SDG ACCELERATION ROADMAP

UNLEASHING THE POWER OF PRIVATE-SECTOR DATA IN THE GLOBAL SOUTH

Accelerating Development of Improved Cowpea Varieties Through Artificial Intelligence and Drone Data

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Accelerating the Development of Improved Cowpea Varieties Through Artificial Intelligence and Drone Data

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Abbreviations

AGRA	Alliance for a Green Revolution in Africa
CRIG	Cocoa Research Institute of Ghana
CSIR	Council for Scientific and Industrial Research
CSIR-SARI	Council for Scientific and Industrial Research - Savannah Agricultural Research Institute
ELS	Early Leaf Spot
HTPP	High Throughput Plant Phenotyping
LLS	Late Leaf Spot
NIAB	National Institute of Agricultural Botany Trust
SDG	Sustainable Development Goals
WACCI	West African Centre for Crop Improvement

Context

Plant breeding is the application of genetic principles to produce plants that are more useful to humans. This is accomplished by selecting plants found to be economically or aesthetically desirable, first by controlling the mating of selected individuals, and then by selecting certain individuals among the progeny. Such processes, repeated over many generations, can change the hereditary makeup and value of a plant population far beyond the natural limits of previously existing populations.[1]

In the last few decades, many varieties of food crops that smallholder farmers have routinely planted no longer perform as they used to due to changes in climate, increasing pressure on land, incomes and the emergence of more stubborn strains of diseases and pests.

These challenges have been most pronounced for smallholder farmers who produce food for subsistence and small-scale commercial purposes under resource constrained conditions. In many cases, the use of inputs that promote production intensification, such as fertilizers, remains below the recommended threshold given the soil types on their farms due to the challenges of accessing affordable inputs on time.

In Ghana, one important staple crop grown by smallholder farmers is cowpea, which is used to make a variety of dishes that are part of everyday life in Ghana and neighbouring countries. Waakye and gari are two very common dishes made from cowpea.

In order to achieve Goal 2 of the Sustainable Development Goals, particularly the target on doubling productivity, countries have to isolate, develop, propagate and make more available improved varieties that can perform under the constraints many smallholder farmers are grappling with. Traditionally however, this is a tedious process that takes a long time.

[1] Allard, R.W. "plant breeding". Encyclopedia Britannica, 25 Mar. 2019, https://www.britannica.com/science/plant-breeding. Accessed 19 May 2023.

This case study explores the relationship between KaraAgro, a for-profit technology services company, and the West African Centre for Crop Improvement (WACCI) in their collaboration to accelerate the time it takes to identify and breed the best cowpea varieties in Ghana.

Data Action –Data collection, Data analysis and technology development

WACCI's collaboration with KaraAgro provides us with a good example of collaboration to make more data available while providing the ability to rapidly analyze the increased volume of data to inform decision-making.
An effort to improve volume of data for decision-making that doesn't concurrently address the challenge of the ability to process and analyse such increased volumes would only result in a scenario of "water everywhere but none to drink". In this collaboration, KaraAgro provided Unmanned Aerial Vehicles, software and the ICT expertise needed to ensure the package of capacities was fit for purpose. WACCI, a public sector agricultural research institution that is part of the University of Ghana, has the plant breeding-related technical capacity to identify the most suitable genotypes using phenological data. Together, they represent a complete set of skills and experience to adopt a novel way of rapidly scanning thousands of plants to find those that exhibit the best characteristics for the environment under consideration.

Methodology

This case study took a mixed methods approach in trying to understand how WACCI collaborated with KaraAgro to leverage cutting edge technology for the development of new varieties of cowpeas.

Desk Research

A number of documents were studied to understand the partners and the technology including journal publications written by members of the KaraAgro team, University of Illinois teams and published articles about the KaraAgro/ WACCI effort.

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[2] KaraAgro. https://www.karaagro.com/. Accessed May 2023
[3] West African Centre for Crop Improvement. https://wacci.ug.edu.gh/. Accessed May 2023

Key Informant Interviews

A number of individuals were key to the design, implementation and use of the HTPP approach and technology. They were identified through key informant interviews.

The interviews were conducted using an interview guide which is shared in Annex 3.

About KaraAgro

KaraAgro was started by Gudra Studio and is led by Darlington Akogo. It gives the public tools to make actionable decisions on farms. Their systems are able to inspect every individual crop on the farm and understand their health, in order to detect and control diseases, pests, water shortages and nutrient deficiency earlier than usual.

In the past, they deployed their artificial intelligence driven systems to support disease identification in cashew nuts in collaboration with the Cocoa Research and Institute of Ghana (CRIG) and for groundnut with CSIR-Savanna Agricultural Research Institute, one of the 13 research institutes of the Council for Scientific and Industrial Research (CSIR).

About the West African Centre for Crop Improvement

The West Africa Centre for Crop Improvement (WACCI) is a partnership between the University of Ghana (UG) and Cornell University, USA. It was established at the University of Ghana in June 2007 with funding from the Alliance for a Green Revolution in Africa (AGRA) to train Plant Breeders in Africa working on the improvement of African crops in local environments for farmers in Africa.

Field Crop Research in Ghana

In conventional practice, when conducting designed experiments on field crops to measure phenotypical and phenological parameters, plant breeders typically sample only a small number of plants to represent the entire plot. For example, in a typical groundnut experiment aimed at evaluating advanced breeding lines, a plot size of 6.4-8 m2 is used, resulting in approximately 160 plants per plot.[4] Out of these, about five plants (3% of the expected plant population) are randomly selected each time agronomic data needs to be collected. The selection of a limited number of plants per plot is mainly due to the labor-intensive nature of manually measuring plant traits, which requires careful selection of a predetermined number of representative plants and sometimes up to 7 different instruments to collect the various types of data.

In addition to the limited number of plants sampled, the current protocols for measuring plant traits suffer from subjectivity and are prone to human error. An example of this is the assessment of disease severity caused by Early and Late Leaf Spot disease[5] (ELS and LLS), which employs a nine-point scale. On this scale, a rating of one represents complete resistance, while a rating of nine indicates complete defoliation or death.[6] The scale assumes that groundnut leaf spot diseases originate at the base of the plant and progress toward the terminal bud. According to the scale, defoliation of the lower leaves becomes visible at a severity score of four, while the upper leaves remain unaffected.

However, it has been observed that certain groundnut genotypes exhibit lesions from ELS and/or LLS on both lower and upper leaves, while all other leaves remain intact. This inconsistency introduces subjectivity in the scoring process,

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[4] Danful, R.; Kassim, Y.B.; Puozaa, D.K.; Oteng-Frimpong, R.; Rasheed, M.A.; Wireko-Kena, A.; Akromah, R. Genetics of Stay-Green Trait and Its Association with Leaf Spot Tolerance and Pod Yield in Groundnut. Int. J. Agron. 2019, 2019, 3064026.

[5] Kanteh, S. M., Ndoleh, P., Dimoh, G. J. S., Luseni, S. J., Koroma, F. M., & Shamie, I. M. O. (2013). Early and Late Leaf Spot on Groundnut. CABI International. Retrieved from https://www.plantwise.org/FullTextPDF/2014/20147800113.pdf.

[6] Subrahmanyam, P.; McDonald, D.; Waliyar, F.; Reddy, L.J.; Nigam, S.N.; Gibbons, R.W.; Rao, V.R.; Singh, A.K.; Pande, S.; Reddy, P.M.; et al. Screening Methods and Sources of Resistance to Rust and Late Leaf Spot of Groundnut. Information Bulletin no. 47. Available online: http://oar.icrisat.org/3477/

causing the severity rating of these genotypes to vary depending on the evaluator rather than accurately reflecting their true susceptibility.

A more robust way of generating the data, analysing it and arriving at a subset of desirable cowpea genotypes led a team at WACCI that was acutely aware of the shortcomings of the conventional approach, to explore an alternative that would make it possible to sample more crops and more cultivars with less researchers and higher accuracy.

In 2019, KaraAgro convinced the Council for Scientific and Industrial Research's Savannah Agricultural Research Institute (CSIR-SARI) to adopt a better approach to phenotyping to study all the plants in a field, collect multiple data points for each genotype and help researchers arrive at a ranking of the genotypes with the most desirable traits. Their approach utilizes artificial intelligence and multispectral imagery collected by automated drones. The collaboration between CSIR-SARI and KaraAgro was a success and resulted in the publication of a paper detailing their approach to high throughput plant phenotyping for groundnut.

The Collaboration on High Throughput Plant Phenotyping

WACCI and Dr John Eleblu

Dr. John Eleblu, originally from Ghana, grew up in a culture where cowpeas played a significant role in local cuisine. Cowpeas are an essential ingredient in Ghana's popular dish, Waakye, as they add both a beautiful color and a unique flavor when combined with rice. After pursuing his PhD abroad, Dr. Eleblu returned to Ghana and joined the West African Centre for Crop Improvement (WACCI).
Through WACCI, Dr. Eleblu learned about CAPREX, a research capacity building initiative led by Cambridge-Africa. He applied for CAPREX funds for sorghum research, but his proposal was not funded. However, Cambridge-Africa provided him with a travel grant to visit Dr. Alison Bentley, his collaborator at the University of Cambridge, and explore new research opportunities.

During his visit, Dr. Eleblu had the opportunity to attend a presentation by a scientist from the Rothamsted Research Institute at the National Institute of Agricultural Botany Trust (NIAB). The scientist shared groundbreaking research about a gene that had been transferred from desert plants to wheat and barley. This gene enabled wheat and barley plants to enter a dormant state during periods of water scarcity and then revive when sufficient moisture became available. Referred to as the "resurrection gene," it sparked Dr. Eleblu's fascination. Given the existing challenges posed by climate change, which were already impacting cowpea harvests and likely to worsen with the deepening climate crisis, the concept of a plant that could withstand extended periods of drought and still produce a yield at the end of its growth cycle held immense appeal to Dr. Eleblu.[7]

When Dr Eleblu and his team at WACCI needed to find a way to accelerate the selection and breeding of improved cowpea varieties, they sought out KaraAgro, a technology services company to try a new approach for plant phenotyping known as high throughput plant phenotyping (HTPP). KaraAgro's collaboration with CSIR-SARI using KaraAgro's technology had been successful on groundnuts during disease monitoring in a phenotyping context and showed promise for scale when used on a different value chain.

KaraAgro was introduced to Dr Eleblu at WACCI when it was still at the conceptual stage. They spent time speaking with him about the right entry point for the technology given their past experience deploying their approach and their technologies to disease surveillance in plant breeding of cashew and groundnuts. As the KaraAgro team learned about the WACCI research and the specific efforts of Dr. Eleblu and his team, they improved their approach and algorithms for use in the WACCI use case. During that period, other scientists contributed to guide the development of the technology and make the use case of high-throughput plant phenotyping (HTPP) more achievable for WACCI and cowpeas in Ghana.

[7] Mwangi, T., & Eleblu, J. (2021, March 15). Transforming the cowpea in Ghana. Cambridge in Africa. https://www.cambridge-africa.cam.ac.uk/cambridge-africa-updates/transforming-the-cowpea/

The Technology

HTPP is the simultaneous production of many data points per observation for a particular trait of interest[8] and for multiple plots at the same time. It offers a non-invasive approach to data collection on several genotypes within a short period, and permits repeated measures on the same sample, giving breeders the opportunity to classically track processes (such as disease development) over time.

KaraAgro's approach to HTPP using artificial intelligence utilizes a combination of software, hardware and cloud services. On the software end, KaraAgro developed a set of Python libraries that are used for analyzing the vast amounts of data that are collected by the hardware. There is also additional software provided by the drone manufacturer that is key to mission planning and control of the drones.

On the hardware front, DJI Phantom 4[9] drones equipped with a set of multispectral cameras that collect data in both the visible light spectrum as well as the invisible light one e.g. infrared, were used.

Once the team is provided with the location where data collection will take place, they deploy the drone to identify the boundaries and use that data to schedule an autonomous flight over a predetermined area.

KaraAgro conducted seven separate flight missions to collect the data for monitoring approximately 2,000 varieties for a set of ten features found to be important and desirable in a cowpea crop. Using the DJI Phantom 4 drones they were able to conduct up to 30 to 40 minutes flights on a single battery charge.
They drew the boundaries of the cultivated area and then conducted automated flights to collect phenotype data for each plant. Once collected, the data was processed using the Python library developed by KaraAgro to perform high-

[9] SZ DJI Technology Co., Ltd. (n.d.). Phantom 4 - DJI. DJI Official. https://www.dji.com/global/phantom-4

speed phenotyping. The algorithm provided data that ranked varieties based on the 10 phenotypic attributes, comparing them to a given set of metrics to determine which ones to move forward with. The amount of data they collected in a single mission of approximately 40 minutes would take a team of researchers several days to compile and even longer to analyze.

The KaraAgro team worked closely with the WACCI team which included a postgraduate student whose supervisor was Dr Eleblu. This was a key to ensuring there was transfer of skills and knowledge from the private sector partner to the team at WACCI and its students.

Today, through this approach, it is possible for WACCI to bring to the agriculture sector a new improved cowpea variety in a fraction of the time it used to take through conventional approaches.

Analysis of the Case

Public sector institutions are very risk-averse, especially when there is no explicit incentive to assume risk in resource allocation decisions. The WACCI leadership was quite progressive and willing to try new approaches, new partners and new technologies that enable them to deliver on their mandate. Using drones and artificial intelligence to generate phenotype data in order to identify the best varieties seemed like an approach that could save WACCI a great deal of time and significant amounts of money.

There were significant challenges on the technology side of the collaboration though. The use of drones to fly over fields resulted in multiple images covering the area surveyed, but each image was saved as a distinct and separate data set. This required that the separate images be “stitched together” to form a single image that could be examined for usable analysis. To achieve this, the team at KaraAgro had to spend considerable amounts of time and effort to write new algorithms that put a significant strain on both human and cloud computing resources.

KaraAgro and WACCI working together on a plant phenotyping project brought together diverse skills from disciplines that may not normally have interacted in everyday life. The drone technicians, software developers and data scientists in KaraAgro brought their expertise to WACCI plant scientists studying the cowpea and in the process learned about the phenology and genotypes of cowpeas. The plant scientists on the other hand learned about alternatives to the various handheld (and lab installed) devices they used for collecting data from plants and which make it possible to work much faster than before.

The DJI drones used for this project were themselves both an opportunity and a challenge. They are an opportunity because they seem to have become an industry standard for the type of tasks KaraAgro were performing on this high-throughput phenotyping project. Innovators or scientists intending to use drones from tasks such as HTPP would not have to experiment with different expensive drones before landing on the ideal one. However, each drone costs upwards of USD10,000 making them particularly difficult for publicly funded agricultural research institutions to acquire due to the prohibitive cost.

In view of what the KaraAgro and WACCI teams were able to accomplish with the technology and what KaraAgro had achieved with CSIR-SARI and CRIG in the recent past, it is clear that this is a useful new source for data for development. Having been used for cashewnut, groundnut and now cowpea, the approach and suite of technologies can be used for other value chains where scientists are trying to achieve the same objective.

Findings & Reflections

Our Analysis

This is certainly a viable and replicable model for collaboration between private sector and the public sector, in this case academia and research.
The costs for the base infrastructure needed in order to make the use of this source of data and technology the norm in plant breeding, makes it somewhat prohibitive without the involvement of partners from the private sector who can make the investments and realize a return by working with a diverse number of national agriculture research institutes.

The knowledge required to stitch together the images created by drones and the time it takes to do so as a step prior to processing by AI is an area of potential growth. However, the government may not be the best institution to recruit, train and deploy annotators in the same way the private sector can. A collaborative approach may be necessary to bring multiple stakeholders to crowd in their expertise to solve the problem.

The increasing ubiquity of drones and the increasing ease of access to compute resources bring the approach within reach of a country's stakeholders and make it possible to deploy in just about any crop value chain.

Show, don't just tell. KaraAgro had successfully implemented aspects of their technology with other research institutions such as CSIR-SARI and CRIG on the cashew and groundnut value chains. It was therefore seemingly less risky for the team at WACCI to create a formal relationship with KaraAgro for purposes of the HTPP project than it would have been had there been no concrete outputs from previous related work.

The Gender Dimension

In Ghana, smallholder agriculture remains predominantly driven by women, and the advancements made in this field hold the greatest potential to benefit women smallholders in terms of household food security and potentially increased incomes.

Recommendations

The key to progress in accessing and using new data sources for decision making in the context of the data revolution is access to data and algorithms. It is crucial to actively promote the open sourcing of algorithms and machine learning datasets that are supported by public or philanthropic funds. This will significantly reduce the barriers for new actors collaborating with research institutions on similar projects, streamlining their efforts and fostering collaboration in related fields of work.

This collaboration was possible because the leadership at WACCI felt safe taking a chance on a young local technology services company. Governments should consider implementing measures that incentivize public sector institutions to embrace calculated and controlled risks when adopting new technologies and exploring novel sources of data. These endeavors are crucial for enhancing decision-making processes in critical development areas, particularly those associated with the attainment of the SDGs.

IT resources remain prohibitively expensive for many small institutions in Africa. The goal of ending hunger by 2030, as envisioned in the SDGs, may require, as part of the means of implementation for many countries in the Global South, additional investment in building data infrastructures for national research networks to reduce costs, improve accessibility, and catalyze use.

Drones, especially those used for research such as phenotyping, remain out of reach for resource constrained institutions. Governments should consider providing incentives for private sector actors to acquire these drones as well as encourage and incentivize sharing of those purchased by the government in order to improve access of these technologies for researchers.

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