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Review of Agricultural and Rural Development System Models and Frameworks to Support Farming as a Business via Benchmarking: The Case of Tanzania

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Abstract: This paper presents a review of the current state of agricultural and rural development (ARD) system frameworks, focusing on their capabilities and limitations to support farming-as-a-business via benchmarking (FAABB). Presented and discussed include the state of system models in relation to five modelling views of the ARD systems, namely: (i) defining factors for agricultural echo systems, (ii) farm characterization and management practices, (iii) simulation systems for predictable farm data, (iv) limiting factors for agricultural optimization, and (v) performance estimation through benchmarking. Also, the paper proposes a new framework to support FAABB in Tanzania that is being tested through various use-cases in the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) with a FAABB Cyber Studio hosted at the Nelson Mandela – African Institution of Science and Technology (NM-AIST) also in Tanzania. The FAABB setup at NM-AIST promises to address not only the agricultural knowledge codification problem, but also the need for cultural change among agricultural researchers to ensure that data for addressing a range of use-cases is available for future mobile application development. The proposed FAABB framework provides a useful starting point for addressing limitations of existing frameworks and considering a ubiquitous m-app development framework for targeted ARD research in developing countries.

Keywords: Agricultural and rural development (ARD), Farming-as-a-business via benchmarking (FAABB), System models, Frameworks, Use-cases.

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1. INTRODUCTION

In many developing countries, agricultural supply-side (i.e. smallholder farmers) is normally weak and cannot meet demands of formal markets due to several problems [1]. In the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), in particular, problems include lack of mechanization; lack of irrigation schemes with too much reliance on rain; lack of skills and knowledge on Farming-as-a-Business (FAAB); poor transportation and logistical networks; and lack or poor farm inputs (e.g. seeds, fertilizers, pests, etc.) [2]; [3].

In recent years, acceptance of agricultural and rural development (ARD) science has increased as more scientists, engineers, and economists graduate from universities with training in systems modelling, analytical approaches, and information technology (IT) tools. Also, there has been a corresponding increase in demands for agricultural systems science to address questions faced by developing countries that transcend agriculture. Relevant questions range from how to better manage systems for higher and more efficient production; what changes are needed in a farming system for higher profitability without harming the environment; what policies are needed to help farming systems evolve to meet broader societal goals, and what systems are needed to adapt to the continual changes that agriculture faces: including climate change, changes in demand for agricultural products, volatile energy prices, and limitations of land, water, and other natural resources. Therefore, agricultural systems and models are being challenged to move beyond just including economic and sustainability issues.

Sustainable solutions that address such multiple questions on FAAB will likely benefit from a convergence of science and technologies that make use of information, knowledge and cognitive sciences [4]. For the case of developing countries, and Tanzania in particular, the problem is further aggravated due to insufficient number

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of experienced extension officers and farm managers engaged in agriculture in general [5] and dairy subsector in particular [6] that can assist smallholder farmers to be responsive to FAAB. For example, while extension officers are expected to be the primary backstopping agents for farmers in bridging agronomic information and knowledge gaps, it has been observed that most extension officers are assigned to subsectors for which their understanding of domain knowledge is handicapped [7]. In some cases, one extension officer serves farmers engaged in multiple subsectors, whose working is ill informed about [8].

In order to analyze these different dimensions of ARD, ideally we would have a cyber-studio containing ARD models, data, analytical tools and IT tools to conduct studies that evaluate outcomes and trade-offs among alternative technologies, policies, or scenarios through benchmarking – hence the concept farming as a business via benchmarking (FAABB). Outcomes of such analyses could be more accessible to farmers through specialized mobile applications (m-apps). Reference [9] testifies that mobile handsets are currently being used in nearly every country and community. Consequently, m-apps for ARD could provide the most economic, practical, and accessible routes to information, markets, governance, and finance for millions of farmers who have been excluded from their use.

The FAABB cyber-studio would allow, for example, mobile and/or web-based application developers to define use-cases; prescribe scenarios covering different social, political, and resource situations through different spatial and temporal scales; and produce reports suitable for interpretation and use by extension officers and decision makers. Clearly, such a cyber-studio does not exist in Tanzania. But where is the industry related to this ideal situation? The purpose of this paper is to review the state of ARD systems science and its capabilities for supporting FAABB for smallholder agriculture in developing countries. Further, the paper discusses the implications of this review to the m-app development frameworks.

A. *Achieving ARD through FAABB*

Profitable agriculture with strong links to markets is the best route out of poverty for the majority of rural poor smallholder farmers in developing countries. For example, with farm productivity in Tanzania at just one quarter of the global average [10], there is a huge potential to increase agricultural output, and thereby boost incomes of smallholder farmers and their communities [11].

Due to economies of scale, farmers and agribusinesses are most likely to be successful when they are located in proximity to each other and to related service providers. ARD focuses on ‘clusters’ where there is a potential for profitable groupings of farming and processing to emerge. Each cluster requires investment along the full agricultural value chain. Some of these investments are public goods (e.g. rural infrastructure) that must come from the government and its development partners; others can expect to earn a financial return and will come from the private sector; more importantly, farmer groups themselves need to be assisted to increase productivity through technology, quality and quantity enhancements all, primarily, aimed at supporting smallholder farmers [3]. Supporting farmers to increase productivity requires proper choices of farms, administration and monitoring of extension services provided to these farms, and product value additions through postharvest handling. All of these choices and their monitoring are formally achieved through benchmarking [12].

FAAB is concerned not only with the ‘bottom line’ of farmers making money but also achieving technical aspects of farming that contribute to making the farm business profitable and efficient. Improving the performance of the farm business, therefore, requires a good understanding of both the business and technical aspects of farming [11]. At farm-level, ‘benchmarking’ is conducted by an extension officer in a way similar to a doctor diagnosing the condition of profitability and efficiency, identifying the problems that prevent the farm from achieving its potential and formulating strategies and actions to improve its business performance, i.e. practicing FAABB.

The term ‘benchmarking’ is used to cover a number of practices designed to highlight the good and make it possible to avoid the harmful. It is, therefore, a process of identifying, learning from and adapting good practices and processes to help improve performance. Benchmarking can show how higher levels of performance can be achieved. Many insights can be gained through a benchmarking exercise. It can uncover problems of production, management practices and other factors that affect productivity, cost of production and profitability. It can also help to trace the farmers’ economic health checks or their qualification for funding.

Despite the good intentions of FAABB, most smallholder farmers’ organizations still suffer from knowledge and information deficits e.g. about good farming practices, the benefits of using improved seeds, market prices for their outputs, etc. Most of these problems are associated with the lack of knowledge and unavailability of timely and correct information to guide farmers. These knowledge and information deficits act as critical constraints on achieving improvements in smallholder farmers’ productivity and economic growth.

B. *FAABB framework and its components*

The proposed FAABB framework is viewed as an integrated system that represents whole ARD related data, models, tools and platforms relevant to the monitoring and evaluation of farmers’ performance, profitability, and economic and social welfare. Fig. 1 shows the six components that define the proposed FAABB framework for developing ARD m-apps [13].

Defining Factors: The defining factors for agriculture are intended to codify the characteristics of the target produces. These factors predict crop/herd growth and yield at farm level and are typically obtained by narrowing down the many factors that are needed to estimate full potential production. For example, potential crop production is determined by defining factors of CO_2, radiation, temperature, and crop characteristics [14].

Farm Characterization: Potential production models also include capturing data regarding the farm's specific characteristics that qualify specific produce in a specific farm location. Farm characterization also captures alternate crops rotations and product dependences for higher farm productivity/gains.

Simulated Factors: In some cases, the complexity of farming systems justify using optimization tools to simulate different factors and their orientation (that would otherwise be complex to prescribe by practitioners). For example, simulations of the biology of livestock enterprises include models representing pasture growth, structure and quality; GIS coordinates; time and calendar stamps; and population dynamics [15].

Limiting Factors: Limiting factors are formalized as constraints on the defining factors that restrict the farm from reaching full potential. For example, water-limited and/or nutrient-limited production constrain the farm from achieving full growth potential. Other limiting factors include farm resource availability, climate, market requirements, logistics, etc. [13].

Benchmarking Factors: These are tools that use predetermined standards and models to predict the actual outcomes of the farm's parameters in the presence of constraints provided by the limiting factors. The economic implications of decisions and policies for a range of scales and purposes are also predicted through benchmarking [11].

Data analytics: These are decision support tools that take the outcome of one or more benchmarking results and produce tailor made reports (aimed at guiding decision makers, informing farmers, achieving selections, managing change, etc.) guided by specific **use-cases** [16].

2. REVIEW OF EXISTING ARD SYSTEM MODELS AND FRAMEWORKS

FAAB system is a complex inter related echo system of soil, plants, animals, implements, water, and other inputs controlled in part by ARD practices and influenced to varying degrees by political, economic, institutional and social forces that operate at many levels. Similarly, models of FAABB share the same fundamental characteristics as ARD systems: both describe agro-echo system growth and yield in response to water and soil nutrients, and plant/herd species characteristics and other limiting factors.

However, several aspects of FAAB achieved through specific ARD modelling present unique challenges. Many of these challenges stem from the requirement that ARD specific models represent several, *but predetermined*, interacting breeds, e.g. perennial and woody species of grasses for crop related products, or water contaminations for dairy related products. In addition, persistence of breeds over multiple years forces the FAABB models to consider complementarity of multiple breeds modelling either through crop rotations or through residual dependence between plants, livestock, and fisheries over time.

Thus, although most production models are similar between FAAB via ARD and FAABB (e.g., relative to photosynthesis, growth, water and nutrient uptake from soil, etc.) additional factors are considered when modelling specific FAABB applications. These additional factors can be limiting factors (e.g. natural climatic factors) and/or factors enforced through management practices at the farm level. At the system utility level, ARD systems are challenged as being narrowed down to specific use-cases to the extent that it becomes difficult to adapt them to other generic or related use-cases. An interesting hypothesis of the reported research is that, although most of the existing ARD models are useful in their own contextual use-cases, they add little value in addressing FAABB use-cases due to their limitations for being complemented by results from the other models.

In this section, we revisit existing ARD systems models as potential components of integrated FAABB framework, focusing on the utility of models for selected views of the framework. Capabilities and limitations of various data and information tools, the different use-cases, as well as what would be the future needs are also discussed.

A. *Defining factors for ARD systems*

Defining factors that influence FAAB require an echo system orientation as opposed to stand alone elements. Current ARD systems are largely concentrated on modelling defining factors for either crops or livestock systems.

Cropping Models: Cropping models have either been functional or mechanistic, depending on the modelling team's knowledge of the cropping system, their purpose, the availability of data for cropping parameterization, and their experience in developing and evaluating models. These differences lead to different models producing different responses when used to simulate the same experiment [17].

Defining factors have been automated through *functional models* which apply simplified functional equations and logic to partition simulated biomass into various plant organs. Functional models also primarily use "capacity" concepts to describe the amount of water stored in a soil that is available to plants. Capacity based functional modelling is the difference between the upper and lower limits of soil water-holding capacity that determine the amount of water available to plants. In contrast, defined crop farming factors through *Mechanistic models* use the potential energy of soil water and "instantaneous rate" concepts from soil physics. In this type of soil water model, water movement and its availability for crop growth are represented by functional equations on a daily time step, even though infiltration and runoff processes may be computed with smaller time steps.

The factors to which models respond vary among models and evolve as modelers attempt to make them more comprehensive and universally applicable. In contrast, some researchers who want to apply them do not have all needed inputs, or they may want to embed a crop model into economic or other models for analyzing responses across scales. For example, authors in [18] used DIAS crop simulation model approach to identify the changes of rice growth and yield in Nilwala river basin for mid-centuries under changing climatic conditions.

Livestock models: Livestock systems are complex and require modelling at several levels: the animal, the herd, and its interactions of the herd with its environment via consumption of feed, use of land and water, and other resources. Several types of models have been used in the past to describe different components of livestock systems [19]. Unfortunately, the current modelling practices in defining ARD systems has been dominated by individual line subsectors operated largely independently, with very little complementarity between them and their agronomists. The defining factors for FAABB should take into account the components of soil, water, crops, livestock, labor, capital, water and other resources, with the farm family at the center managing agriculture and related activities.

B. Farm characterization and management practices

Understanding crop and farm characterization, management practices and their links to farm(er) characteristics, productivity, biodiversity, marketing channels and perceptions of climate change influence the farming system design and development [20]. Specific models and IT systems are developed to (a) identify factors influencing crop choice and crop rotations on farms [21], (b) evaluate effects of management practices on crop performance indicators [22], (c) investigate farmers' perceptions and adaptation strategies to climate change [23], and (d) explore linkages between marketing channels, farm characteristics and biodiversity.

Limitations of most existing ARD system models are such that they only imitate the major factors that affect crop performance, e.g. weather, water and soil nitrogen availability and are available only for the most important agricultural crops [24]. Components to describe the effects of tillage, intercropping, pests, weeds, salinity, excess water, interplant competition and other factors on crop performance are largely ignored. Therefore, most models today do not have the capabilities to compute yield loss associated with specific pests and diseases or insufficient soil fertility level and to diagnose the reasons for the gap between potential and actual yield. At present, existing models are parameterized for different crops but not or seldom for different crop varieties [17].

Farmers need to develop their adaptive capacity. To support this process, agricultural research has developed two main approaches: *hard* approaches that are mainly science-driven and rely on simulation models, and *soft* approaches that rely fully on stakeholders' knowledge. Both approaches present several drawbacks to achieve relevance to real-world decision-making and management. A conceptual framework hybridizing hard and soft approaches to develop farmers' adaptive capacity is being advocated but no systems exists that can facilitate the hybridization modelling [25].

The types of land management practices farmers use differ across the different ecological zones, which further justifies modelling of farm characterization and management practices [26]. The policy implication is that agricultural interventions should be developed on the basis of agro-ecological zones, and blanket crop improvement packages should be avoided. The recommended policy action is that food crop farmers should be helped to improve the management of their agricultural lands by ecological zones at two levels. First, the practices that are common and promote agricultural production in each zone should be targeted and codified for improvement. Such a policy will re-orient farmers towards the adoption of more sustainable farm practices. Second, land management practices that are not currently being used by farmers in each zone but have potential to improve crop production should be identified, codified and promoted in the respective agro-ecological zones. A modelling framework to facilitate data capture and codification will provide farmers better land use alternatives in each ecological zone.

Although ARD conceptual models and their associated Farm Management Information System for Decision Support are being developed, they have only focused on the different ways of using the information coming from various sources as sensors to assist farmers in decision making of agriculture business [27]. Their ignorance on other limiting factors have limited their adoption.

Overall, FAABB framework calls for development of farm characterization and management practices that require an integrated data collection, validation, and codification mechanisms.

C. Simulation systems for predictable farm data

Various researchers have developed a reduced-form of crop models that can be interpreted as the "production function" that is the foundation of economic production models [17]. Production function can be linked to economic models to create “hybrid” models for policy analysis and impact assessment. Similar processes of summary model development are evaluated in [28], building from the foundation of a comprehensive set of crop soil and management system simulations in Asia.

In [19], Tedeschi, *et. al.*, confirm that several types of models have been used to describe different components of livestock systems. They concluded that livestock systems are complex and require modelling at several levels: the animal, the herd, and its interactions of the herd with its environment via consumption of feed, use of land and water, and other resources. Examples of these are DSSAT [18] and APSIM [28].

Reference [29] testifies the application of GIS to precision farming, satellites, drones, web maps and sophisticated models. The modern-day farmer needs to understand a lot more than just what to seed – soils, weeds, nutrients, weather, insects, disease, machinery and climate. The powerful analytical capabilities of the technology are used to examine farm conditions and measure and monitor the effects of farm management practices including crop yield estimates, soil amendment analyses, and erosion identification and remediation. GIS can also be used to reduce farm input costs such as fertilizer, fuel, seed, labor, and transportation. From collecting data in the field with mobile devices to the analysis of remote-sensed data at the farm manager's office, GIS is playing an increasing role in agriculture production throughout the world by helping farmers expand production, reduce costs, and manage their land more efficiently. Farm management practices are also affected by Calendar (Date and Time). Event triggers are required as functions of calendar not only for the reasons of alerting farmers of the upcoming events during the production life cycle but also to interact with other modules to simulate the input values in the context of the environment.

Reference [30] addresses the challenges of weather and climatic patterns simulations in linking climatological information with a wide range of farming decisions. In particular, while a considerable amount of weather and climate information is now available to farmers, types of information are focusing on isolated factors which are ill-suited for use by farmer-groups for their decision-making that may depend on a combination of multiple interdisciplinary factors. Developing appropriate interdisciplinary systems to connect climate, weather, and agronomic information is needed if uptake of such information by farmers is to be useful. Provision of output of climate change scenarios and trend information to aid long-term strategic farm management decisions is missing and needs to be considered, especially in FAABB.

D. Limiting factors for agricultural optimization

Reference [31] discusses the coupling of pest and disease models (as limiting factors) with crop models (as defining factors). They also propose a roadmap to improve pest and disease modelling focusing on improving the data resources available for parameterization and validation, bettering the coupling of crop to antagonist models, and creating a community of researchers that can collaborate to share expertise and produce community tools. Modelling has also proved valuable in assessing possible pest risks and in guiding general policy development [32]. Today, sophisticated mathematical tools are available for calculating the basic epidemiological number (R0) for complex structured populations, for spatially extended populations, and in the presence of stochastic effects. R0 is the number of secondary cases of a disease that are expected to happen when a primary case occurs in a susceptible population. Calculation of R0 for prevalent human diseases has proved useful in prioritizing investment in control strategies and vaccine development.

One of the applications of population genetics to weed, pest and disease issues in agriculture are models of the evolution of resistance to pesticides, and of the dynamics of plant diseases [33]. Evolutionary models can be broadly categorized as genetic or phenotypic. Some of the most sophisticated pest monitoring software (typically based on statistical rather than on process models) now include specific economic variables with parameters such as commodity prices that can be updated dynamically. The farmer may make different decisions about pest management depending on current market conditions. More generally, a goal of many people working to increase the sustainability of agriculture is to reduce chemical inputs by practicing “integrated pest (or disease) management”. The models required to support such work are challenging to construct, but some of the most advanced models incorporate economic elements as well as various biological processes.

E. Agricultural performance estimation through benchmarking

A number of approaches have been developed to model the economic implications of decisions and policies for a range of scales and purposes. The widely acknowledged models and their limitations are summarized in the following:

In [34], authors developed ***animal performance models*** that use animal performance as a central element driving production, profitability, and efficiency in livestock systems. Since then, the most commonly used livestock models are those that predict animal meat and milk productivity. Nutrient requirements models are the workhorse of the feed industry for ration formulation and for recommending changes in feed management to farm advisors. Although these models are good for calculating feed requirements, they are less accurate in predicting the nutrient supply to animals under a wide range of conditions [19] [35].

Linear economic optimization models of farm systems that were developed in the 1950–60s provide a basis for prescriptive *farm management advice* [24]**.** These models are characterized by a complex set of linear inequality constraints that represent the production possibilities available to a farmer. The simplex optimization algorithm is used to select the optimum production possibilities. A major problem with linear programming models is that they need complex constraint structures to achieve some degree of calibration to base data; those constraint structures restrict alternative solutions and are difficult to implement for applications such as adoption and impact of new technologies.

Reference [36] report on econometric methods developed and used for single function models, single-equation models, and simultaneous system models that represent input demand and output supply behavior for crop production. However, the econometric approach has limitations in its ability to extrapolate responses that are outside the estimation sample, or those that employ systems that are not present in the data sample [37].

Benchmarking modelling from a widely-used econometric ***risk behavioral model*** have also been analyzed [38]. As improved algorithms to solve quadratic optimization problems were developed, specification of risk expanded to a mean-variance measure of risk and imputed a risk aversion value based on observed farmer actions or primary surveys.

Reference [39] describes recent studies on application of models that combine bio-physical and economic models to represent agricultural systems. The studies characterize bio-economic models into farm, landscape, regional, and national models. Systems in each of these scales include crops, livestock, and socioeconomics components that interact in complex ways. Two areas of application of integrated bio-economic models are Climate Change Impact Assessment Models and Hydro-Agricultural Economic System Models.

Reference [40] devised a "*Farm Sustainability Index*" (FSI) model for measuring farm level sustainability using "Multiple Weight Method"**.** The model covered measures which could assist in automating decision support systems for farmers along five variables: (i) economic sustainability; (ii) environmental sustainability (e.g. fertilizer application, use of pesticide, sewage management, etc.); (iii) social sustainability (e.g. training courses, household facilities, etc.); (iv) Production and farm management practices (e.g. crop rotation, soil testing, calcium fertilization, animal welfare, etc.); and (v) Production space (e.g. soil quality index, soil acidity, etc.). While producing a comprehensive list of benchmarking measures, the FSI model is criticized by ignoring the defining factors in the modelling; consequently, relying on the farmers interviews as opposed to capturing live data from the fields.

F. Existing ARD m-Apps development frameworks

Reference [9] testifies that mobile handsets are currently being used in nearly every country and community. The development of applications for them offers uses that extend well beyond voice and text communications. Consequently, mobile applications for ARD could provide the most economic, practical, and accessible routes to information, markets, governance, and finance for millions of people who have been excluded from their use.

Reference [41] summarizes how 15 case studies, considered to best represent ARD m-apps in the three case study countries, are placed in the typology for ARD. The study provided eight critical application areas necessary for realizing FAABB: (a) Price information (b) Market links (c) Extension and support (d) Distribution, logistics, & traceability (e) Resource management (f) Labor migration & human development (g) Governance/political issues, and (h) Rural finance infrastructure. None of the existing m-Apps has more than three FAABB tools mentioned above. More critical, no single application links market access, extension services and resource management within a single application. This suggests that none of the existing applications has an embedded framework for realizing FAABB through mobile apps.

3. SELECTED CASE STUDIES IN THE CONTEXT OF FAABB USE-CASES IN SAGCOT

The state of current ARD system science was evaluated for its capabilities and limitations in providing information to assist a wide range of decision makers engaged in FAABB in SAGCOT. Typical ARD system use-cases would contain a set of interactions between systems and users in a developing country environment aimed at addressing the FAAB challenges through decision support systems (DSSs). The SAGCOT believes that profitable agriculture with strong links to markets is the best route out of poverty for the majority of Tanzania's rural poor. With backing from the government of Tanzania, development partners, and the private sector, the Nelson Mandela – African Institution of Science and Technology (NM-AIST) in Arusha, Tanzania, will take on the upfront costs and risks of developing FAABB information and research platform that will serve the corridor (as a pilot). The framework is illustrated in Fig. 2.

This section highlights the five uses cases that justifies long term investment in the proposed FAABB framework, which is being realized through FAABB Cyber-Studio at the NM-AIST, Tanzania.

A. Benchmarking for farms selection in the SAGCOT

In this Use-Case, an extension officer (EO) is providing advice to a group of paddy farmers in SAGCOT. There is a need to help her select the appropriate paddy farm blocks, register respective farmers as group members, and manage their expectations in terms of required farm services and expected yields per block. The EO engages in a group discussion about aspects of their farms that they are satisfied with and aspects that they are dissatisfied with as they participate in FAABB [3]. The m-app is required to assist the EO conduct benchmarking for such farm selection.

A typical m-app will be activated by the EO (through her hand-held device) to capture farm-block coordinates, basic geo-location features, and farmers' information and send them to the FAABB cyber studio server at NM-AIST. In return, the server should use the information to compare with the benchmark farms and return results as to which ones are eligible for registration. The benchmark farms are identified farmers in the learning blocks within the same farm or in other areas in SAGCOT who are performing well and can be regarded as benchmarks.

B. *Benchmarking for optimization of agricultural practice in the SAGCOT*

Government ministries responsible for agriculture possess a lot of data on agricultural best practices. Their challenge is often reaching the farmer in the last mile, or continuously updating extension officers with the latest information. The insufficient number of experienced extension officers and farm managers engaged in agriculture sector in general [5] and the crops [12], fishing [42], and livestock [6] subsectors in particular, in part, reflect the reality that farm management practices add on to the compounded problems farmers face in achieving FAABB. By providing agronomic data as open data to support farm management services, many more farmers can benefit from the latest agronomical insights.

From Crop Point of View: A typical purpose for the benchmarking in SAGCOT areas is to collect live farm data (from crops to soil to weather conditions as well as water and nitrogen fertilizer inputs) and send these data to the NM-AIST FAABB server that uses them to simulate actual yield in production. In the absence of such m-app, the EO will simulate yields that are higher than actual yields in farmers' fields, which are reduced due to poor management. In addition, fields are usually not homogeneous; for example, spacing between plants may vary considerably, whereas the models assume homogeneity. Benchmarking through FAABB m-app will assist the EO to prescribe the customized preferences and improvements.

From Dairy Point of View: A typical purpose of the benchmarking in the SAGCOT areas is to record and benchmark economic performance of dairy herds of all sizes, in order to identify the top 25% of the industry within each management system, and to drill down into why they are outperforming their peers, confirming critical best practices. The performance data analysis identifies the elite animals in the upper quartile to assist farmers with selection decisions (breed and strain) and to develop and refine a local profitability index for cows, cow families and the future local bull team. The FAABB system at NM-AIST should have at least three sub modules (i.e. Soil, Crop and Animals), and the system should include a series of "How To" guides that describe how processes are conducted on farm in simple or localized languages. Over time these guides will enable efficient monitoring and management of extension officer service to farmers and reinforces "FAABB" thinking and habits for farmers through EOs' mobile phones.

C. *Benchmarking for rural finance in SAGCOT*

Smallholder farmers in the SAGCOT area often have less access to information about rural finance than other specialist actors. This is partly because of their education level, but even more so because of the remoteness of many such rural areas, the relative immobility of the farmers due to poor roads, and the many things farmers need to know. The combination of open data and mobile information services can help to overcome this power imbalance. Relevant benchmarking data for farmer empowerment includes actual versus historical market prices, physical infrastructure and its condition, location of licensed organizations (e.g. service providers, logistics, transport), land registration, etc.

The price of financial services for farmers is strongly dependent on the assumed risks by financial institutions. These institutions (whether MFIs or banks) require information on local price history, regional production figures over time, regional farm profiles, regional growing conditions, local crop characteristics, climate change predictions, and extreme weather events to set out financing strategies, and accurately estimate risks while lending to or insuring clients. Of recent trend, more agents are investing on rural finance on the basis of loyalty programs that are driven by data about the farmers and their associated farm productivity indices. [3].

Although there are models that simulate loyalty programs as their basic benchmarking tools for lending to smallholder farmers, most of them are still not able to use farmers' compliance information as a basis for guaranteeing their loans. Instead, they are still requiring collaterals from farmers as a primary basis for managing their financial risks. Benchmarking for financial compliance requires FAABB framework at NM-AIST to have embedded models that integrate farmers' economic performance with farm productivity and efficiency.

D. *Benchmarking for optimizing agribusiness value chains in SAGCOT*

Actors in one part of the value chain need to know about performance in other parts of the value chain in order to make decisions such as who to do business with, or how to comply with the quality standards in different markets. Key datasets include regional production figures over time, regional farm product profiles, registered service provision companies, the condition of transportation infrastructure, market providers, etc. This requires benchmarking for performance optimization.

Although there are models that simulate logistical services like "*Ube*r or *Twende-Abiria*" that use Google-maps to simulate passenger's roots on mobile phones, these apps have not been able to serve the agribusiness sector because they require codification of services and products available by different actors on the value chain. Furthermore, these actors and reactors require a platform that allows reception of service enquiry and manage multiple subscribers to publish their offers.

The FAABB framework at the NM-AIST provides links into prescribed local and international search engines and websites as credible sources of information that may be required by various actors for a given value chain. On the other hand, such tools may be connected to local radio and EOs network within geographical areas that could provide responses through voice or video clips. Having this data and the related markets that are available can lower administrative costs of gathering the data, promote internal collaboration between farmers, and enable third-party services to make this information easily accessible for actors in the SAGCOT agribusiness value chain to act upon.

E. *Benchmarking for enforcing agricultural policies in SAGCOT*

Many policy decisions in the government or parliament in Tanzania are permitted, restricted or forbidden based on estimated rather than actual data. Most of the time these decisions are based on practitioners experience as opposed to the actual reality on the ground. Can existing ARD models, data, and ICT tools provide the DSSs that the policy makers can use as their basis for policy planning? The short answer is "No"; the allocation of the budget for subsidizing farmers in Tanzania largely depends on generic (sometimes unrealistic) computations as opposed to adopting models that embed such information as the: locations/zones, types of crops, types of inputs, the number available farmers that are ready to cultivate a typical crop for the coming seasons, their purchasing power, etc.

Relevant datasets that can be available include land registration, licensed organizations (farmer groups), farm input requirements, import/export tariffs, and permitted pesticides, etc. Donors, policymakers, beneficiaries, and civil society also require data on government spending in the agricultural sector to promote more efficient decision-making, equity and prevent corruption. Relevant data includes government spending, subsidy distributions, and rural development projects.

4. TOWARDS A UBIQUITOUS ARD SYSTEM FRAMEWORK FOR FAABB AT NM-AIST

As a direct implication of issues reported in the previous sections, two critical challenges emerge that make the existing frameworks and models less practical. First, there is a knowledge codification problem. There is no single ARD systems framework that systematically captures knowledge that comes out of various models and codifies them for future adaptation and/or use for generating new DSSs for specific use-cases. Second, there is a challenge of having software development toolkits (SDKs) that are generic and ubiquitous enough to facilitate the development of m-apps to support a wide range of use-cases.

In order to address the above two critical challenges, the FAABB information architecture was developed at the NM-AIST to simulate the platform for data collection, storage, processing and applications to facilitate the development of m-ARD applications.

A. *The enterprise architecture to support FAABB*

Fig. 3 provides a framework architecture for the interaction between various stakeholders involved in the knowledge codification process within the SAGCOT areas. The main data collection agent for FAABB is the extension officer (EO). Farm-level data is captured directly by the EO into the system as (s)he interacts with the farmers through "m-Apps" loaded on their phones. The market-level data is captured by the off-takers and/or service providers who (in-turn) will push or pull the data to the NM-AIST FAABB cyber studio through specialized "connect-and-exchange" interfaces at their office terminals. Various stakeholders could then have access to the reports that come out of the system either through their phone or web portals to provide them with specialized reports.

The main principles behind the NM-AIST enterprise architecture for the FAABB are the following:

- Farmers can only be registered by FAABB system at NM-AIST through their markets (off-takers).
- Farm characterization and management system for FAABB can only be fed by EO who is an agent of the market (or off-taker).
- Off-takers with their own IT systems can connect to NM-AIST servers through dedicated connect and exchange interfaces otherwise the NM-AIST system suffices as M&E tool for off-takers who do not wish to invest on IT systems.

The enterprise architecture has been validated and endorsed by the Government of Tanzania through the agricultural public private partnership (PPP) initiative, coordinated by the SAGCOT and involving the Government coordinated through Prime Minister's Office, the Development partners, the local Private sector, the international private sector, and associations of smallholder farmers in Tanzania (ref. *www.sagcotctf.co.tz*).

B. *The information architecture for FAABB*

The information architecture is a four-layered system in that it cohesively connects all envisaged model concepts through defining factors, limiting factors, and benchmarking factors. It is the heart of the envisaged FAABB Cyber Studio at NM-AIST, as illustrated in Fig. 4.

The first inner layer is the "Farm Characterization Systems" layer that captures and presents the *echo system set* up for enabling specific farm *characterization and management*. It captures all relevant context-driven data to serve a specific instance of the FAABB at specific locations. It is driven by the principle of location (*i.e. "no farms can be defined without location"* principle).

The second inner layer is the "Defining Systems" layer that codifies the basic types of agricultural *production variables* and defines performance **benchmarks/KPIs** for each of the four dependent variables (i.e. soil, crop, animal and water). The modules that drive this layer provides a codified knowledge of "How-to guides" that describe how production processes should be conducted on the farm in the absence of constraints. The "How To" guides are typically adapted from a country context and made available to the public in the database context in a form of codified rules or events. In the long term, this framework layer is expected to codify a Tanzanian baseline data for soil, plants, animals, and water in specific locations. Each defining factor should be associated with a location data in the first layer before its KPI is defined.

The third inner layer is the "Limiting Systems" layer that captures the possible contextual factors that may limit the attainment of the **KPIs** in the second layer**.** The limiting factors are either a results of natural environmental setups or available technologies that allow for accessibility of environmental information (mainly through simulations).

The fourth outer layer is the "Benchmarking Systems" layer that performs analytics for the purposes of providing DSSs. Theoretically, Each of the DSS is a function or a combination of parameters of the previous three layers passed through a chosen modelling platform that structures the validity and visibility of information to the intended user. In situations where the output is intended to be an m-app, the application development toolkit (ADT) will further be required to pull and push information to and fro between the mobile user and the DSS. Other instruments other than mobile devices can also be used.

The information architecture for FAAB has been validated through three pilot projects in the SAGCOT regions involving two off-takers for dairy farmers (engaging over 2000 dairy farmers) and one off-taker for crop farmers (involving over 500 paddy/rice farmers).

As indicated in Fig. 4, data collection is primarily managed through Internet of Things (IoT), image recognition tools and technologies, and other specialized data capture equipment that are being developed and tested through the School of Life Science and Bio-engineering at the NM-AIST. The IoT, refers to the billions of physical devices around the world that are now connected to the internet, collecting and sharing data. When applied to FAABB, IoT will add a level of digital intelligence to devices that would be otherwise dumb, enabling them to communicate real-time data without a human being involved, effectively merging the digital and physical worlds.

5. DISCUSSION AND CONCLUSION

A. Discussion

This review of ARD modelling shows that major contributions have been made by various disciplines, addressing different production systems from field to farms, landscapes, and beyond. There are good examples of component models from different disciplines being combined to produce more comprehensive system models that consider defining factors, farm management and characterization, limiting factors and environmental situations, as well as benchmarking to facilitate data analytics to produce a wide range of system use-cases.

The use-cases studied included relevant examples across the spectrum of users from small-holder agricultural systems in developing countries point of view (using Tanzania as a case study). They include examples that need models and associated data to evaluate technologies at a field or farm scale and others requiring the integration of component models to address socioeconomic, food security, and environmental issues at different scales.

Although the adequacy of available models varies among use-cases, one constraint is common across all of them, namely the scarcity of data. Data are the foundation for all agricultural systems analyses. This constraint restricts the capabilities of existing models to include factors of importance in most use-cases. The constraint also limits researchers' abilities to evaluate models across wide ranges of contextual setups (which limits user understanding of and confidence in the reliability of models) and limiting information that can be used as inputs to apply models [17].

Addressing data shortages is more important in developing countries than gaps in conceptual theories and approaches that can easily be adapted. Therefore, limitations of current agricultural system models and tools are more strongly rooted in missing or wrong data than in knowledge gaps. Existing tools restricts users' model choices to provide reliable results and therefore their use for decision making is missing particularly in the developing countries.

Although there are prospects for considerable developments in agricultural systems data, models, and knowledge systems, there are inherent limitations in these tools due to irreducible uncertainties in model structures, spatial variability of physical and genetic, conditions, and model interoperability.

Based on the current status of models, data, and knowledge systems, a strategy should include having a framework that facilitate appropriate modification and codification of existing component models that already include many needed capabilities. This would facilitate use-cases that are not currently considered by models, using a range of methods including statistical models, extended databases, farm-level models and knowledge products with simulated data and models.

These limitations will continue to vary depending on contexts, which suggest that future ARD capabilities should be based on multiple use-cases. This review indicates that the current state of ARD systems models is sufficient for some modern applications, but that major advances are needed to achieve the next generation of data, models, and knowledge systems to address more complex use-cases and achieve informed sustainable farming (guided by persistent benchmarking).

The lack of data is especially severe in less developed countries and Tanzania, in particular. This is true for production models of crops and animals as well as economic models across the use-cases that addressed issues in data-poor areas in Sub Saharan Africa. But it is also clear that many data-rich countries also suffer from lack of accessible and usable data.

B. Conclusion

Contributions from multiple disciplines have made major advances relevant to a wide range of ARD applications at various scales. Although current ARD system models have features that are needed for FAABB, it is established that all of them have limitations and less ubiquitous. Common limitations across all system models, include (a) scarcity of data for developing, evaluating, and applying agricultural models and (b) inadequate knowledge systems that effectively communicate model results to farmers. These limitations are greater obstacles to developing useful applications than gaps in conceptual theory or available methods for using these models

The FAABB Framework for mobile application development is being advocated at NM-AIST to address the two limitations observed in the existing frameworks. As a direct result of this work, the FAABB Cyber Studio was launched at NM-AIST in 2018. The FAABB framework is being piloted in SAGCOT through two pilot projects: the first one being implemented on Dairy and second one being driven by Crops. Further pilots and tests on FAABB framework utility are being encouraged from multiple disciplines of IT, mathematical modelling, m-Apps development and agricultural DSSs.

It is planned to extend this work by building on this initial version of FAABB Framework by deepening the testing of the utility of the framework in more locations and through other product types. Future research is also intended to test the effectiveness of various models to FAABB. Immediate research interests are encouraged for refining the current version of the FAABB framework architecture and m-apps software development toolkits. As data quality is an important issue to deal with, targeted research is also encouraged to develop a landscape of national agriculture data collection infrastructure through IoT and image recognition technologies. These technologies could help to collect live data, which is a real problem in practice. Lastly, we also encourage researchers to contribute their own use-cases to the FAABB package and develop a library of mobile apps targeting users within the package.

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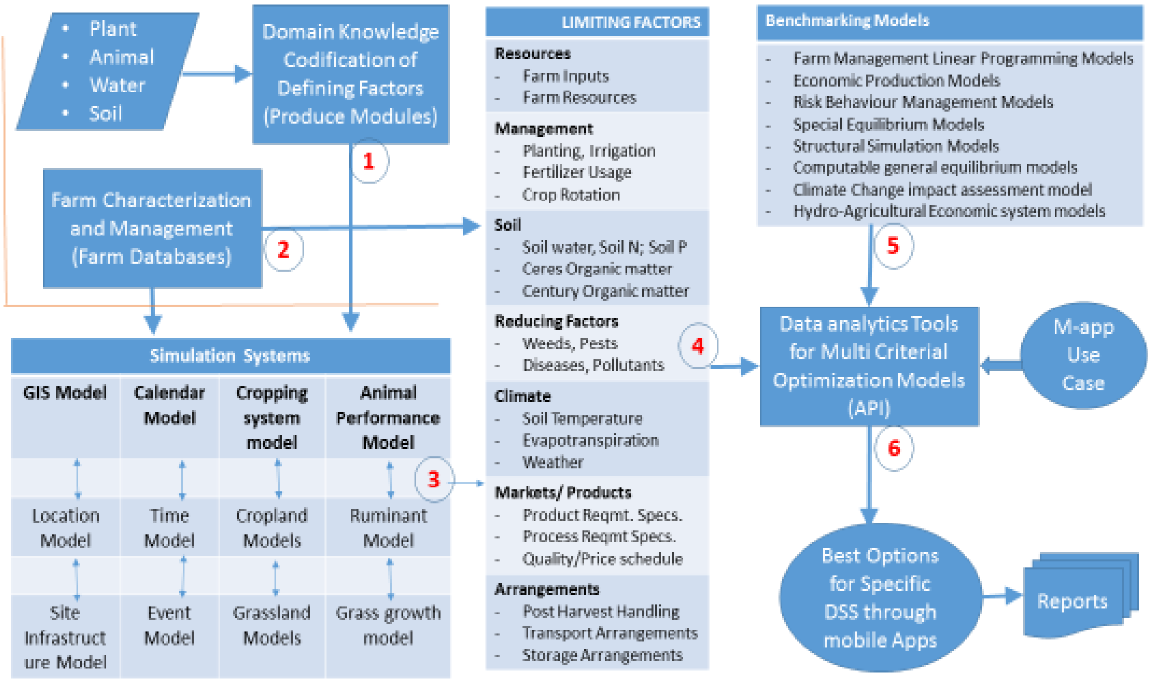

Figure 1. The FAABB Framework for developing ARD m-apps (Adapted from Herrero et al., 1996).

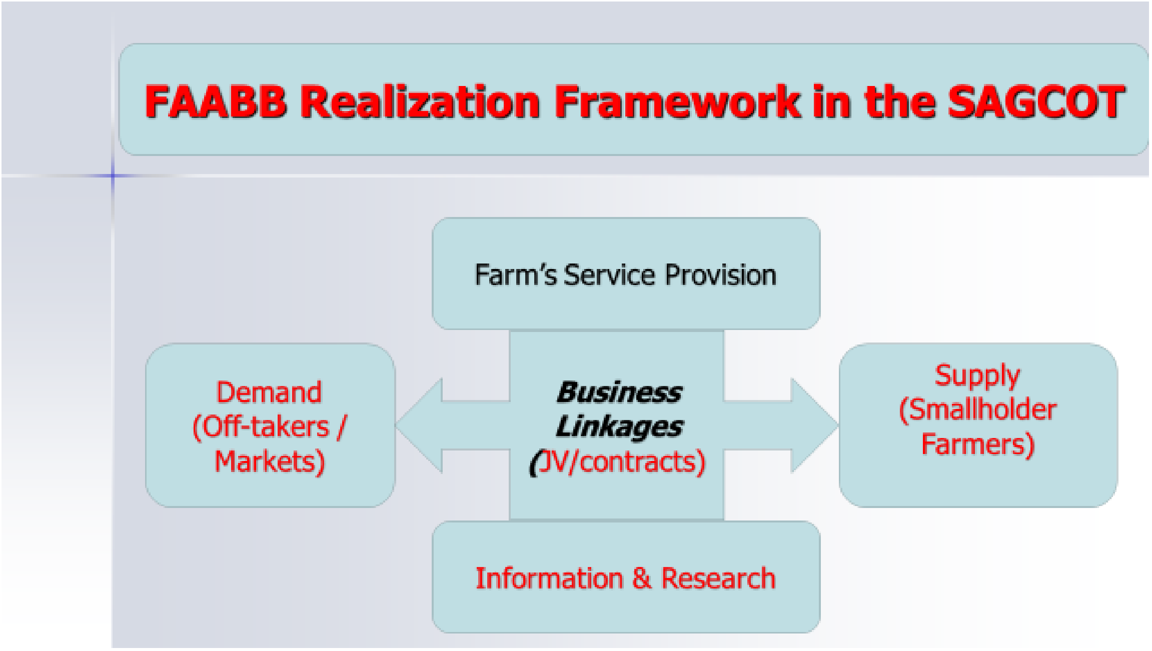

Figure 2. The SAGCOT Business Model for supporting FAABB Framework.

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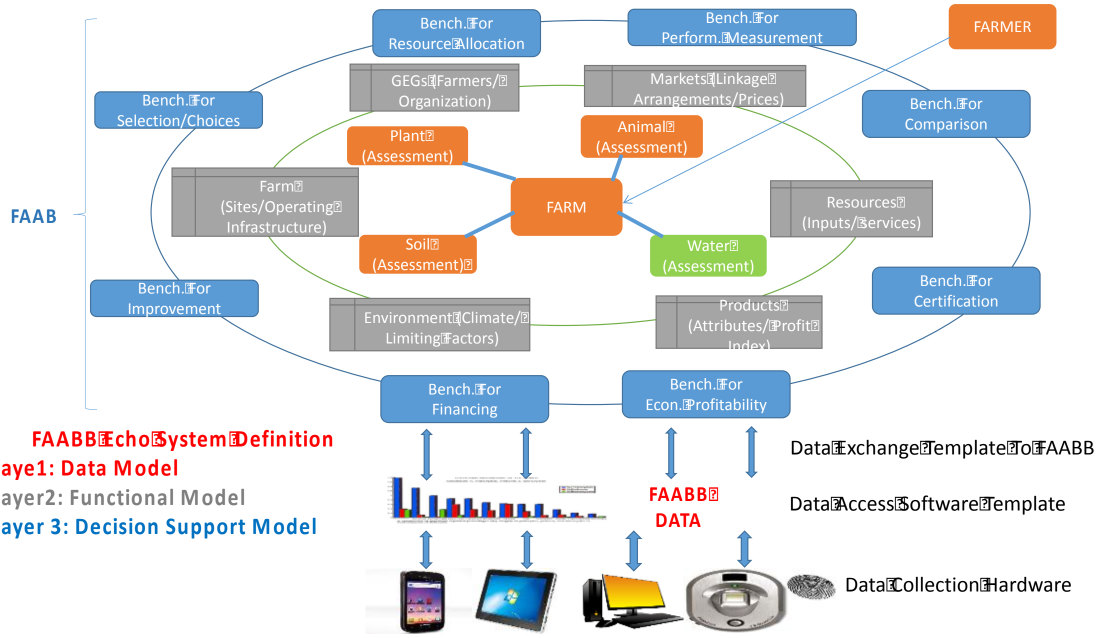

Figure 3. A framework architecture for codifying FAABB knowledge.

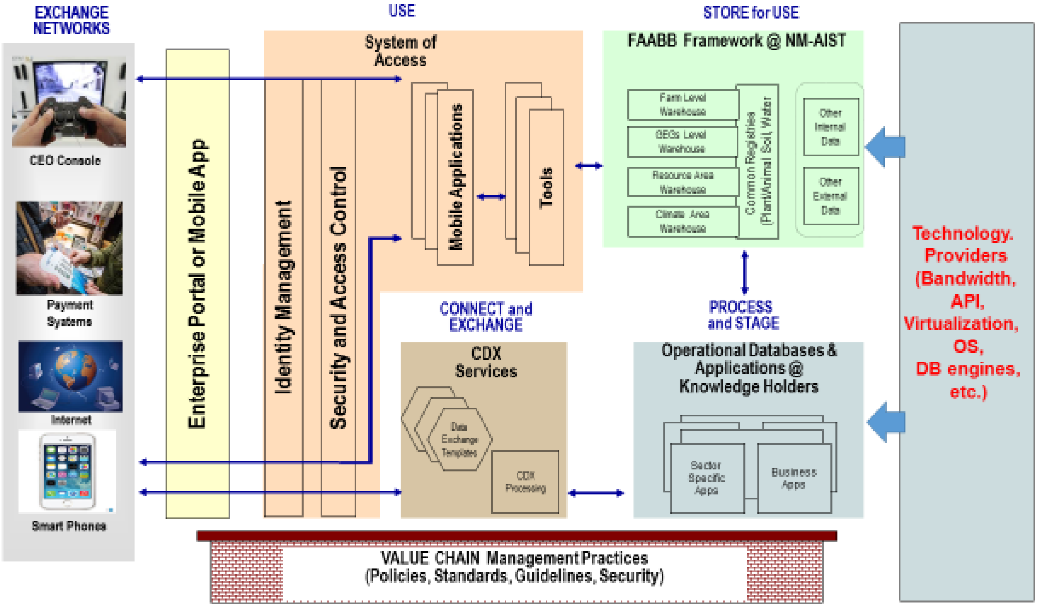

Figure 4. The enterprise architecture and its orientation to support FAABB framework at NM-AIST.