Improving the Sustainability and Productivity of Poor Smallholder Farmers in Northern Ghana Using Electromagnetic Induction Guided Precision Irrigation

Final Project Report

To

Geoscientists Without Borders

July 31, 2020

Erasmus Oware
SUNY at Buffalo

John Lane
US Geological Survey

Vincent Gbedzi
University for Development Studies
Tamale - Ghana

Patience Bosompemaa
Ghana Geological Survey Authority
Accra – Ghana

Samuel Guug
The West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), Bolgatanga – Ghana
Abstract

Food production in some parts of Sub-Saharan Africa, including northern Ghana, is under threat due to changing climate that has resulted in unreliable weather patterns with prolonged dry seasons. The situation has resulted in widespread poverty in northern Ghana, which has fueled seasonal rural-urban migration of mostly women and children to big cities in search of meager or non-existent jobs. Enabling dry season farming is critical to poverty reduction and socio-economic development in northern Ghana. The primary goal of the GWB Ghana Project was to develop a strategy to assist poor smallholder farmers to make judicious use of their limited irrigation water during the long dry season, with the ultimate goal of extending the farming season to promote socio-economic development and food security. To this end, the project developed a precision irrigation framework (PIF), which is a low-cost strategy to guide irrigation scheduling for efficient irrigation water management to enable sustainable dry season farming. PIF applies machine learning to integrate multi-scale ground-truth data and satellite imagery to create irrigation water management zones for an entire region. The successful demonstration of PIF in northern Ghana provides a blueprint for a potential low-cost strategy to facilitate dry season farming to address the climate change induced diminishing food production in some parts of Sub-Saharan Africa.

In addition to the development of the PIF, the project conducted multiple activities geared toward long-term project sustainability and in-country capacity building, namely: (i) Collaborated with three in-country institutions, (ii) Engaged and trained two local students, eight local farmers, and four in-country participants (iii) Conducted two workshop series to educate and train over 150 smallholder famers about efficient irrigation water management to facilitate sustainable dry season farming, (iv) Organized field trials based on the project recommendations to demonstrate to farmers in the area how to grow new crops in the middle of the sweltering dry season heat (v) Provided experiential learning opportunities to three University at Buffalo students (two graduate students and one undergraduate student), with one of the graduate students leveraging the project data for his MS thesis with the second graduate student’s MS thesis currently in progress, (vi) The project produced several publications including one abstract in the Humanitarian Geophysics Session at the 2018 SAGEEP Conference at Nashville, TN, two expanded abstracts presented at the 2018 and 2019 SEG annual meetings with a final peer reviewed publication in submission.
1. Background Information

1.1 Project Overview and Goals

Changing climate has resulted in increasingly unreliable weather patterns with prolonged dry seasons (Yengoh et al., 2010) in some parts of Sub-Saharan Africa, specifically countries in the transition belt between the Sahara Desert and the tropical rainforest. The prolonged dry season is adversely impacting sustainable food production because farmers in the region mostly depend on rain-fed farming. Northern Ghana is a classic example of an area in this transition zone. Hence, the project used northern Ghana as a testbed to develop a precision irrigation framework to facilitate sustainable dry season farming that is applicable to Sub-Sharan Africa in general. Northern Ghana, in particular, experiences long dry season lasting seven to eight months with only four to five months of wet season in a year. While over 70% of the inhabitants are farmers (Ghana Ministry of Food and Agriculture, 2007), the singular rainy season limits rain-fed farming to only four to five months of the year (Kyei-Baffour and Ofori, 2006), resulting in severe poverty in the region. The poverty situation has fueled an undesirable coping mechanism of seasonal migration to major cities in the south in search of meager jobs (Quaye, 2008; Assan et al., 2009). Enabling dry-season farming is crucial to sustainable food production and poverty reduction in northern Ghana specifically and Sub-Saharan Africa as a whole.

The primary goal of the GWB Ghana project was to facilitate dry-season farming for sustainable food production in northern Ghana. Specifically, we sought to develop a precision irrigation framework to assist poor smallholder farmers to make judicious use of their limited irrigation water with the long-term goal of extending the farming season to promote socio-economic development and food security in northern Ghana. Moreover, in spite of the increasing efforts and awareness of the potential of irrigation in addressing the perennial unemployment during the extended dry-season in northern Ghana [e.g, Dinye and Ayitio, 2013], the crucial role of water management in irrigation is completely ignored. The project also sought to create awareness of the importance of efficient water management as an integral component of irrigation management practices and offer a practical approach to address the problem.

1.2 Location and Climatic Setting

Ghana is located within latitudes 4°44′ N and 11°11′ N and longitudes 3°11′ W and 1°11′E [Oppong-Anane, 2006] with northern Ghana spanning almost 50% of the approximately 238,500 km² landmass of Ghana [Oppong-Anane, 2006]. There were two project locations, project year 1 (PY1) and project year two (PY2) areas. Figure 1 shows a map of Ghana, inserted is the relative location of Ghana within Africa, including marked PY1 and PY2 locations. Ghana is divided into a total of 10 administrative regions with three regions comprising northern Ghana, namely: Northern Region, Upper East Region, and Upper West Region. PY1 and PY2 are located in the Northern and Upper East Regions, respectively.

The country is divided into six agro-ecological zones on the basis of their climate with northern Ghana falling under the Sudan and Guinea Savannah Zones [FOA, 2005]. The Sudan and Guinea Savannah Zones are the only zones characterized by a uni-modal rainfall pattern whereas the remaining zones have bi-modal rainfall patterns [FOA, 2005; Oppong-Anane, 2006], thereby limiting northern Ghana to only one farming season in contrast to the major and minor farming seasons prevailing in the rest of the country. Furthermore, the environmental conditions in northern Ghana is semi-arid [Dinye and Ayitio, 2013] characterized by hot and dry winds with excessive evapotranspiration, favoring only 4 to 5 months of farming in a year with long 7 to 8
months of extended dry-season [Namara et al., 2011]. To address the poverty situation, it is widely acknowledged that irrigation is needed in northern Ghana to enable farming during the extended dry-season [e.g., Namara et al., 2011], in an attempt to provide a year-round employment for the people. The adoption of smallholder irrigation, for instance, has helped the inhabitants to cope with the changing climate, reduced poverty, and reversed rural-urban migration [Laube et al., 2012]. This project sought to improve the dry season farming efforts in the area.

Figure 1: Map of Ghana showing the river basins of Ghana. Insert is an African Map indicating the relative location of Ghana in Africa. The red boxes mark the approximate locations of project year 1 (PY1) and two (PY2) regions. Modified from Namara et al. (2011).
2. Field Studies

2.1 Field Studies

The primary objective of the project was to develop a precision irrigation framework (PIF) for the two project areas to facilitate smallholder dry-season irrigation farming. The PIF simply creates irrigation water management zones of the entire project area with irrigation recommendations (irrigation frequency and duration) to guide irrigation scheduling for efficient dry-season irrigation water management. Soil texture controls water-holding characteristics of soils, which determines the amount of water that will be available to plants for optimal growth. Consequently, spatial variability in underlying soil texture is key to determining spatial variability in any irrigation scheduling scheme. Given that it’s impractical to collect high-resolution soil texture data across the entire project area, we adopted a multi-scale (two-step) approach to unify high-resolution farm-scale data with a large-scale soil-texture map to create the PIF. The following Sections present summaries of the field studies. Results of the Project Year 1 (PY1) and Project Year 2 (PY2) field campaigns are presented in Appendices A and B, respectively. A final peer-review publication will be published in a Special Section on Humanitarian Geophysics in Geophysics or Journal of Precision Agriculture.

2.2.1 Farm-Scale Surveys

We performed multiple farm-scale surveys on eight project participating farms to acquire high-resolution data to be unified with large-scale soil texture map to create the PIF. The farm-scale surveys included electromagnetic induction (EMI) surveys, field infiltration tests, and high-resolution farm-scale soil sampling. We performed the EMI surveys using the Geonics EM38-MK2 conductivity meter with a DAS70-AR2 Data Acquisition System mounted in a custom-made sled and towed behind a tractor. The goals of the EMI surveys were to rapidly identify various soil units within a field to target soil sampling locations and guide the selection of infiltration test sites. To identify spatial variability in the water-holding characteristics of a field, we performed the EMI surveys for dry and wet field conditions. The difference between the wet and dry EC maps provided insight into spatial variability in the water-holding characteristics of the field (e.g., Fontaine et al. (2018), Appendix A). Figure 2 shows a picture of the team with farmers after an EMI survey of a field.

We performed field infiltration tests to directly estimate the water-holding capacities (field-capacity (FC) and water depletion rate (WDR)) of soil units within a field. The infiltration test sites were selected based on soil units identified from the EC maps in an attempt to capture representative hydraulic responses of the identified EC (soil) units within a field. For the soil moisture monitoring, we used the Onset Time Domain Reflectometry (TDR) soil moisture probes with a HOBO USB Micro Station logger. The sensors were programmed to log soil moisture every 30 s to provide high temporal resolution of soil moisture profiles to calibrate the water-holding characteristics of the soil units. Additionally, soil samples were collected at each infiltration test site to provide direct, co-located soil texture data for each soil moisture profile from the infiltration experiments. Soil samples were also collected across each field to provide farm-scale soil texture data to help tie-in the high-resolution farm-scale data to the large-scale soil texture map of the entire project area.
A soil texture map for the area is needed to create the PIF for the entire project area. To create a soil texture map for the entire project region, we collected coarse-scale soil samples across the entire project region. We collected a total of 18 and 22 coarse-scale soil samples across PY1 and PY2 regions, respectively. Overall, we collected a total of 217 soil samples in both the coarse-scale and farm-scale soil sampling efforts for PY1 and PY1. The soil samples were collected with a handheld auger over a composite depth of 0–0.4 meters. All of the soil samples were analyzed at the Spanish Laboratory at the University for Development Studies (UDS) in Nyankpala, Ghana. Estimates of the sand, silt, and clay proportions of the soil samples were obtained using the hydrometer method (Bouyoucos, 1962). We used the soil texture calculator and plotting tool developed by the USDA’s Natural Resources Conservation Service (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167) to classify soil texture based on the soil separate proportions from the particle size analyses.

To create the project-scale soil texture map, we employed the soil texture data to condition the prediction of the sand, clay, and silt proportions for the entire project area. Because the project-scale soil texture data have poor spatial resolution, we applied remote sensing data to compliment the soil texture data for the large-scale soil texture prediction. To do so, we applied Landsat 8 (30 m resolution) as secondary data to co-krig with the soil texture data to create the project-scale soil texture map. We performed the co-kriging in ArcMap®.
2.2.3 Creation of the Precision Irrigation Framework

Soil texture is the primary driver of water-holding characteristics of soils, which in turn informs irrigation scheduling. Hence, to create the PIF, we applied soil-texture as the basis to unify the high-resolution farm-scale data with the project-scale soil-texture map. To do so, we first created water management zone (WMZ) classes from co-located soil texture and hydraulic properties (field capacity and water depletion rate) estimated from the field irrigation experiments. We then applied the identified WMZ classes and their corresponding soil texture data to train a non-parametric machine leaning classifier, the k-nearest neighbors (KNN) algorithm (e.g., Harrington, 2012). We then applied the trained KNN classifier to classify the project-scale soil texture into WMZ class map. The WMZ class map constitutes the PIF for the project area (e.g., Fontaine et al. (2019), Appendix B). To facilitate long-term sustainability of the project impacts, the in-country collaborators, the department of Agriculture at the University for Development Studies and the West African Science Services Center for Climate Change Adapted Land Use (WASCAL), will incorporate the project recommendations in their outreach programs.

2.2 Field Trials According to Project Recommendations

There is a general perception in the area that dry-season farming is a waste of time, energy, and resources, based on their experience, particularly during the peak of the dry and hot weather from January to April. Hence, a successful demonstration of dry season farming during this period based on our irrigation water management and recommendations is crucial to increasing awareness about the project and convincing more farmers to adopt the strategy, as part of the project sustainability plan. The goal of the field trials was to provide evidence-based demonstration to promote the project ideas to smallholder dry season irrigation farmers in the area. Toward this end, we performed dry-season farming field trials on five of the eight project participating farms.

Based on their experience, the farmers were unwilling to participate in the field trials by investing resources to grow new crops in the middle of the sweltering heat in January. To alleviate their concerns, the project supported the farmers by covering the costs of plowing the fields, seedlings, and fertilizer. The contributions of the farmers were then to manage and irrigate the crops according to the project recommendations and keep the produce at the end of the season, which excited the farmers to get on board. They were also required not to over-irrigate to create ponds around the crops, which is their current irrigation practice. Specifically, their current irrigation practice is to make bunds around the crops and pond them (Figure 3 Left). This creates an issue of severe over-irrigation resulting in water, energy, and fertilizer wastage while increasing the environmental footprint of their farming.
Moreover, ponding the crops in an 80-100 °F hot and dry weather also amounts to “cooking” the crops while growing. As the project raised these issues with their current irrigation practice, the farmers started providing anecdotal evidence of the issues raised. They testified to observing that crops in the middle of the ponds that are submerged for a long period have poor yields in contrast to yields obtained from crops at the edges of the bunds that are unsubmerged. Figure 3 (Right) shows a farmer showing the team how crops at the edges of the bunds produce large onion stock compare to the small onion stock of crops in the middle. They testified that the produce from crops submerged in the middle of the ponds also rot quickly, which increases post-harvest losses. All these issues were raised and thoroughly discussed and addressed during the two workshop series.

Figure 4: Pictures from two of the five field trials during the growing season showing strict adherence to the project recommendation, i.e., frequent (every 2-6 days) irrigation without ponding.
Depending on the location of a farm and the underlying soil type, we deduced from our irrigation field experiments that irrigation frequency ranges from two to six days (e.g., Appendix 2). A key requirement of the field trial was for the farmers to adhere strictly to the project recommended frequency of irrigation in their area and irrigate to saturate the soil without ponding (e.g., Figure 4). The trials on all the five fields were hugely successful. Unlike their current irrigation practice that produced larger onion stocks for only crops on the edges of the bunds, our field trials produced consistently large onion stocks across the whole field.

![Image of farmers displaying produce](image)

**Figure 5**: Two of the five farmers happily displaying some of the produce from their field trials.

The farmers were surprised and excited about the success of the field trials, which involved growing new crops in the middle of the sweltering heat in January, something they will not venture on their own. Figure 5 shows some of the farmers displaying the large onion stocks from their field trials. The success of the field trials did not only demonstrate the performance of the project to only the farmers involved in the field trials, but demonstrated to other farmers in the area that it is possible to grow new crops in the middle of the dry-season. This provided evidence-based demonstration critical to changing the perception in the area that dry-season farming is a waste of time, energy, and resources, especially growing new crops in the middle of the dry-season. Indeed, the ability and willingness of the farmers to grow new crops in the middle of the dry-season is crucial to extending the farming season, which is one of the long-term goals of the project.
3. **The Human Element**

The project engaged and trained multiple participants and provided experiential learning opportunities to both local and American college students. Figure 6 shows the project team at the campus of the in-country institution on the last day of the Year 1 field campaign.

![Image of project team](image)

**Figure 6:** The Project Team at the Spanish Laboratory at the University for Development Studies on the last day of the Year 1 fieldwork. From left to right: Project Driver Paa, Laboratory Manager Abdul-aziz Bawa, Laboratory Technician Ayaaba Atongi, UB Graduate Student Jeremy Fontaine, Local Student Simon Amuzi, PI Oware, Patience Bosompemaa, Vincent Gbedzi, Local Student Sahaban Muni, Laboratory Technician Harris Musah, Dr John Lane, and UB Undergraduate Student Alexander Percy.

3.1 Team Leaders

- Erasmus Oware, *Assistant Professor*, University at Buffalo.

Dr. Oware served as the Principal Investigator for the project and the primary liaison with GWB. He led the design and supervision of all aspects of the field work, data processing and interpretation, student and participant training. He served as the resource person for the two workshop series to educate and train local farmers on the need for irrigation water management and how to improve their current irrigation practices for sustainable dry-season farming.
• John Lane, *Chief of the United States Geological Survey Office of Groundwater*, Branch of Geophysics. Dr. Lane served as the Co-PI of the project. He participated in the field work and provided technical support and advisory to the PI. His involvement in the electromagnetic induction survey design, laboratory soil analyses, and student training were invaluable.

• Vincent Gbedzi, *Lecturer*, University for Development Studies, Tamale – Ghana. Vincent is a lecturer at the in-country collaborating institution. He served as the in-country main point of contact for the project. He played a pivotal role in coordinating all in-country activities, including pre-preparations for the fieldwork, recruitment of local students, identification of project participating farmers, etc. He was also very instrumental in the organization of the two workshop series.

• Patience Bosompemaa, *Assistant Geologist*, Ghana Geological Survey Authority, Accra. Patience Bosompemaa is an Assistant Geologist with the Ghana Geological Survey Authority (GGSA). Patience participated fully in the fieldwork and was trained in all aspects of the project. As an early-career geologist, her training and involvement in the project are crucial to the long-term sustainability of the project. After the year 1 fieldwork, PI Oware assisted Patience to secure admission with funding for her graduate studies at his alma mater Illinois State University. She’s completed her MS degree in Hydrogeology at the Illinois State University and about to start her PhD at University of Kansas in fall 2020.

4.3 College Professors

In addition to the involvement of the in-country collaborator, Vincent Gbedzi, the project also worked with researchers at the Spanish Laboratory of the University for Development Studies (UDS). The Spanish Laboratory is a soil laboratory funded by the Spanish government for the Department of Agriculture of UDS. The laboratory supported student training and performed soil texture analysis using the hydrometer method for a total of 216 soil samples for the project. The laboratory benefited from the project through international collaboration with PI Oware and Dr. John Lane to improve their soil texture analysis procedure. For instance, to take representative soil sample for texture analysis, they dried and sieved the sample through the 200 mm sieve without crushing lumps in the soil sample. Given that clay particles absorb water to form big lumps that cannot go through the 200 mm sieve, taking representative sample after drying without grinding the sample will result in under-representation of clay proportion in the texture analysis. PI Oware and Dr. John Lane explained to the lab technicians this lapse in their procedure and how to address it. The project then donated two stainless steel mortar and piston to the lab for soil grinding. This improvement in their procedure will not only improve texture analysis results for the project, but will benefit the lab and its soil texture analysis procedure going forward.

4.4 Professional Consultants

Two professional consultants, Samuel Guug and Eric Doe, were engaged on the project. Samuel is from the West African Science Services Center for Climate Change Adapted Land Use (WASCAL) and Eric is from the International Institute of Tropical Agriculture (IITA). WASCAL and IITA are both NGOs working to improve agricultural production in the area. Specifically,
WASCAL is a German funded NGO working to address agricultural challenges related to the issue of climate change in West Africa, while IITA is interested in agricultural innovations to meet the pressing challenges of hunger and poverty in Africa, which both aligns perfectly with our project. Given their familiarity in the terrain and several years of experience working with farmers in the area, the involvement of Samuel and Eric in the project was invaluable particularly in community entry and coordinating and organizing the workshops to train and educate farmers. They both participated fully in the fieldwork and were also trained in all aspects of the project, as part of the in-country capacity building. Samuel also served as the interpreter and farmer’s liaison for the project in the PY2 area while Eric did same in the PY1 area. Their training and involvement in the project will allow them to incorporate the project ideas and recommendations in their duties and outreach programs at their respect NGOs, which will contribute to the long-term project impacts.

4.6 Student Involvement and Training

Student training was integrated in all aspects of the project, including field data acquisition and processing, workshop training, and laboratory soil texture analysis. After the field surveys, which included student training on soil sampling and electromagnetic induction (EM) surveys, a day was dedicated as Laboratory Day (Figure 7) purposely for student training in the laboratory. Students were trained on the full procedure of soil texture analysis using the hydrometer method. In all, two local students from the Agricultural Department of the University for Development Studies, Simon Amuzi and Sahaban Mumin participated in the project and were trained during both the PY1 and PY2 field campaigns. Under the supervision of the in-country collaborator Vincent, the local students also worked with the project participating farmers to perform soil-moisture monitoring and irrigate according to the project recommendation during the growing season.

Figure 7: Laboratory Day for student training at the Spanish Laboratory on the campus of University for Development Studies.
Moreover, the project also provided invaluable experiential learning opportunities to three University at Buffalo students. While graduate student Jeremy Fontaine and undergraduate student Alexander Percy were involved in the PY1 fieldwork, graduate student Joseph Fentzke participated in the PY2 field campaign. Jeremy leveraged the project data for his MS thesis (Fontaine et al., 2018, 2019) and he’s currently working as a Project Geologist at HRP Associates. Alexander Percy is also currently working at SJB Service Inc. as a Geologist and Lab Technician. Their field experience in Ghana played a crucial role in their competitiveness for their current positions. Joseph Fentzke is also currently using the project data for his MS thesis.

4.7 Local Residents

A total of eight project participating smallholder irrigation farmers (local residents) were involved in the project. The farmers were trained and participated in all aspects of the project. Five of the eight farmers also participated in the field trials (Section 2.2) to demonstrate to other farmers the potential of the project recommendations to improve their dry season farming. The field trials were highly successful, which demonstrated to farmers that with efficient irrigation water management practice, new crops can successfully be grown in the middle of the sweltering heat in January. The successful demonstration of the field trials to farmers can have far-reaching consequences on the potential of extending the farming season in the area.

Furthermore, to extend the project beneficiaries beyond the eight project participating farmers, we organized two workshop series during the PY2 field campaigns in the two project areas. As noted by Dinye and Ayitio (2013), in spite of the increasing efforts and awareness of the potential of irrigation to address the perennial unemployment during the extended dry-season in northern Ghana, the crucial role of water management in irrigation is completely ignored. This motivated the goals of the two workshop series, to educate and train smallholder irrigation farmers on the need for efficient irrigation water management for sustainable dry-season farming to increase productivity and profitability.

Farmers were educated on the need for them to make deliberate efforts to improve their irrigation water management practice in an attempt to sustain their dry-season farming efforts. They were briefed on the project goals and how to use the developed precision irrigation framework to improve their current irrigation water management practices. In addition, we identified some key limitations of their current irrigation practice and addressed them during the workshops. Key among the limitations was the issue of over-irrigation (ponding, Section 2.2), which did not only waste farmer’s time but also wasted water and fuel for pumping the water thereby increasing production costs. It also induces leaching of applied fertilizer beyond the root zone, which makes the applied fertilizer unavailable to the crop and contaminates their groundwater resources. These issues were thoroughly discussed during the workshops to make it clear to the farmers the benefits to not over-irrigate.

We stressed that their irrigation goal should always be to irrigate to just saturate the soil without ponding. We also used soil moisture depletion curves from our field irrigation experiments (e.g., Figure 2 Appendix B) to demonstrate to them the water depletion behavior after irrigation. From the curves, we showed the farmers how over-irrigated water flashes through the soil, which will become unavailable to the crop and also depletes their soil nutrients. The workshops were also designed to be interactive (e.g., Figure 8 top picture) in an attempt to solicit feedback from the smallholder farmers about the challenges of their current irrigation practice and, generally, dry-season farming in the area.
Overall, 150 smallholder irrigation farmers attended the two workshop series, including several women (Figure 8 bottom picture). This means that about 150 smallholder irrigation farmers in the area, in addition to those that the 150 farmers will pass on the information to, now understand the need for efficient irrigation water management, limitations of their current irrigation practice and how to address them. This also satisfied one of the goals of the project; creating awareness about the need for efficient irrigation water management to facilitate dry season farming. Hence, the two workshop series and the field trials form key components of the long-term sustainability of the impacts of the project.

Figure 8: Pictures from the two workshop series. (Top) a farmer sharing his experience and challenges with their current dry season irrigation management practice during the workshop in the project year 2 area. (Bottom) a group picture of the team with participants after the workshop in the project year 1 area.
4. Lessons Learned

An important lesson learned in working in rural communities particularly in Africa is the need for a deliberate action to mitigate the issue of cultural risk. Project leaders should seek some rudimentary understanding of the norms and traditions of the people and incorporate them in their project plan. For instance, it’s a taboo in some communities to just enter a village and start working with the farmers without first introducing the team’s presence to the local village chief. In essence, starting work without acknowledging that there is a leader in the village. The project participating farmer introducing strangers to the community without greeting the chief first may be seen as a sign of disrespect to the chief, and may land him/her into trouble. Hence, future projects should always have community entry plans to introduce the project to the local chief and, if possible, solicit their participation.

Local chiefs wield a lot of influence on their communities and their acceptance and participation in the project can play a crucial role in the long-term sustainability of the project. Figure 9 shows a project participating farmer introducing the team to the chief of the Arugu community in the project year 2 area.

Even though projects may meticulously plan for their field campaigns, there may still be unforeseen challenges in working in mostly remote areas. While financial limitations may not allow multiple field campaigns, we encourage future projects to plan for at least two field campaigns to provide an opportunity to address unforeseen problems in the first field work, in an effort to realize the project goals. Finally, we learned that shipping geophysical instruments and project equipment via shipping carriers to remote project areas, which includes fees for customs duty, can be extremely expensive. If possible, future projects should consider shipping project equipment via airlines as checked baggage, which can be fast and less expensive.

5. Conclusion

Food production in some parts of Sub-Saharan Africa is under threat due to changing climate that has resulted in prolonged dry-seasons. The situation is expected to only get worse. The GWB Ghana Project has developed a precision irrigation framework (PIF), which is a low-cost strategy to guide irrigation scheduling for efficient irrigation water management for sustainable dry season farming. PIF applies machine learning to integrate multi-scale ground-truth data and satellite imagery to create irrigation water management zones for an entire region. The successful demonstration of PIF in northern Ghana provides a blueprint for a potential low-cost strategy to address the challenge of diminishing food production in some parts of Sub-Sahara Africa due to changing climate.
The project is also anticipated to have lasting impacts on dry season farming of local communities in the project area. More precisely, the project organized field trials that successfully demonstrated to the local communities that, with efficient irrigation scheduling and water management, new crops can be grown in the middle of the sweltering dry season heat, something they will currently not venture to do. This has the potential to extend the farming season because farmers will now be encouraged to attempt to grow new crops in the middle of the dry season. Furthermore, through two workshop series, the project created awareness of the importance of efficient irrigation water management as an important aspect of successful dry season farming. The workshops also educated smallholder farmers about the limitations of their current irrigation management practice and how to address them. The two workshop series reached over 150 smallholder irrigation farmers in the area, including several women. While the combined field trials and workshops provide important contributions toward long-term sustainability of the project’s impacts, we hope to have multiple follow-up field trials to extend and consolidate the success of the project.
Application of electromagnetic induction to develop a precision irrigation framework to facilitate smallholder dry season farming in the Nasia-Kpurigu area of northern Ghana


Summary

Arid climatic conditions coupled with the prolonged dry season in northern Ghana (NG) place great restrictions on year-round smallholder farming. Because small-scale farming is the main source of livelihood for over 70% of rural inhabitants, limitations on dry season farming have contributed to severe poverty in NG. Although the adoption of individual smallholder irrigation in the area is enabling dry season farming, these practices do not account for spatial variability in physical soil properties (e.g., soil texture) that determine the amount of water available to plants. Hence, current irrigation practices in NG are inefficient. Here, we present preliminary results of the development of a precision irrigation framework (PIF) for the Nasia-Kpurigu area in NG intended to enable smallholder farmers to make judicious use of limited irrigation water, and facilitate more sustainable dry season farming in the area. We also demonstrate the use of electromagnetic induction surveys to characterize field-scale spatial variability in soil water-retention capacity.

Introduction

Northern Ghana experiences a tropical savanna climate, with a distinct dry season lasting seven to eight months and a wet season lasting only four to five months. The singular rainy season limits rain-fed farming to these four to five months of the year (Kye-Baffour and Ofori, 2006). Meanwhile, farming is the principal occupation of over 70% of northern Ghana’s inhabitants (Ghana Ministry of Food and Agriculture, 2007). Consequently, the northern parts of Ghana are among the most impoverished regions in the country. While the rest of Ghana has seen a marked decrease in poverty over the last two decades, poverty incidence rates and extreme poverty remain high in the northern half of the country (Ghana Statistical Service, 2007, 2015). The poverty situation has fueled a coping mechanism of seasonal migration to major cities in southern Ghana in search of meager jobs (Quaye, 2008; Assan et al., 2009). Moreover, recent global climate trends have amplified the risk of prolonged dry spells during the short farming season (Yeboh et al., 2010), making dry season farming a crucial aspect of poverty reduction strategies in northern Ghana.

The recent adoption of individual irrigation schemes involving the use of water from the White Volta River and its tributaries (e.g., Dinye and Ayitio, 2013) presents a unique opportunity for smallholder farmers to engage in dry season farming and to create off-season employment during the long dry season. However, their current irrigation practices do not account for the natural spatial variability in the physical properties of the soil, making their current practices inefficient. Specifically, soil texture (i.e., the relative abundance of clay, silt, and sand) and porosity control the water-holding and water-transfer capacities of soils, which ultimately determine the amount of irrigation water available to plants. Efficient irrigation management practices should, therefore, involve careful examination of the soil and accounting for the spatial variability in the underlying properties of the soil.

Geospatial measurement of soil apparent electrical conductivity (ECa) using electromagnetic induction (EMI) is a quick and reliable ground-based sensing approach used for general characterizations of the spatial variability of soil properties, and is commonly applied to site-specific farm management practices (Corwin and Lesch, 2003, 2005). The soil texture and hydraulic characteristics of spatially distinct soil units may be estimated with data from particle size analyses of samples and from field infiltration tests, respectively. Continuous monitoring of soil water content (SWC) during field infiltration tests produces time series data that may be analyzed to estimate relevant agricultural parameters, such as field capacity (FC) and permanent wilting point (PWP) (e.g., Zottelli et al., 2010). These provide practical estimates of SWC ranges for soils, and allow for more efficient irrigation management practices.

Data will be used to construct a large-scale soil texture map of the project area which details the optimal SWC ranges of major soil texture units. This map will guide site-specific water management practices (e.g., frequency and duration of irrigation) in the project area.

Project region

The project region comprises an area of about 205 square kilometers extending between the villages of Nasia and Kpurigu in Ghana’s Northern Region (Fig. 1).

Methods

To develop a precision irrigation framework (PIF) for the entire study area in an attempt to increase the number of long-term project beneficiaries, we adopted a multi-scale approach to unify a large-scale soil texture map with high-
Precision irrigation framework in northern Ghana

EMI surveys to generate ECa maps for PPFs
For a quick understanding of spatial variability in soil properties across a field, we conducted EMI surveys to generate apparent electrical conductivity (ECa) maps for each of the five fields. We used the Geonics EM38-MK2 conductivity meter with DAS70-AR2 Data Acquisition System. The meter was mounted in a custom-made portable protective sled and towed behind a tractor. For two of the fields (SF1 and KNF), the EMI survey was conducted for both dry and wet conditions. That is, after the survey for the dry field, the field was flooded and allowed to drain for three days; the survey was then repeated for the wet condition. Allowing the field to drain for three days provides ample time for varying rates of infiltration to occur, resulting in variable moisture distributions that will reflect in the ECa measurements. To calibrate the dry and wet surveys to the same scale, a region of the dry field was excluded from the flooding to serve as a control region.

Field infiltration tests
To directly estimate the water-holding capacities (FC and PWP) of soil units within a field, we performed infiltration tests at eight selected locations within each field. The infiltration sites were chosen in accordance with dominant patterns observed in the ECa maps to capture representative hydraulic responses of the identified ECa units. Additionally, soil samples were collected at each infiltration site to provide direct, co-located soil texture data for each infiltration profile. IRROMETER's IRRonemesh wireless soil moisture monitoring system was used for the infiltration tests. The IRRonemesh system consists of several solar-powered, intercommunicating units (nodes) capable of sharing data collected from a network of soil moisture sensors. At each test site, a pair of WATERMARK granular matrix soil moisture sensors were installed at 0.1 m and 0.3 m depths, to provide multi-level soil moisture monitoring during the infiltration tests.

Soil sampling and particle size analysis
Soil samples were collected from each field in both a grid-like design and in accordance with dominant patterns observed in the ECa maps. A total of 124 soil samples were collected in both the coarse-scale and farm-scale soil sampling efforts. All of the soil samples were analyzed at the Spanish Laboratory at the University for Development Studies (UDS) in Nsukpana, Ghana. Estimates of the sand, silt, and clay proportions of the soil samples were obtained using the hydrometer method (Bonyonco, 1962).

Results and Discussion
To classify the soil texture from the proportions of the separates obtained from the particle size analysis tests, we used a soil texture calculator and plotting tool developed by the USDA's Natural Resources Conservation Service (https://www.ars.usda.gov/wps/portal/arcs/detail/soils/survey/?id=arc142p2_054167). The classification of the soil texture types for all 124 soil samples are shown in Fig. 2. The soil textures from each participating farm seem well
Precision irrigation framework in northern Ghana

grouped. For instance, soils from Sammy farm are mostly silty-clay, whereas those from Kparigu and Nasir-Kubobila farms have, respectively, loamy sand and sandy loam textures. The silty-clay texture of soils from Sammy farm coincide with a flood plain of the Nasir River. The coarse-scale samples, conversely, reveal more variability in the soil texture across the project area, as expected.

![Soil Texture Classification Triangle](image1)

Figure 2: A soil texture classification triangle showing the proportions of sand, silt, and clay for all 124 soil samples.

![Soil Texture Map](image2)

Figure 3: Preliminary soil texture map of the project region. Inserted points mark actual (black) and replicated (red) sample sites.

Creation of a coarse-scale soil texture map of the region

Because soil texture is the primary driver of water-holding capacities of soils, which in turn influence irrigation scheduling, we use a soil texture map of the project area as the basis for the creation of the PIF. To create the initial coarse-scale soil texture map of the project area, the coarse-scale soil texture data (Fig. 2) were assigned integer values ranging from 1 (loamy sand) to 6 (clay) (with values increasing with clay content [see scale in Fig. 3]). Because not all of the areas within the overall project region were accessible for soil sampling, a series of sample replicate sites were established to extend the perimeter of the soil map. These replicate sites were chosen based on the co-occurrence of ground truth samples with large-scale soil patterns and features in the project area identified through comparative analyses of both satellite imagery and published mineralogical maps. The ground truth sample locations are shown with black filled circles while replicated sample sites are marked with red filled circles in Fig. 3.

The integer parameterized soil texture data were then kriged with a linear variogram using Surfer® 14 software to produce a preliminary soil texture distribution map of the entire project area (Fig. 3). Examination of Fig. 3 indicates a general split of the area into loamy sand and sandy loam with a clay-rich zone in the southwestern corner of the project area. The clay-rich area coincides with a flood plain of the Nasir River.

EML characterization of spatial variability in water-holding characteristics of soils

Knowledge of spatial variability in water-holding capacities of soils is critical to variable-rate irrigation scheduling. We processed the EC$_w$ data for the dry and wet conditions to estimate high-resolution spatial variabilities in the water-holding characteristics of the PIFs. Particularly, while an attempt was made to obtain co-located wet and dry data points between the dry and wet surveys, it is impractical to achieve this goal precisely. Hence, we employed a Euclidean distance criterion to find the nearest wet measurement for every dry data point. We noted several instances where multiple dry data points had the same nearest wet measurement, which may be due to discrepancies in the speed of the towing vehicle between the two surveys. To adjust for this, we paired the wet data point with the average of the dry data points instead of having several dry data points co-located with the same wet data point. This increased the correlation coefficient between the dry and wet co-located data points within the control region (from $-0.40$ to $-0.85$ in the case of SFI).

Furthermore, we assumed that differences in the EC$_w$ measurements between the two surveys in the control region were due mainly to differences in instrument calibration and external environmental factors, such as temperature. To adjust for this, we fit a least-squares curvilinear regression model to the co-located EC$_w$ values within the control region from the two surveys. A scatter plot of the co-located control region EC$_w$ values for SFI (Fig. 4a) shows a strong correlation between the two datasets with a curvilinear trend. An inspection of the distributions of the prediction errors (Fig. 4b) indicates a fairly uniform error distribution with a near zero mean and slightly increased prediction errors for EC$_w$ values less than 8 mS/m. Nevertheless, the model appears reasonable for the range of EC$_w$ values observed in the two surveys (Fig. 5). The regression model was
subsequently applied to recalibrate the entire wet dataset to the same scale as those of the dry survey. We then subtracted the dry EC₃ values from the corrected wet data to produce a difference dataset. Because we anticipate general increases in EC₃ values in the wet versus dry surveys, data points with negative difference values were considered outliers and excluded from the final data for the kriging of the final EC₃ maps (Fig. 5). The initial 38,810 co-located data points were reduced to 16,184 after the complete data cleaning effort with 3,207 located in the control region.

**Summary and Future Work**

Coarse soil sampling across the study area was conducted to establish a preliminary large-scale soil texture map of the project region. High-resolution, farm-scale data were obtained from EMI surveys, infiltration tests, and soil sampling conducted at each PPF. This information was used to further characterize distinct soil types identified in the region, and will be integrated with large-scale data in order to refine the coarse-scale soil texture map. We demonstrate an innovative application of EMI surveys to characterize the spatial variability of soil-water retention at the farm scale.

Ongoing work involves the analysis and integration of data obtained during field infiltration tests. Data from the tests will be used to calibrate direct water-holding characteristics of soil samples across the study area. Time series soil water content (SWC) data will be analyzed to determine the field capacity (FC) and permanent wilting point (PWP) of the soil present at each station. Each unit on the coarse-scale soil map will therefore be defined by both a characteristic soil texture and, by extension, characteristic water-holding and water-transfer capacities. Accordingly, each unit will comprise a unique water management zone (WMZ) — a region with specific water management recommendations. To prevent crop water stress, SWC thresholds above the PWP will be recommended as the maximum allowable depletion (MAD) for common crops grown in the area. The SWC range between the FC and the MAD will constitute the optimal operating range of SWC for each WMZ.

**Acknowledgements**

We thank the Society of Exploration Geophysicists Geoscientists Without Borders Program for their financial support for this project. We also thank the technicians at the Spanish Laboratory of UDS and two UDS students, Simon Anzuo and Sahabu Abdulhummin, who assisted with the fieldwork. We thank Eric Doe of the International Institute of Tropical Agriculture for his volunteer time on the project. We thank the University at Buffalo Global Health Equity for their travel support for Alexander Percy.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.
REFERENCES


Ghana Ministry of Food and Agriculture, 2007, Rural livelihoods in Ghana: Policy, planning, monitoring and evaluation directorate: Ghana Ministry of Food and Agriculture.


APPENDIX B
Developing a precision irrigation framework to facilitate smallholder dry-season farming in developing countries: A case study in northern Ghana

Jeremy M. Fontaine, Joseph Fentke, and Erasmus K. Oware*, The State University of New York at Buffalo; Eric Doe, International Institute of Tropical Agriculture, Tamale; Samuel Guog, The West African Science Service Center on Climate Change and Adapted Land Use (WASCAL); John W. Lane, Jr., US Geological Survey

Summary
Changing climate has resulted in increasingly unreliable weather patterns with prolonged dry-seasons in some parts of Sub-Saharan Africa. Food production in these areas is under threat because the people depend mostly on rain-fed farming. Enabling dry-season farming, in light of the prolonged dry-seasons, is central to sustainable food production and poverty alleviation in these areas. Efficient water management is key to successful dry-season farming. Ideally, efficient irrigation water management should involve real-time monitoring of soil moisture (SM) to guide irrigation scheduling. However, farmers in these areas are mostly poor smallholder farmers without the financial capacity to instrument their farms for real-time SM monitoring. We present a precision irrigation framework (PIF) as a low-cost alternative to site-specific SM monitoring to guide irrigation scheduling. PIF applies machine learning to integrate multi-scale ground-truth data and satellite imagery to create irrigation water management zones for an entire region. We demonstrate the strategy in the Pwalugur area in northern Ghana.

Introduction
Changing climate has resulted in increasingly unreliable weather patterns with prolonged dry-seasons (Yengolo et al., 2010) in some parts of Sub-Saharan Africa, specifically countries in the transition belt between the Sahara desert and the tropical rainforest. The situation is adversely affecting food production. Northern Ghana (NG) is a classic example of an area in this transition zone. NG experiences distinct dry season lasting seven to eight months and a wet season lasting only four to five months in a year. While over 70% of the inhabitants are farmers (Ghana Ministry of Food and Agriculture, 2007), the singular rainy season limits rain-fed farming to only four to five months of the year (Kyer-Baffour and Ofori, 2006), resulting in severe poverty in the northern half of the country. The poverty situation has fueled a coping mechanism of seasonal migration to major cities in the south in search of menial jobs (Quaye, 2008; Assan et al., 2009). Enabling dry-season farming is crucial to sustainable food production and poverty reduction in NG.

Recent irrigation farming along the White Volta River and its tributaries (Dinve and Ayittey, 2013) presents a unique opportunity for smallholder farmers to engage in dry-season farming and to create off-season employment during the long dry season. Efficient irrigation water management is central to successful dry-season farming. However, irrigation water management is completely ignored in the current irrigation practices in the area, resulting in water, energy, and fertilizer wastages with dire environmental consequences. In this project, we present a precision irrigation framework (PIF) as a low-cost strategy to guide efficient irrigation scheduling to facilitate small-holder dry-season farming. Fontaine et al. (2018) presented results from the Project Year 1 fieldwork. Here, we present preliminary results of the Project Year 2 field work.

Project Region and Methods
The Project Year 2 (PY2) region comprises an area of about 351 square kilometers in the Pwalugur area in the Upper East Region of Ghana. Figure 1 shows the PY2 area and its relative location within Ghana. Fontaine et al. (2018) presented results of the PY1 field work, which was in the Nsia-Kpangwu area in northern Ghana. PY2 moved further north of the PY1 area and repeated the experiments of Fontaine et al. (2018). The objective is to develop a precision irrigation framework (PIF) for the entire PY2 area (Figure 1) to facilitate small-holder irrigation farming during the dry-season. We consider creating the PIF for the entire project region in an attempt to increase the number of long-term project beneficiaries beyond the five project participating farmers. To accomplish this, we adopted a multi-scale approach to unify high-resolution farm-scale data with a large-scale soil-texture map. This approach was employed because it was impractical to collect multiple high-resolution data types at the entire project scale.

Figure 1: Project Year 2 (PY2) area showing locations of the five project participating farms and coarse-scale soil sampling locations. Inserted is a map of Ghana showing the location of the PY2 area.
Precision Irrigation Framework in northern Ghana

Large-scale soil sampling
To create a soil texture map for the entire project region, we collected coarse-scale soil samples across the entire project region. A total of 22 coarse-scale soil samples were collected. Due to the sample-site inaccessibility issues encountered in PY1, we engaged the services of a motor bike, which helped to increase the number and spatial coverage of the coarse-scale soil samples (Figure 1). We collected the samples with a handheld auger over a composite depth of 0–0.4 meters. To promote representative sampling across the sampling depth, each soil sample was first mixed thoroughly in a bucket. Representative subsamples were then bagged and labelled.

Farm-scale surveys
We performed multiple farm-scale surveys in an effort to acquire high-resolution data to be unified with the large-scale soil texture map. The farm-scale surveys included electromagnetic induction (EMI) surveys, field infiltration tests, and high-resolution soil sampling, which were performed on the fields of five selected project participating farms (PPFs). To ensure good spatial coverage of the high-resolution data, we selected the PPFs almost evenly spaced across the length of the project area (yellow pins in Figure 1). All the five PPFs are engaged in dry-season, small-scale irrigation farming. For a quick understanding of spatial variability in soil properties across a field, we conducted EMI surveys to generate apparent electrical conductivity (ECa) maps for each of the five fields. We used the Geonics EM38-MK2 conductivity meter with DAS70-AR2 Data Acquisition System. The meter was mounted in a custom-made portable protective sled and towed behind a tractor. Similar to Fontaine et al. (2018), we performed the EMI surveys for dry and wet field conditions to estimate high-resolution spatial variability in the water-holding characteristics of a field. To directly estimate the water-holding capacities (FC and soil moisture depletion rate) of soil units within a field, we performed infiltration tests at two selected locations within each field. The infiltration sites were chosen in accordance with dominant patterns observed in the ECa maps to capture representative hydraulic responses of the identified ECa units. Additionally, soil samples were collected at each infiltration site to provide direct, co-located soil texture data for each infiltration profile. For the soil moisture monitoring, we used the Onset Time Domain Reflectometry (TDR) soil moisture probes with the HOBO USB Micro Station logger. We programmed the logger to log soil moisture every 30 s, providing high temporal resolution of soil moisture profiles to calibrate the water-holding characteristics of the soils.

Soil sampling and particle size analysis
Soil samples were collected from each field in both a grid-like design and in accordance with dominant patterns observed in the ECa maps. A total of 85 soil samples were collected in both the coarse-scale and farm-scale soil sampling efforts. All of the soil samples were analyzed at the Spanish Laboratory at the University for Development Studies (UDS) in Nyankpala, Ghana. Estimates of the sand, silt, and clay proportions of the soil samples were obtained using the hydrometer method (Bonyounou, 1962). We used the soil texture calculator and plotting tool developed by the USDA’s Natural Resources Conservation Service (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/an veg/?cid=nrcs142p2_054167) to classify the soil texture from the proportions of the separates obtained from the particle size analysis tests.

Creation of the Precision Irrigation Framework
Soil texture is the primary driver of water-holding characteristics of soils, which in turn informs irrigation scheduling. Hence, to create the PIF, we applied soil texture as the basis to unify the high-resolution farm-scale data with the project-scale soil-texture map. Field capacity (FC) and water depletion rate (WDR) are two important soil water-holding characteristics that inform irrigation scheduling. While WDR informs frequency of irrigation, FC helps to determine when to stop irrigation. We, therefore, applied estimated FC and WDR from the irrigation experiments to guide the creation of water management zones (WMZs). Irrigation experiments with similar FC and WDR were classified into the same WMZ. The WMZ classes were then assigned to their corresponding sand, clay, and silt proportions to create a “level 1" WMZ training set. While we collected a total of 85 ground truth soil samples in Py2, it is impractical to perform irrigation experiments at all the 85 soil sample locations in order to calibrate their corresponding FC and WDR to determine their WMZ class. To include all the soil samples in the training set, we applied the “level 1" WMZ learning set to train a non-parametric machine learning classifier, the k-nearest neighbors (KNN) algorithm (e.g., Harrington, 2012). We then applied the trained KNN classifier to assign WMZ labels to all the soil texture data. For a robust training set, we included 132 soil texture data from Py1, making a total of 217 ground truth soil texture data. This constitutes the “level 2" WMZ training set.

To create the PIF, we employed the coarse-scale soil texture data to condition the prediction of the sand, clay, and silt proportions for the entire project area. Because the project-scale soil texture data have poor spatial resolution, we applied remote sensing data to complement the coarse-scale soil texture data for the large-scale soil texture prediction. Specifically, Landsat 8 provides 30 m resolution of surface reflectance data coverage across the project area. Because Landsat 8 consists of nine spectral bands, we first performed exploratory analysis to identify the spectral band with the highest correlations with the soil texture data. Similar to Liao et al. (2013), we identified band-7 to have the highest correlations with the sand, clay, and silt...
Precision Irrigation Framework in northern Ghana

proportions. Hence, to predict soil texture for the entire project area, we applied Landsat 8 band-7 as secondary data to co-krig with all the 85 soil texture data (Figure 1, including all the farm-scale soil samples) collected across the PY2 area. We performed the co-kriging in ArcMap®. We then applied the “level 2” WMZ mapping set to train the KNN classifier, and then applied the trained KNN classifier to assign WMZ labels for the entire project region based on the co-kriged sand, silt, and clay proportions. The WMZ class map constitutes the PIF for the project area.

Results and Discussion

Figure 2 shows an example of the soil moisture time series data from the irrigation experiments. We deliberately over-irrigated to induce drainage. The rapid depletion (drainage zone) of soil water content (SWC) is followed by slow depletion rate (extraction zone) where the soil now holds water in its micro-pores that is available to the plant. The SWC corresponding to the interception of a tangent to the drainage and extraction zones (Figure 2) provides an estimate of the FC of the soil (e.g., Zotarelli et al., 2010). We also estimated the WDR of the extraction zone. We identified three WMZs based on the FC and WDR. The corresponding sand, clay, and silt proportions for the WMZs were, respectively, in the ranges of 55%–73%, 4%–14%, and 19%–30% (for WMZ 1), 40%–69%, 20%–30%, and 30%–32% (for WMZ 2), and 15%–25%, 42%–61%, and 24%–33% (for WMZ 3). We observed that the WMZ class was driven primarily by the relative proportions of sand and clay, with silt remaining fairly constant (19%–33%). More precisely, WMZ 1 is driven by high sand content with sand exceeding 55%. The sand content reduces in WMZ 2 with clay increasing. Clay dominates WMZ 3 with clay content exceeding 42%. Using these data (“level 1” training set) and KNN classification, we assigned WMZ labels to all the ground truth soil texture data. Figure 3 shows a scatter plot of the “level 2” WMZ training set revealing distinct clustering of the WMZs in the 3D soil texture feature space.

Figure 3: A scatter plot of the “level 2” water management zones (WMZ) training set showing distinct clustering of the WMZs.

To create the PIF, we applied the “level 2” WMZ training set (Figure 3) and KNN classification to assign WMZ classes to the entire project region based on the co-kriged sand, clay, and silt proportions. Figure 4 shows the created PIF for the Pwalulgua area. The results show a general north-east south-west banding of the WMZs with a massive band of WMZ 1 in the mid-section of the project area. WMZ 3 is found only in the north-west corner of the project area, which was expected because soil samples with clay content exceeding 42% were found only in Farm 1. The average FC and WDR were WMZ 1: 0.28 m³/m², 0.014 m³/m²/day; WMZ 2: 0.30 m³/m², 0.006 m³/m²/day; and WMZ 3: 0.36 m³/m², 0.005 m³/m²/day. We are currently developing the irrigation scheduling recommendations for the WMZs.

Project Sustainability Plan

Long-term sustainability of a project beyond the project years is a major pillar of the Geoscientists Without Borders (GWB) program. The concept of developing a PIF (Fig. 4) for the entire project area to benefit more farmers beyond...
the project participating farmers (PPFs) and to extend the project’s impacts beyond the project years is an important aspect of the project’s long-term sustainability plan. As part of the outreach program of the project, we organized two workshop series during the PY2 field work, one in each of the two project regions. A total of 150 farmers participated in the two workshops. Figure 5 shows a photo of the team with farmers after the workshop in the PY1 area.

The goal of the workshop was to educate smallholder irrigation farmers on the importance and the need for efficient irrigation water management practice to the success of their dry-season farming efforts. We also aimed to use the workshop to recruit non-PPFs to adopt the PIF.

During the fieldwork, we identified some key limitations of their current irrigation practice and addressed them during the workshops. Specifically, their current irrigation practice is to make bunds around the crops and pond them (Figure 6A). This creates an issue of severe over-irrigation resulting in water, energy, and fertilizer wastage while increasing the environmental footprint of their farming. Ponding the crops in 80°F - 100°F also translates into “cooking” the crops whiles growing. These issues were thoroughly discussed and addressed during the workshops.

As we brought up the issues, some farmers identified potential consequences of ponding the crops in 80°F-100°F that they have observed. They testified to observing that crops in the middle of the ponds that are submerged for a long period have poor yield and the produce rots quickly compared to the produce from crops at the edges of the bunds that are unsubmerged.

Furthermore, while there is growing interest in dry-season farming in the area, there is a general perception that it is a waste of time, energy, and resources, based on their experience. A successful demonstration of dry-season farming based on our irrigation recommendations is crucial to increasing awareness about the project and convincing more farmers to adopt the PIF. Toward this end, we used the PPFs as dry-season farming trial fields. We supported the farmers by covering the costs field plowing, seedlings, and fertilizer. They were then asked to irrigate strictly according to our recommendations and keep the produce, which creates a win-win scenario to solicit the farmer’s commitment to the trial. The trials on all the five fields were hugely successful. Figure 6B shows a farmer excited and displaying the produce from the dry-season farming trial on his farm. We are confident that this will encourage other farmers to adopt the PIF and its recommendations, thereby extending the long-term impact of the project. We also hope to have multiple follow-up trials to consolidate the success of the project. Finally, local chiefs have a lot of influence on their communities. Community entry should always involve introduction of the project to local chiefs and, if possible, solicit their participation. This is important to community engagement and participation.

Figure 5: A photo of the PY2 team and small-holder irrigation farmers after the training workshop in the PY1 area.

Figure 6: (A) a photo of the current irrigation practice, and (B) a project participating farmer displaying the produce from the dry-season farming trial on his farm.

Summary

Food production in some parts of Sub-Saharan Africa is under threat due to changing climate that has resulted in prolonged dry-seasons. The situation is expected to only get worse. There is an urgent need for low-cost irrigation water management strategies to facilitate sustainable smallholder dry-season food production. Use of a precision irrigation framework (PIF) is a low-cost strategy to guide efficient irrigation scheduling. PIF applies machine learning to integrate multi-scale ground-truth data and satellite imagery to create irrigation water management zones for an entire region. Although we demonstrated the application of PIF in northern Ghana, it is applicable to any region with the need for low-cost irrigation water management practices.

Acknowledgements

We thank the Society of Exploration Geophysicists Geoscientists without Borders Program for their financial support for this project. We also thank the technicians at the Spanish Laboratory of UDS and UDS student, Simon Amuzu, who assisted with the fieldwork.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.
REFERENCES


Ghana Ministry of Food and Agriculture, 2007, Rural livelihoods in Ghana: Policy, planning, monitoring and evaluation directorate: Ghana Ministry of Food and Agriculture.


