

5-2 Application of user-friendly software for the implementation of farm management models in sub-Saharan Africa

Junji Koide^{1*}, Wataru Oishi², Ryuichi Yamada³

¹ Japan International Research Center for Agricultural Sciences

² University of Tsukuba

³ Tokyo University of Agriculture

* Corresponding author; E-mail: koidej0187@jircas.go.jp

Abstract

Despite the increasing application of mathematical programming models in agricultural research, there is a dearth of user-friendly model-based decision-support tools available for agricultural practitioners, particularly smallholder farmers in developing regions. To address this, we developed efficient software that facilitates the rapid implementation of a mathematical programming model to achieve major objectives of smallholder agriculture, including enhanced income and food security based on diversified crop production. Unlike other expensive and expertise-dependent software, the developed software is freely accessible and open to anyone interested in supporting farmers' decisions, including those without programming expertise. Its easily applicable environment and functions, low data requirements and computational costs, and simple user interface are among its most notable features, enabling widespread application of model-based decision support. Our training experiences with major intended users, including agricultural researchers and extension agents in African countries, have confirmed that the software is highly intuitive and user-friendly, with many users able to grasp the concepts and operate the software to compute optimal solutions. Nonetheless, challenges persist in the operating environment of intended users, such as the glitches associated with older computers predominantly in use. To further promote agricultural decision support using the software, it is recommended to develop complementary tools, including a lightweight smartphone application that enables similar model-based optimization of farm operations, along with handy operation manuals, brochures, and accessible tutorial videos.

1. Introduction

Developing decision-support systems capable of optimizing the allocation of farm resources for smallholder households can provide opportunities to efficiently improve their food security and income. However, utilization of agricultural decision-support systems is generally limited (Collins et al., 2013). This issue may be attributed partly to inadequate system design and convenience. In sub-Saharan Africa (SSA), existing agricultural decision-support systems are primarily designed to optimize specific resource use practices such as fertilizer application (Ouattara et al., 2017; Rurinda

et al., 2020; Rware et al., 2020) and irrigation (Nigussie et al., 2020). However, focusing on optimizing specific resource uses can adversely impact other resource uses, potentially hindering the overall improvement in farm performance needed to enhance food security and income. Therefore, optimizing the whole-farm resource allocation is crucial while addressing the tradeoffs between different production activities.

Major applied decision-support models capable of handling the economic optimization of whole-farm management range from single-objective linear programming models to multi-objective goal programming models, fuzzy or stochastic programming models, and more spatially extensive programming models integrating GIS (Mellaku and Sebsibe, 2022). The more sophisticated and integrated the model, the higher the demand for high-precision data, extensive technical skills, and expertise, thus raising the application requirements. Additionally, specialized mathematical programming software capable of executing these models demands high technical skills and expertise, and has a cost burden. Designing simple, accessible, demand-driven farm optimization software is crucial for promoting farmers' decision support. However, such software is exceedingly limited. To the best of our knowledge, there are also very limited agricultural decision-support tools available that are widely usable in rural areas of developing countries, including African farming communities with no or unstable network connection.

Therefore, we developed software that works offline and enables the easy execution of a simple and practical farm management model for smallholder farmers as a new agricultural decision-support tool usable in SSA. This chapter highlights the features of the software and lessons learned from our training experiences with the target users, specifically agricultural researchers and extension agents in different African countries. As such, we clarify the opportunities and challenges of agricultural decision support using the software.

2. Features of BFM series for Africa

We have newly developed multiple software packages called the Builder of Farming Model BFM series for Africa (the “BFM series”). The BFM series was developed by customizing and upgrading the original BFM software (designed to formulate optimal cropping plans in Japan (Oishi 2008) for use in African countries. The series comprises specialized BFMs tailored to the official languages, currencies, cultivated crops of specific African countries, and more generalized BFMs whose users can flexibly modify all these settings. The specialized versions, created as part of agricultural technology development projects implemented in African countries, include an English version for Ghana (BFMgh), a French version for Burkina Faso (BFMbf), and a Portuguese version for Mozambique (BFMmz). The generalized version (BFMen) is an English version that allows for easily modifying area and currency units, farming conditions, and cropping options. All versions possess notable features in the following aspects.

2.1 Easily implementable Excel add-in software

All functions of the BFM series are executed through Microsoft Excel macros, eliminating the need to prepare other calculation tools, such as costly mathematical programming software. This holds a significant advantage in developing regions, including SSA, where potential users may not have the means to purchase or the knowledge to operate such tools. Many agricultural researchers and extension agents in African countries routinely use Microsoft Excel, so there are minimal barriers to starting to use the BFM. Furthermore, the BFM series supports offline work. Therefore, BFMs can be used even in developing countries, including African countries, with insufficient internet connectivity.

2.2 Functionality designed to address farmers' strategies

The BFM series is designed to execute farm management planning models for SSA and to easily identify the optimal combination of crops and the optimal areas to cultivate. The BFM automates a series of processes, from creating linear programming models to executing optimal calculations using those models and outputting calculation results. This contrasts with other mathematical programming software, where numerous codes and formulas must be correctly entered to execute the same processes. With the automation feature of the BFM, users can derive optimal solutions by simply registering information on the farming conditions and management indicators mentioned below (2.3 Data requirement). In contrast to current software designed primarily for developed countries, which optimize farm operations based on monoculture, the BFM series also allows for including various cropping systems, including monocropping, mixed cropping, and intercropping. This allows for farm optimization without compromising the production and market risk hedge through crop diversification, one of African smallholders' most important farm management strategies. Furthermore, the BFM series can incorporate food self-sufficiency requirements based on household dietary preferences. By doing so, the series can compute solutions that enhance the profitability of the entire cropping system and contribute to household food security. These aspects are key livelihood strategies for smallholder farmers in SSA and essential for effective decision support. Additionally, by registering management indexes for cropping options using alternative technologies, the BFM can output solutions showing optimal technology selection and adoption scale. This can assist agricultural extension organizations in devising appropriate dissemination plans for recommended technologies.

2.3 Readily accessible input data

The data that users of the BFM series should input are limited to farming conditions, including the area of agricultural land and leasable area by land-use type, the number of family workers and hired workers, and the number of workable days, and management indicators for each cropping option, including yields, sale prices, costs, and labor requirements. The data that users can optionally input

include the types and consumption quantities of staple crops for food self-sufficiency requirements. None of these data requires specialized skills or instruments for acquisition and can be collected through interviews with farmers, though more accurate, high-frequency data collection methods such as farm-based recordkeeping are recommended (as highlighted in Chapter 5-1). Therefore, users can input primary data obtained from farmers into the BFM and immediately perform optimal solution calculations. Data collected in typical farm household surveys in SSA often contain the data required for the BFM; some are publicly available. Therefore, it is also possible to perform optimal solution calculations using this secondary data.

2.4 Availability of sample data

The specialized software packages tailored for respective African countries, including BFMgh, BFMbf, and BFMmz, are accompanied by sample data on typical farming conditions and management practices collected from farmers as part of agricultural research projects conducted by the Japan International Research Center for Agricultural Sciences (JIRCAS) in each country. The sample data included in BFMgh, BFMbf, and BFMmz cover the major local crops project sites in northern Ghana (i.e., maize, pepper, rice, and vegetables), in central Burkina Faso (i.e., sorghum, millet, cowpeas, groundnuts, and rice), and in northern Mozambique (i.e., cassava, maize, pigeon peas, groundnuts, and common beans). The same sample data as BFMgh is available for BFMen. Users in these countries can load their country's sample data and, if necessary, modify and update it to generate optimal cropping plans for local agricultural decision support. Users from other regions can also attempt calculations with the sample data to deepen their understanding of the operational procedures and functions.

2.5 Low cost

Unlike other mathematical programming software, which entails high acquisition costs, the BFM series is free of charge, ensuring accessibility for individuals interested in agricultural decision-support tools but hindered by financial constraints. The BFM series, operation manual, and sample data can be downloaded from the website (JIRCAS, 2024). It can be utilized with basic knowledge of Microsoft Excel, obviating the need for specialized expertise or skills. Additionally, its offline functionality eliminates concerns regarding network connectivity, a common issue in many rural areas of African countries. There are no data acquisition costs when using secondary or sample data. As previously mentioned, the data required from farmers by the BFM series is limited to basic farming information that can be easily collected through simple inquiries. Therefore, even when primary data are used, the acquisition cost is significantly lower than other specialized agricultural decision-support tools that necessitate agronomic and/or environmental variables, which are often challenging and costly for farmers to obtain. Furthermore, the BFM series is characterized by low computational costs, enabling

time-efficient model creation, optimal calculations, and output of results. These comprehensive cost advantages significantly lower the financial barriers for users in low-income countries in SSA to utilize agricultural decision-support tools.

2.6 Simple user interface

When the user runs BFM, a startup menu is displayed (Figure 1), and the functionality of BFM is added to Microsoft Excel as an add-in and becomes available for use. The main sheets where users are supposed to read, browse, input, edit, and save are limited to four sheets: the farming condition sheet (fCondition sheet), management index data sheet (iData sheet), index edit sheet (iEdit sheet), and output farming plan sheet (fPlan sheet). The fCondition sheet is designed for easy registration of information on the land to be used, labor force, cost of agricultural machinery and facilities, and types and quantities of crops to be self-sufficient (Figure 2). In BFMen, users can specify the currency and area units to be adopted on this sheet. In the iEdit sheet, designed to register information about cropping options, users can set details such as yield, cost, and labor distribution for each crop (Figure 3). The registered cropping options are automatically listed on the iData sheet (Figure 4). Users can select cropping options they want to include in the optimal calculation and generate the fPlan sheet by clicking a button (Figure 5). The information displayed on the fPlan sheet includes the combination of cropping options to maximize total agricultural income under the set farming conditions, the optimal area of each cropping option, and its maximal income. Users can support decision-making by presenting this information to farmers. Additionally, users can display the specific seed amount required for the optimal cropping areas on the fPlan sheet by registering the sowing rates of cropping options on the iEdit sheet. This information is helpful in proposing cropping solutions to African farmers, especially when measuring the cropping area is not feasible. Users can refer to the detailed operational procedures from the startup of BFM to the output of calculation results in the operation manual (Figure 6). The manual is available in English, French, and Portuguese.

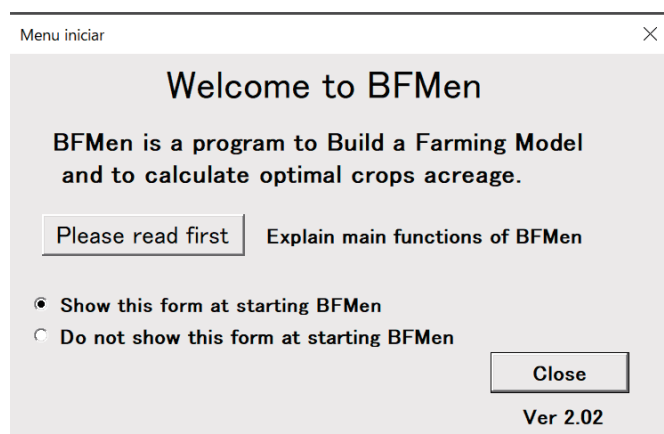


Figure 1. Startup menu of BFMen

	A	B	D	E	F	H	I	J	L	M	N	P	Q
1		FC Farming condition											
2													
3			Number of person	Working hour	–								
4		Family labor	5.0 people	8 hour/day	–								
5			–	–	–								
6		–	–	–	–								
7													
8			Daily wage	Working hour	Use								
9		Hired labor	12 GHc	8 hour/day	No								
10													
11		Farmland category	Owned land	Rentable land	Rent per ha								
12		1) Lowland	0.5 ha	0.0 ha	0 GHc								
13		2) Upland	1.7 ha	0.5 ha	0 GHc								
14		–	–	–	–								
15		–	–	–	–								
16		–	–	–	–								
17		6) Other	0.0 ha	0.0 ha	20 GHc								
18													
19													
20		Use of rented land	No										
21													
22		–	–										
23		–	–										
24													
25		Fixed cost	0 GHc										
26		1) Machinery	0 GHc										
27		2) Building	0 GHc										
28		3) Others	0 GHc										
29													
30													
31													
32													

Figure 2. Example of fCondition sheet (Sample data for Ghana are loaded on BFMen.)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		IE											
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													

Figure 3. Example of an iEdit sheet (Sample data for Ghana are loaded on BFMen.)

	A	B	C	D	E	F	G	H	I	J	K	L
1	[M]											
2		No.	Area	Crop	Cropping system	Scale of investigation	Variety	Yield	Unit price	Gross income	Cost of seeds	Cost of fertilizer
3	<input checked="" type="checkbox"/>	1	Tamale	Maize				1485	0.91	1351.35	10	515
4	<input checked="" type="checkbox"/>	2	Tamale	Pepper				1687	4.59	7743.33	70	2782
5	<input checked="" type="checkbox"/>	3	Tamale	Rice	Rainfed			3122	1.1	3434.2	172	1353
6	<input checked="" type="checkbox"/>	4	Tamale	Rice	Supplementary irrigation			3842	1.1	4226.2	234	554
7	<input checked="" type="checkbox"/>	5	Tamale	Leafy veget	Dry season			1012	8.3	8399.6	2725	682

Figure 4. Example of an iData sheet (Sample data for Ghana are loaded on BFMen.)

	A	B	C	D	E	F	G	H	I	J	K
1	[Farming plan]	[Memo space] This table is an optimal plan which is calculated using the data of sheet "fCondition" and sheet "iData". You can get the new plan by modifying the numerical values (crop acreage, income, cost etc.) in the cream-colored cells.									
2	Copy										
3	Detail of Plan										
4											
5											
6			whole management	Maize	Pepper	Rice Rainfed	Rice Supplementary irrigation	Leafy vegetables Dry season		Rented land acreage Part time days	Land rent Part time Unit price
7		Crop acreage (unit: ha)	2.70 ha								
8		Lowland (ha)	1.00 ha	-	-	0.11	0.40	0.50		0.00 ha	0 GHc
9		Upland (ha)	1.70 ha	0.94	0.76	-	-	-		0.00 ha	0 GHc
15		Quantity of seeds(kg/ha)									
16		Maize		26.5	-	-	-	-			
17		Pepper		-	3.6	-	-	-			
18		Rice		-	-	19.4	92.4	-			
19		Leafy vegetables		-	-	-	-	2.4			
35		Total gross income (GHc)	13,366 GHc	1,274	5,862	361	1,669	4,200			
36		Total variable cost (GHc)	5,971 GHc	688	2,428	226	474	2,155			
37		Proportional profit (GHc)	7,395 GHc	586	3,434	135	1,196	2,045			
38		Fixed costs(depreciation etc.) (GHc)	0 GHc								
39		Land rent (GHc)	0 GHc								
41		Hired labor cost (GHc)	0 GHc							0.0 day	12 GHc
42		Agricultural income (GHc)	7,395 GHc								

Figure 5. Example of fPlan sheet (Calculated using sample data for Ghana on BFMen.)

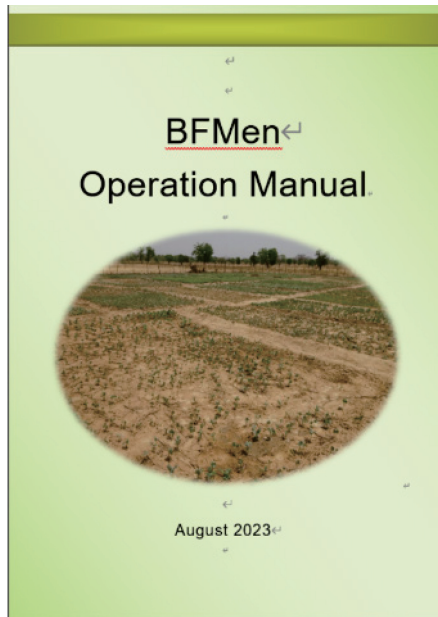


Figure 6. Operation manual of BFMen

3. Local needs and challenges of the BFM series identified through training sessions

The BFM series aims to support farmers' decision-making. However, many farmers in SSA lack the knowledge to operate both computers and Excel. Therefore, we promoted knowledge sharing with the local extension agents responsible for providing agricultural guidance to farmers through training sessions on using the BFM series, assuming that they would be the primary intended users. Training sessions were conducted for approximately 120 agricultural extension agents and their technical advisors from various African countries, including Ghana, Burkina Faso, Nigeria, Mali, Ethiopia, Uganda, and Mozambique. Next, we use the training sessions we conducted with agricultural researchers and extension agents in northern Mozambique and the local technical staff of the Sasakawa Africa Association (SAA) to highlight the opportunities and challenges of the BFM series from the perspective of the trainees' evaluation and proficiency.

In northern Mozambique, we initially instructed researchers in agricultural economics at the Mozambique Agricultural Research Institute (IIAM), who are mainly responsible for training agricultural extension agents on utilizing BFMmz. These researchers effortlessly mastered the operation of BFMmz and successfully calculated optimal cropping solutions using available regional statistics on the necessary inputs and outputs for various cropping practices (Figure 7). Additionally, we provided training on BFMmz to IIAM researchers from other fields, including agronomists, and discovered that some participants subsequently used it for analyses, such as evaluating the impact of introducing new crops. This implies that the BFM series holds potential applications not only for agricultural economists but also for agronomists.

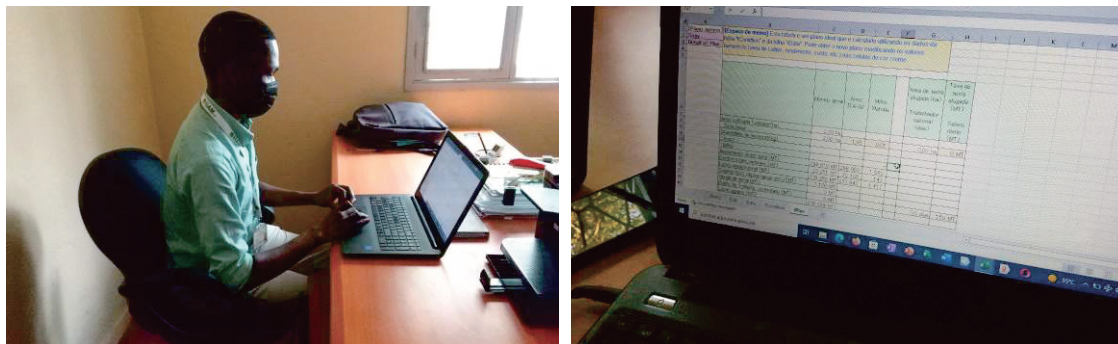


Figure 7. Calculation of optimal cropping solutions using BFMmz by an agricultural economist (left) and the output screen (right)

Agricultural economists at IIAM conducted BFMmz training sessions for agricultural extension agents across multiple regions. The trainees engaged in hands-on learning by operating BFMmz on their own computers and adhering to the operational procedures from input to output, as demonstrated by the instructors. Even though most trainees were unfamiliar with agricultural economics, they were engrossed in BFMmz. They were passionate about simulating how the optimal cropping solutions change when altering farming conditions such as the cultivation area, labor force, and employment, and were diligently exploring ways to efficiently improve total agricultural income (Figure 8). Although BFMmz is intended as a support tool for those who receive cropping solutions (i.e., farmers), it was confirmed that it also serves as a learning tool for those who provide cropping solutions (i.e., researchers and extension agents). In addition, we paired the participants into groups of two, with one acting as a farmer and the other as an extension agent. The extension agent's role was to extract farming information from the farmer role and create optimal cropping plans, then present them to the farmer role, engaging in role-playing learning. As many trainees were extension agents who also engaged in farming themselves, they provided accurate farming information to the extension agent role, identifying the optimal cropping solutions. As a result, they seemed to realize the usefulness of BFMmz even more.



Figure 8. Creation of optimal cropping plans by agricultural extension agents at the training session

We also provided training on the BFM series to the local technical staff of SAA, who are engaged in technical guidance of agricultural extension agents in Nigeria, Mali, Ethiopia, and Uganda. We explained the basic operation of the BFM series and how to use the BFM series to identify the optimal technology adoption for improving the benefits to farmers using regenerative agricultural technologies, which the technical staff was focusing on. For example, based on the on-farm trial results of cultivation techniques such as intercropping between cereals and legumes, and the integrated use of chemical fertilizers and compost, we showed the trainees how to calculate the desired combinations and scale of adopting these techniques among existing cropping options using the BFM series, along with their expected benefits. Many trainees showed a keen interest in using the BFM series, and after training, they decided to collect data from farmers they were supporting and attempt to identify the optimal cropping and technology adoption of regenerative agriculture.

Through the training sessions for target users from various African countries, we confirmed that most trainees could understand and master the concepts, operational methods, and specific applications of the BFM series after a few hours of training, indicating that the BFM series is simple and user-friendly. However, some trainees did not own a computer and had to borrow one, while others who owned a computer used old ones with slow or unstable Excel macros. Such challenges in the operating environment could substantially constrain increasing the use of the BFM series in SSA. In addition, in the rural areas of SSA, where agricultural extension agents are scattered for farmer guidance over a wide area, ensuring the means for initial trainees to convey the methods of using the BFM series to potential users in other regions would also be an important challenge.

4. Concluding remarks

Very limited agricultural decision-support tools are available for smallholder farmers in developing regions such as SSA. To our knowledge, there is no easy-to-use decision-support software that fully considers the key livelihood strategies of smallholder farmers, including the pursuit of food security, risk management, and income improvement. The BFM series can serve as such software, allowing for implementing a farm management model that explicitly integrates these key livelihood strategies. Unlike costly and expertise-based mathematical programming software whose main users are limited to researchers and experts in operations research, the BFM series is free and open to anyone who seeks to support farmers' decisions, including those without programming expertise. The easily applicable environment and functions, low data requirement and cost, and simple user interface are among the most prominent features, enabling extended application of model-based decision support. Our training experience in using the BFM series for agricultural researchers and extension agents in African countries has confirmed that the BFM series is virtually uncomplicated and user-friendly, with many users able to understand the concepts and handle operations to compute optimal cropping solutions under different conditions. However, there remain challenges in the operating environment among intended users, including the glitches of many older computers in use.

Considering the ease with which African users comprehend the BFM series and the challenges their usage environments present, two advanced utilization strategies for the BFM series appear promising. The first strategy entails expanding the application of the BFM series to other developing regions, including Southeast Asia, where research and extension personnel and computer usage environments are relatively more prevalent. Although the BFM series is tailored for smallholder farming in SSA, a generalized version such as BFMen could be effectively deployed to support decision-making in numerous other developing countries where smallholder farming predominates, either directly or with additional modifications. In Southeast Asia, where integrated farming systems involving diverse production sectors are common among smallholders, fostering the development and application of such software through collaboration with researchers and extension workers in these regions would be highly advantageous.

The second strategy is to upgrade the BFM series to a more adaptable and user-oriented decision-support tool by, for instance, developing a lightweight smartphone application that enables similar mathematical model-based optimization of cropping systems. The release of such a smartphone application could lead to more widespread decision support, given the increasing number of smartphone users in developing countries, including African and Asian nations. In order to communicate the use of the BFM series to more potential users, it is also important to promote time- and cost-efficient training methods (e.g., using ICT tools) as an alternative to direct face-to-face training. In addition to the operation manuals, handy brochures highlighting the features of the BFM

series and accessible tutorial videos demonstrating the operation procedures would also contribute to further promoting the use of the BFM series.

Acknowledgments

The authors greatly appreciate the support of the Japan International Cooperation Agency (JICA), the NTC International Co., Ltd., and the Agricultural Research Institute of Mozambique for the implementation of the training on BFMmz to agricultural extension agents in Mozambique under “The Project for Improving Research and Technology Transfer Capacity for Nacala Corridor Agriculture Development, Mozambique.” The authors are also grateful for the support of the Nippon Foundation and the Sasakawa Africa Association (SAA) for the implementation of the training on the BFM series to SAA technical staff under the “Technology Establishment for Regional-adapted Regenerative Agriculture in Africa (TERRA Africa)” project.

References

- Collins, A. J., Vegesana, K. B., Seiler, M. J., O'Shea, P., Hettiarachchi, P., & McKenzie, F. (2013). Simulation and mathematical programming decision-making support for smallholder farming. *Environment Systems and Decisions*, 33, 427–439.
- JIRCAS (2024). Programs for creating Improved Farming Plans for African Smallholders. https://www.jircas.go.jp/en/database/farm_management_model_for_shfa
- Mellaku, M. T., & Sebsibe, A. S. (2022). Potential of mathematical model-based decision making to promote sustainable performance of agriculture in developing countries: A review article. *Heliyon*, 8(2).
- Nigussie, E., Olwal, T., Musumba, G., Tegegne, T., Lemma, A., & Mekuria, F. (2020). IoT-based irrigation management for smallholder farmers in rural sub-Saharan Africa. *Procedia Computer Science*, 177, 86–93.
- Oishi, W. (2008). Program "BFM" for automated building of farm planning models. *Agricultural Information Research*, 17(2), 50–59.
- Ouattara, K., Serme, I., Bandaogo, A. A., Ouedraogo, S., Sohero, A., Gnankambary, Z., Youl, S., Yaka, P., & Pare, T. (2017). Chapter 4. Optimizing fertilizer use within an integrated soil fertility management framework in Burkina Faso. In C. S. Wortmann & K. R. Sones (Eds.), *Fertilizer use optimization in sub-Saharan Africa*. CABI.
- Rurinda, J., Zingore, S., Jibrin, J. M., Balemi, T., Masuki, K., Andersson, J. A., Pampolino, M. F., Mohammed, I., Mutegi, J., Kamara, A. Y., & Craufurd, P. Q. (2020). Science-based decision support for formulating crop fertilizer recommendations in sub-Saharan Africa. *Agricultural Systems*, 180, 102790.
- Rware, H., Kansime, K. M., Watiti, J., Opio, J., Aloit, C., Kaizzi, C. K., ... & Mibei, H. (2020).

Development and utilization of a decision support tool for the optimization of fertilizer application in smallholder farms in Uganda. *African Journal of Food, Agriculture, Nutrition and Development*, 20(4), 16178–16195.