Big Data & Small Farmers:
Leveraging Data Science to Inform Best Farming Practices in India

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Dow Sustainability Fellowship Program 2015 & Dow Distinguished Awards for Interdisciplinary Sustainability

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INTRODUCTION

Rural households in semi-arid Telangana, India have been farming the same lands for generations. Recently, changing[1] climate[2] , increased variety and volatility of agricultural inputs such as seeds, fertilizers and pesticides have caused rapid depletion of natural resources[4] such as soils and water, and widely varying market prices for farm outputs have pushed the average farmer into a quagmire of uninformed decision making[5]. Coupled with complex changing political and policy factors in India, this has led to rampant poverty and high farm suicide[7] rates[8], which are likely underreported[9 10].

It is therefore imperative for farmers to focus on risk management under resource constrained conditions and uncertain times[11]. In the developed world, including the United States, this takes the form of site-specific guidelines such as nutrient management based on the 4R principle: Right timing, Right rate of application, Right source and Right Placement[12] and technologies for precision agriculture, among others. However, this approach is data intensive and the infrastructure to implement these techniques is only at the initial stages of being set up in developing world regions as Telangana[13].

PROJECT SCOPE

Our project proposes to harness the power of data to inform both risk management and local best management practices for small landholding farmers in India. The scope of this project includes data collection from individual farmers in the State of Telangana, India, to determine nutrient management practices. Concurrently, soil tests are being conducted to determine the quality and composition of soils across two villages, and temperature/ precipitation data from the Indian Meteorological Department (IMD)[14] have been obtained with the goal of expanding to other villages in the region. Using data science, we seek to tease out relationships between productivity, nutrient management and exogenous factors for rural villages in this region. The overarching objective of the project is to design and establish a framework to collect and analyse spatial and temporal high resolution farming data on a regional or national scale to subsequently leverage big data science to inform nutrient management practices among small farmers.

BUILDING ON PAST WORK

The current project is a natural evolution of our past work, started by the Adithya Dahagama, Leon Espira, and John Monnat as Dow Sustainability Fellows in 2014. Previous work by the team focused on the utility of de-silting irrigation ponds (also called "tanks") in Telangana as part of decentralized resource distribution model. Of note is that during the course of the project, a number of knowledge and logistic gaps were identified that need to be addressed to make farming a more sustainable endeavour.

To this end, we have been engaged in a concerted data collection effort. Beginning this past Spring, we conducted

a survey of more than 1100 farmers across 43 villages in the state of Telangana. The survey enabled us to collect a set of agricultural and economic metrics that we will integrate with our geospatial database. The survey quantified economic indicators such as income and debt load, gauged crop yields and corresponding inputs across the communities. It also provided us a better understanding of the use of silt in the farming matrix of Telengana.

We intend to build off the groundwork that we have laid, especially by focusing our ongoing data collection through the growing season (July - February) with the aim of identifying differences in nutrient and farm management practices among farmers that result in yield disparities both between and within villages.

LEVERAGING ESTABLISHED COLLABORATIONS

Over the last two years, support from the Dow Distinguished Awards on Interdisciplinary Sustainability to work on sustainability and systems influenced by irrigation ponds in South India, has helped us establish relationships and networks across various political and administrative functionaries in Telangana and India. Specifically, we've formed connections with the Ministry of Agriculture, Finance, Irrigation, and Rural Development in Telangana, allowing us to work with local government on ongoing policy decisions and real time feedback. We were able to disseminate our research and findings through press and media (refer to page 7) to raise interest across the diverse stakeholders involved in this process.

In this video from ABN Telugu news channel, the Chief Minister of Telangana, Kalvakuntla Chandrasekhar Rao, mentioned our ongoing research and collaboration efforts in Telangana in his address to the state on the occasion of India's 69th Independence day[15]. Thaneeru Harish Rao, the Minister of Irrigation, and Pocharam Srinivas Reddy, the Minister of Agriculture, have encouraged our engagement and efforts in Telangana state by directing relevant departments in the state to provide informational and logistics support as required. Thaneeru Harish Rao has expressed interest to visit U-M and accepted the invitation from Marie Lynn Miranda, the former dean of School of Natural Resources & Environment. We are currently working with the offices of Agriculture and Irrigation ministries on scheduling a convenient date for the Minister's' visit. We will continue to work with the government as part of a long term commitment to the region, and hope to build further bonds between the University of Michigan and the State of Telangana. Full list of collaborators is provided in Appendix 1.

TEAM

The project team consists of four students from five different schools at U-M. Collaborators include four recent graduates from four schools at U-M and two current students who worked on last year's Dow Distinguished Award for Interdisciplinary Sustainability on De-silting irrigation ponds in South India and an undergraduate student from Northwestern University. Advisors include interdisciplinary faculty from two schools at U-M. The recent graduates plan to advise the current team from their experiences in working in the region and are committed to furthering the impacts of the ongoing and future efforts by U-M in Telangana state. Rachel Jaffe, Stacy Pancratz, Samhita Shiledar, and Brendan O'Rorke bring diverse, unique, and critical areas of competence to complement the strengths of the existing interdisciplinary team.

Samhita Shiledar is a dual degree student in Sustainable Systems and Chemical Engineering. She comes from the Indian state of Maharashtra, where the farmer suicide rate is highest in the country. In May 2015, Samhita travelled to Hyderabad to learn more about the team's engagement, and met with Dr. Shailendra Kumar Joshi, the then Principal Secretary of Irrigation and Dr. Sambaiah, Director of Groundwater Department to talk about groundwater monitoring techniques and future collaboration. Samhita would work on data analysis and communication with government and field level partners.

Meeting with Agriculture officer in Adilabad to discuss farming.
Adilabad, Telangana

Meeting with Farmers and Surveyors in a de-silted pond.
Nalgonda, Telangana

Rachel Jaffe is a Dow Sustainability Fellow and a dual-degree student in Urban Planning & Design and Human-Computer Interaction at School of Information and Taubman College of Architecture & Urban Planning. She aims to address how information flows through regions to streamline the process of collecting data from farmers and how that data flows to policy-makers. Moving ahead, she is interested to design frameworks that can seamlessly update the geospatial map with data from the farmers that can provide an equally automatic feedback.

Stacy Pancratz is earning a Master of Science in Survey Methodology from the U-M Institute for Survey Research. She brings expertise in survey methodology, specifically questionnaire design, survey management, interviewing, and data management. She will lead the efforts to standardize, evaluate, and improve procedures for survey data collection from the farmers. Stacy has survey data collection experience in Malawi, Morocco and Qatar.

Brendan O'Rorke is an undergraduate student in Industrial Engineering and Economics at Northwestern University. He has over 10 years of experience working on a small sized American farm and will utilize this experience to assist the team with his practical farming knowledge. He also plans to provide a comparative perspective on the technological gaps in agriculture between the developed and underdeveloped regions.

PROGRESS SO FAR

1. Building the database
We focused on two villages: Chandaram village, Adilabad District that cultivates mainly paddy and Goliwada village, Karimnagar District that cultivates mainly cotton.

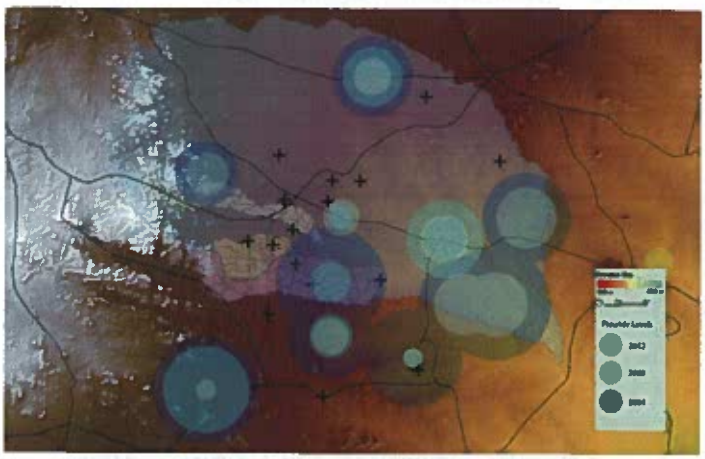
A. Daily Farmer Management Practices Survey
We have set up three databases to collect information from farmers :
(i) A general database of farmer land information including acreage and cropping history
(ii) A database for planting and harvest-specific information
(iii) A daily form for each individual farmer indicating management actions undertaken that day

B. Soil Data
Soil samples from 50 farmers from Chandaram and 200 farmers from Goliwada have been collected and sent to two laboratories - the Krishi Vignana Kendra, Karimnagar District and Nigama Engineering College, Karimnagar. Krishi Vignana Kendra also provides advice for corrective measures based on soil test results.

C. Spatial Database
We obtained hard copy government land survey maps and have digitized these maps to integrate farmer data collection with individual land parcels. This will help us visualize differences within the village by overlaying the other data on the maps. (Maps 1, 2)

D. Climate Data
We are in the process of obtaining 15 year climate data timeline for the two pilot villages from National Data Centre, India Meteorological Department in Pune[15]. This includes daily surface precipitation and temperature data of the

Map 1: Chandaram Village Map Digitized with survey numbers, farmer survey plots, and boundary information.
Adilabad, Telangana



Map 2: Local elevation map overlaid with flouride levels over time. The pond soil sample points and watershed and basin information show localised water flow and runoff. Nalgonda Region, Telangana.

A de-silted pond and the rebuilt berm.
Warangal, Telangana

weather stations - Ramagundam and Luxettipet - nearest to the two pilot villages from 1995 onwards. Data from these two stations covers 50,000 acres of agricultural land in the two mandals[17].

Exhibit: The basic inputs to the database (show graphic with soils, climate, survey map, farmer practice info) (hassan)

2. Setting up the information network and workflow
To facilitate data collection by the field managers in these villages, we purchased three computers and have installed the first internet connections in these villages. We are excited to have installed the first internet connections in these villages and hope this will create channels for the Base of the Pyramid farmers to connect with the data world.

Two of the computers purchased are for data collection in the villages through field managers. The other computer is used to monitor the data collection in the villages and to help us co-create the farmers survey questionnaire by Umamaheshwar Dahagama, who has 35 years of experience in farming and grassroots stakeholder engagement. So far, we have collected identifier data of farmers (name, age, phone number, etc) and farmland (survey number, acreage, crops cultivated, livestock owned, crop insurance, irrigation sources). Buying computers is an upgrade over the initial proposal of paper-based weekly survey as it is easier to obtain data through the field manager as the single point of control, collecting information from farmers over a mobile phone call (all the farmers we talked to have mobile phones). This reduces noise and errors in the data by eliminating a variety of answers by the farmers for the same questions. Further we found that using a computer was cheaper than printing out daily surveys for 180 farmers and hiring help to input the data into a database.

3. Hiring field managers

We hired one field manager per village for daily data collection from farmers. However, we have had to let one field manager go (See Challenges). A brief bio of our field manager is under Team CVs.

Exhibit: Examples of spatial distribution of data collected so far - according to survey numbers: show location of irrigation pumpsets (in HP) and distribution of Seed Variety, acres under farming, Irrigation Source, first tillage date; from Chandaram (at least) and Goliwada (if possible) data collected so far - (John)

Our current efforts will preliminarily introduce the farmer to the internet of agriculture and enable data-driven agricultural practices. The flow of information is fairly one sided now - from the farmers to us; we hope to soon create a feedback system to inform farmers as we assimilate the areas that create value from our data driven interventions.

ASSOCIATED OUTCOMES AND IMPACTS

More than half the population in Telangana is supported directly by employment in agriculture[18]. Given the length of the growing season, we expect to work on this project for six more months of data collection from farmers, and continue for the following six months to look at de-silting and outcomes. This will be followed by data analysis and more stakeholder engagement to summarize our findings. We will share the outcomes, impacts and experience from this project through two avenues: 1) Framework for data collection and analysis for nutrient managements 2) Presentations, reports or recommendations to appropriate stakeholders - political, administrative, academic through print and electronic media.

Prior to the award of the seed grant, some team members were in India interacting with stakeholders including farmers, agricultural field officers, irrigation engineers, administrative officials, and ministers State Government, particularly from the Ministries of Agriculture, Irrigation, and Rural Development. These ties on the ground have since given access to both data at the village level (survey and catchment maps) and other potential/continuing institutional collaborations (soil testing labs and mandal agricultural offices) that we are leveraging now.

Since May 2015, we have established the very first internet connection in two villages and designed a data collection mechanism and workflow for the field manager we have hired. This will streamline our future daily data collection from farmers. We have also gathered soil test samples from 180 farmers in the two villages. We will use this medium resolution spatial and temporal data to derive local relationships between exogenous factors like the climate and soils and farmer-specific practices that will facilitate informed decision making. Specifically, we think this data will help us understand the informational gaps such as 4R nutrient management and technical gaps such as precision agricultural practices among farmers and help us address them.

The value of our framework lies in the scalability with the potential to scale across the rural village communities not only in Telangana but across other Indian states. Over the next month, we plan to explore strategic partnerships and collaborations with agricultural research institutions in the area such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Institute of Information Technology Hyderabad (IIITH), and Professor Jayashankar Telangana State Agricultural University (PJTSAU). Particularly, an initiative launched by IIIT called e-Sagu[19] has the infrastructure we are looking for to scale up to the state level.

CHALLENGES AND LESSONS LEARNT

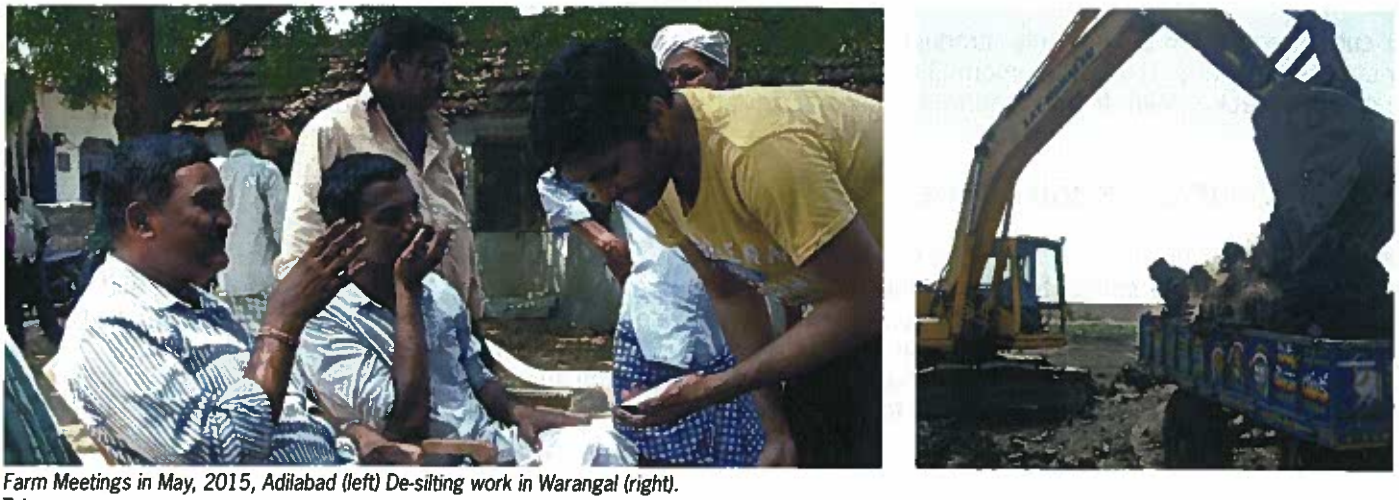
The team experienced some logistical problems with hiring the field manager and beginning work in Chandaram. The first field manager we hired had agricultural knowledge but worked fulltime for a fertilizer distribution store and could not provide effective service as a field manager. It was difficult to motivate this field manager to work on a part time basis to conduct the daily survey without supervision. However, in our second village, Goliwada, we hired a fulltime field manager in August, recommended by the Agricultural Officer from Ramagundam Mandal. This arrangement has worked better and we will bring in future hires who can work full-time as a field manager.

The other impact of this bottleneck is that we do not have data for the first two months for either village. While we are sure that the major agricultural practices can be traced back to weeks or in other cases the month in which it took place, this does leave some data gaps in our survey results.

We will address this in two ways. First, where farmers are unable to recall management operations for the past weeks, we will use the median farmer response for that week. Second - we will consult the agricultural calendar provided by the Government of Telangana to fill in the remaining data gaps.

NEXT STEPS

In order to meet the goals of our project we intend to undertake the following four actions



Farm Meetings in May, 2015, Adilabad (left) De-silting work in Warangal (right).
Telangana

1. Obtain new data and perfect data collection procedures

Over the summer we modified our initial approach to collect data from using paper surveys to using electronic data entry as it facilitates high quality data collection and seamless information exchange from the farmers to us through the field manager. Currently, we are co-creating and designing the survey framework for daily data collection of parameters and metrics for farming practices in different phases for paddy and cotton. Here, we are leveraging the help of farmers from Chandaram and Goliwada villages, as well as Ms. Aliveni Reddy and Mr. Prabhakar Rao, Mandal Agricultural Officers of Luxettipet & Ramagundam Zones. We are also in the process of obtaining historical climate data from IMD and historic aggregated crop data for the mandals from agricultural department, so that we could analyse them and provide insights to farmers using our information tool described below. Finally, we expect to continue data collection through the crop cycle with the help of field managers.

2. Attract new talent and create expert information tools

Our goal is to get an Agricultural, Soil, Agronomy expert on board. At the moment our team is talking to experts at U-M, Dow, Professor Jayashankar from Telangana State Agricultural University[20] and the International Institute of Information Technology Hyderabad[21]. It is important to add such expert to the team to internalize agricultural knowledge on growing paddy rice and cotton, which contribute to more than 70% of agricultural lands in Telangana, and to confidently advise the farmers on their practices. Leveraging knowledge of this expert we intend to build four information tools that would assist with developing recommendations for farmers on how to reduce inputs and increase harvest:

A. Build an interface for the farmers and field managers to refer to historic (15 years) climate (rainfall, temperature, wind) and aggregated crop yield timeline (5 years), as well as access weather forecast to inform farmers

B. Design field-manager and farmer friendly interface to collect daily activity data from farmers.

C. Analyze the data to understand parameters that have the highest influence on crop productivity. Examples of parameters include seed variety, amount of silt applied, water used for irrigation, quantity of fertilizers and pesticides applied. Finally, develop a feedback tool, which would highlight deviations from best baseline practices, to help field managers advise the farmers.

3. Continue strengthening ties with Government of Telangana & establish new partnerships

Discussed above in Leveraging Established Collaborations (and) Associated Outcomes and Impacts sections.

4. Scaling up/wrapping up the project

Finally, our team intends to make the nutrient management advice process thrive in other places in Telangana and India after the end of the current project. To accomplish this, we plan to evaluate perspectives of either making nutrient management recommendations a sustainable enterprise, or establishing this mechanism as a service provided by Mandal Agricultural Officers.

In the former case, we plan to evaluate suitability existing business base-of-the-pyramid models, as well as assess revenue streams from three sources:

1. Payments from farmers. At the moment we estimate farmers' willingness to pay as 600 Rs (9 USD), while cost of simple soil test is 200 Rs (3 USD)

2. Income from carbon credits through nutrient management as the mechanisms are already standardized for such interventions. Also, according to the McKinsey GHG abatement curve, Nutrient Management ranks among the

Newspaper clippings from local newspapers in the Telangana about the ongoing research. May 2015. Warangal, Telangana

top 5 interventions, to reduce global GHG emissions, that have a high return on investment[22].

Our ongoing work on selling carbon credits from silt transportation and application (still in progress) would fit well with the acre/farmer level monitoring system that our model facilitates to generate additional value. Finally, we expect to see strong economy of scale as we increase number of farmers involved in nutrient management advice program.

Given the strong social and environmental impact of our project, as well as longer term returns, we plan to finance our enterprise efforts with patient capital from Acumen fund. In case our team concludes that we won't be able to pursue a sustainable business enterprise, we plan to wrap up the project by transferring our accumulated experience, knowledge, and tools to the Ministry of Agriculture and Ministry of Rural Development. Leveraging our strong ties in the region, we plan to implement nutrient management advice mechanism as a standard practice of Mandal/Village Agricultural Officers by integrating this into the Telangana State Government's novel Rural Development program called Grama Jyothi[23] through which the government plans to spend close to 900 Million USD starting this year. This route will help to rapidly disseminate the model to positively impact the 23 million populace living across 8685 gram panchayats (11000 plus villages) in the state with agriculture as the primary source of livelihood.

Funding at 50% of the Proposed Amount

We believe that we have provided a cost-effective budget that has been optimized for the needs of the project. However if funded at only half the requested amount, the project expenses can be pared down as follows; the time spent by the Graduate Student Researchers would be cut down to half for a total US personnel budget of $10,800. The in-country team would also be reduced to 2 on-site Field Managers for a total in-country personnel budget of $2250. The soil tests expenses would also be cut in half to $1500, resulting in only 250 standard soil tests and 50 comprehensive soil tests being done. We however feel that the our remaining data collection infrastructure should be funded to the full amount and we would consider further budget reallocation depending on the funding level. Travel expenses would be halved to $4,800 for International Travel and $1,500 for in country travel since only 3 researchers would be funded for travel to present our work to the government. Furthermore our community outreach and communication budgets would be cut down to $750 and $800 respectively. With the outlined streamlining, our budget would total $21,540, with our data collection infrastructure remaining intact.

Appendix 1. List of collaborators (existing & potential)

University of Michigan
Center for Sustainable Systems at U-M
Government of Telangana
Department of Agriculture
Department of Irrigation
Department of Rural Development
Mandal Agricultural Officers of Ramagundam and Luxettipet
Krishi Vignana Kendra (KVK)
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
International Institute of Information Technology Hyderabad (IIIT-H)
Professor Jayashankar Telangana State Agricultural University (PJTSAU)
Nigama Engineering College, Karimnagar
Farmers in Chandaram and Goliwada Villages
Local Field Managers

Pond full during the rainy season
Adilabad, Telangana

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All Photos by John Monnat and Umamaheshwar Dahagama

Results From Farmer Survey Implemented in 2015

Surveyed Farmers by Caste and Silt Use

Caste	Number of People in Survey	Percent of Survey total	Percent within the caste who use Silt
Other Castes (OC)	78	8.1%	21.8%
Backward Castes (BC)	637	65.8%	28.3%
Scheduled Castes (SC)	232	23.9%	26.7%
Scheduled Tribes (ST)	21	2.2%	33.3%
Survey Population Total	968	100%	27.48%

Table 1: Displays survey population demographics and silt use. Nearly 2/3 (65.8%) of the farmers we surveyed were from BC. Of the 968 farmers surveyed, only 27.48% said they have used silt before. Interestingly, in our survey a greater percentage of farmers from BC, SC, and ST used silt than farmers from OC. A greater percentage of farmers from BC and ST castes used silt than the survey population average.

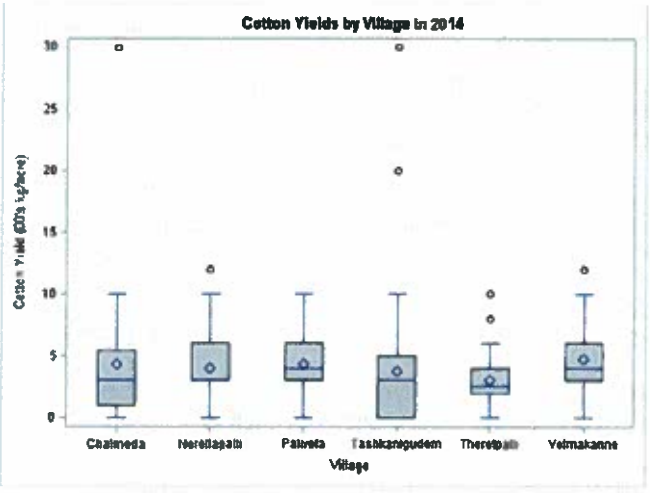

Figure : Box plots comparing distributions of cotton yields across six villages in Nalgonda district, Telangana. Average cotton yields for these villages was approximately 3.5 kg/acre in 2014. Three farmers out of those surveyed produced dramatically more cotton per acre, even after the removal of several outliers from this particular analysis.

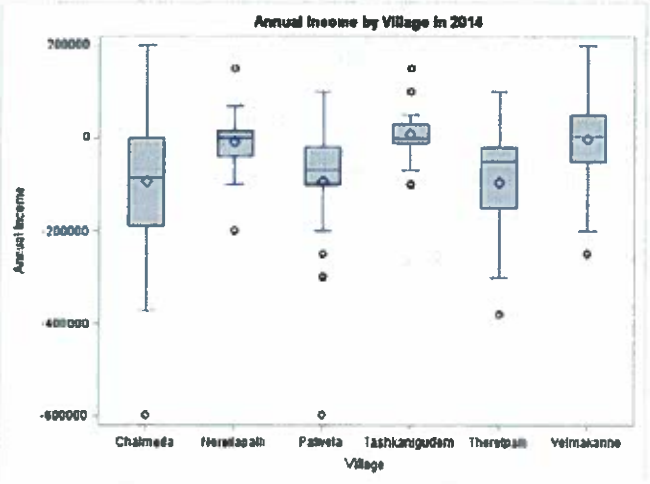

Figure: Farmer income for 2014 varies the most in Chalmeda village and least in Tashkanigudem village. Several famers reported negative income because they lost money on their farms that year, and are in debt. Incomes reported and displayed here in Rupees (Rs).

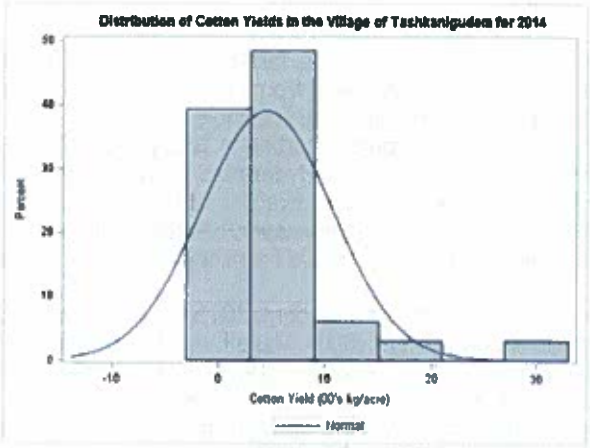

Figure 3: 2014 cotton yields for Tashkanigudem village vary dramatically, where a few farmers produced 20 – 30 times as much cotton in kg/acre as most of their neighboring farmers.

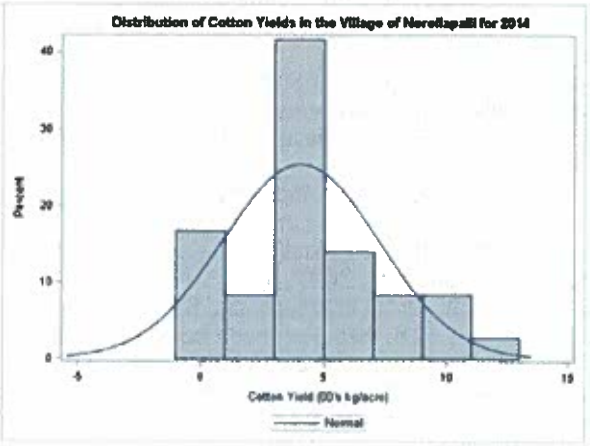

Figure: Cotton productivity in kg/acre among the farmers surveyed in the village of Nerellapalli in Nalgonda district, Telangana, follows a roughly normal distribution. On average the farmers here produced 3 – 5 kg/acre.

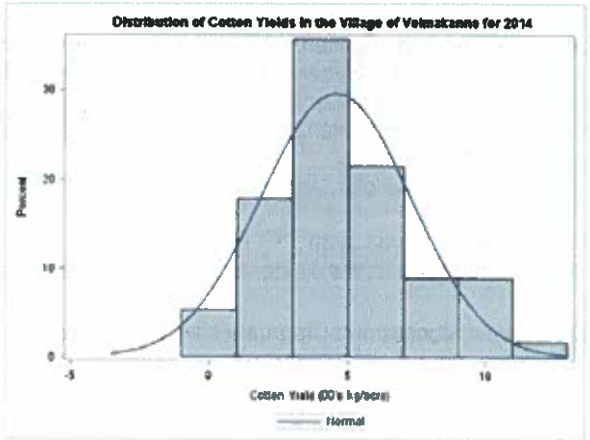

Figure 1: In Velmakanne, Telangana, the 2014 cotton yields for cotton farmers surveyed followed an approximately normal distribution, with slight right skew. The range of cotton yields was 0 – 12 kg/acre. One third of farmers produced 4 kg/acre.

Actual expenditures in the first phase (May through September 2015), and proposed budget for the second phase (September through April 2016)

	Already Awarded: Pilot (May'15-Sep'15)			Current Proposal: Further Execution (Oct'15-Apr'16)		
Description of Expenditure	Unit Cost (USD)	Quantity	Total Cost (USD)	Unit Cost (USD)	Quantity	Total Cost (USD)
Labor expenses			2,240			**26,100**
Graduate Student Researchers with expertise in building data input interfaces				18/hr	100 hrs	1,800
Graduate Student Researchers with expertise on digitizing maps and geospatial modelling	18/hr	40 hrs	720	18/hr	250 hrs	4,500
Graduate Student Researchers with expertise on Survey Design & Research	18/hr	40 hrs	720	18/hr	300 hrs	5,400
Graduate Student Researchers with expertise on Data Analysis	-	-	0	18/hr	350 hrs	6,300
Operations Manager to monitor local field managers and other logistics	-	-	0	150/week	24 weeks	3,600
Agricultural Scientist/Agronomist from local Research Institution or University				750/month	3 months	2,250
Weekly wages for onsite Field Managers	25/week	2 persons x 18 weeks	800	25/wk	3 persons x 30 wk	2250
Soil sampling and analysis			150			**3000**
Simple farm soil test (one per acre)	3/test	50 tests	150	3/test	500 tests	1500
In-depth farm soil test (one per field)	-	-	0	15/test	100 tests	1500
Data collection & processing expenses			820			**1640**
Computers/tablets for Field Managers	250/unit	3 units	750	200/unit	1	200
15 years historic climate data from IMD, Pune	100/station	2 stations	200		-	-
Hard copy village maps	30/village	2 villages	60		-	-
In-country data entry and processing	100/month	4 months	400	200/month	6 months	1200
Internet connections	20/month	2 villages x 4 months	160	20/month	2 villages x 6 months	240
Travel expenses			100	-	-	**12700**
Soil samples transportation	25/set	4 sets	100	25/set	4 sets	100
International travel from Michigan to India	-	-	0	1600	6 persons	9600
In-country travel and accommodation	-	-	0	500/person	6 persons	3000
Outreach & Farmer Engagement	-	-	500			**2500**
Communications & Press - print & electronic	300	-	300	1500	-	1500
Farmer interest meetings & symposium	50 per meeting	4 meetings	200	2/farmer	500 farmers	1000
TOTAL EXPENDITURE			4,760			**48,140**

Project Timeline and Activities 2015-2016