    - Bionutrient Food Association seems to promote Brix but offers no empirical evidence
    - Arden Anderson
    - Individuals such as Steve Soloman and Jeff Lowenfels have written books on growing nutrient dense crops on home plots – not clear whether any scientific measurement is used on quality
  - It's less easy to find empirical evidence. Here are some possibilities that will need a bit more investigation
    - The most promising I've found is Ross Welch from Cornell University Institute for Food Systems – he seems to be an expert in the field, but I can't access his papers online because they are all in scientific journals. They have promising titles, such as:

    - A Systems Approach to Optimizing Plant Nutrition for Human Health
    - Agriculture: the real nexus for enhancing bioavailable micronutrients in food crops
    - Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: Principles, perspectives and knowledge gaps
- Allen Barker at The Center for Agriculture, Food and the Environment at the University of Massachusetts Amherst – they are researching how replenishing the soil affects nutrient density of vegetables. It is not clear how they measure nutrient density. This seems to be ongoing research.

Conclusion

Brix is the standard and long-standing index used to measure sweetness in horticultural products. The refractometer is the most reliable tool to measure Brix and is readily available and low cost. However, while sweetness is the most common indicator of quality in terms of broad consumer preferences for fruit and vegetables, we need to investigate further whether it is the best indicator: i) for the green leafy vegetables e.g. basil and spinach that will be grown in our field trials and ii) to explore the linkages between improved agricultural practices, improved soil health, improved vegetable health and better human nutrition - what other nutrient composition is important to measure in the plants and what is the best, most cost-effective tool to measure these nutrients?

In addition, the research has highlighted two broader underlying questions that we can research further as the project progresses:

1. What research is available on the impact of water regulation/optimization on the nutrient composition of vegetables, and on human health?
2. What research is available on the impact of a range of ecological agricultural practices on the nutrient composition of vegetables, and on human health?

Appendix 3

Nutrition and Soil testing protocol

One of the assumptions of SCORRES is that optimal irrigation will improve soil fertility and also improve the nutrient composition of vegetables and will ultimately benefit human health. This note outlines a potential protocol for soil analysis and also a protocol to test the nutrient composition of vegetables.

1 Nutrient Testing Protocol

The following protocol is proposed for two rounds of testing:

i) An initial test of vegetables currently being harvested at BG (the 'non-SCORRES vegetables')
ii) Testing of the second round of vegetables (the 'SCORRES vegetables' - (pumpkin, corn, lady's finger).

1.1 Which vegetables to test

- The 'non-SCORRES vegetables' – the vegetables at BG that are available now for nutrient testing are: pumpkin, lady's finger, brinjal (aubergine), long bean, basella. It is proposed that one of each vegetable is tested for reasons outlined below.

- The 'SCORRES vegetables' - the vegetables being grown in this current round are pumpkin, corn, lady's finger.

1.2 Which minerals to test

i) Research carried out to identify relevant nutrients

There have been several sources of information to help decide which nutrients to test in the vegetables. These are outlined below:

- James Hutton Institute (Philip White) has recommended that we measure the minerals most important to human health and in which there are significant deficiencies in India – iron (Fe), zinc (Zn), calcium (Ca) and magnesium (Mg) – this is directly in line with our objective.
- Bruce Napier (Andew's contact from NIAB) only offered suggestions around measuring plant growth, some of which are already in place. He also suggested we use Brix, which only measures sweetness, rather than nutrients valuable to human health.
- Kirsten Brandt from Newcastle University suggested we measure vitamin C, calcium, nitrate, iron, phenolics, pro-vitamin A carotenoids and oxalic acid. The EMS Lab does not have the facilities required for biochemical analysis (which are the vitamins etc), they only have the capacity to test metals (iron, zinc etc).

ii) Linking vegetable nutrient analysis to soil nutrient analysis

It will be useful to identify nutrients in the vegetables that can also be tracked in the soil. This will help us to make a correlation between changes in the soil nutrients and changes in vegetables nutrient levels. If we track different minerals in the vegetables compared to the soil analysis, eg Vit C, it will harder to gauge why nutrient levels have changed in the vegetables. This is because there will many factors influencing vegetable nutrient composition apart from optimal irrigation.

iii) Recommended nutrients for testing

It is therefore proposed that we focus on testing iron (Fe), zinc (Zn), calcium (Ca) and magnesium (Mg), in line with the recommendation from Philip White. These minerals are In line with our objective to test nutrients in the vegetables that are important to human health in India. They are also being measured as part of the soil analysis currently being carried out by EMS Lab**.**

iv) Checking these micronutrients against the nutrients present in each vegetable

It was hoped that we would be able to check how significant these four metals are in the vegetables to be tested. Consultation at the EMS lab and some online research indicated that all vegetables tend to have reasonably significant quantities of these meals. However, it is difficult to get specific information on which metals are most significant, partly because it varies according to the variety of the vegetable and we don't have access to such specialist information (or is not possible where BG have created their own varieties).

1.3 Presentation of results

The concentration of the essential elements in plants is expressed on a dry-matter basis as either percent or grams per kilogram (glkg) for the major elements (P, K, Ca, Mg, S), and either parts per million (ppm) or milligrams per kilogram (mglkg) for the micronutrients (B, Cl, Cu, Fe, Mn, Mo, Zn),

1.4 Sample size

- The 'non-SCORRES vegetables' – the vegetables at BG that are available now for nutrient testing are: pumpkin, lady's finger, brinjal (aubergine), long bean, basella. **It is proposed that one of each vegetable is tested because we are not looking for statistical significance.**

- The 'SCORRES vegetables'
    - The sample size suggested by HWU is 30 per bed. This will amount to 270 vegetables in total.
    - Testing for variability within a bed – the lab will dry out the sample and create a powder from each vegetable, so it would be possible to mix together the vegetable samples from 30 different plants from one bed. However, this will not provide a statistically significant sample, as the test result for each bed will be from a sample size of n=1 rather than from n=30.

1.4.1 Timeframe

- The 'non-SCORRES vegetables' Testing of the non-SCORRES vegetables can begin the week of 11 Sept, providing the budget is agreed.

- The 'SCORRES vegetables'
    - There will be several harvests for each vegetable type during its lifetime. Lady's finger will have around 15-20 harvests (every other day) and pumpkin & corn will have 4-5 harvests in total.
    - Vegetables will be tested from the first harvest, which is expected to produce a more nutritious crops.
    - The first harvest will be around mid Oct, depending on the rains (and also depending on replanting of pumpkin because the current seedlings in arrays A & B are diseased).

2 Soil Analysis Protocol

2.1 Which minerals to test

- One round of soil analysis was completed by EMS lab in June for N, P, K, organic carbon and pH.

- A second round of soil analysis was carried out by EMS in August for 2 arrays (A & C) for the same elements. The following additional elements were added to those tested in the first round because the soil kit failed to provide reliable readings: EC, Ca, Mg, Zn, Fe, Mn, S, B.

- This means that the nutrients proposed for testing in vegetables are already being tested in the soil analysis, which is useful (as outlined in point 1.2 ii) above).

2.2 Budget

- First soil test - the basic soil test for N, P, K, organic carbon and pH - the total cost was around INR 5,000.
- Second soil test - the basic soil test (above), plus EC, Ca, Mg, Zn, Fe, Mn, S, B - the total cost was around INR.10,000.

2.3 Timeframe

- It has already been agreed that there will be one soil test carried out at each of the three stages of plant growth (once plants have been transplanted into the arrays from the nursery).

- Soil testing for the second round of SCORRES plants (pumpkin, lady's finger and corn) is outlined below:
  - Plant stage 1 - the soil test from August for Arrays A and C will be used because it was carried out recently (and to save on costs). Therefore only Array B will need to be tested in this current plant cycle (Sept).

  - Plant stage 2 – the next test will be at the mid stage of the crop, which is expected to be mid-October, depending on the rains.

  - Plant stage 3 – soil testing will take place just before removing the plants, which will be sometime around mid Dec, again depending on the rains.

i David, D.R, Epp, M.D. and Riordan, H.D. (2004) Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999. Journal of the American College of Nutrition, Vol. 23, No. 6, 669–682

ii Streat, S. and Paul, K. (2014) Regenerative Agriculture: Sowing Health, Sustainability and Climate Stability. Organic Consumers Association

iii Magwazaa, L. S. and Opara , U.L. (2014) Analytical methods for determination of sugars and sweetness of horticultural products—A review. Scientia Horticulturae 184 (2015) 179–192