Overcoming barriers to sustainable and regenerative climate-smart agriculture, agroforestry and environment projects: The case of Banana Industrial Research and Development Centre, Uganda[1]

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Abstract

This paper examines how banana production has improved through farmers' adoption of climate-smart agricultural/agronomic practices, and improving resource-use efficiency at subsistence farm level. It highlights how the Banana Industrial Research and Development Centre (BIRDC) has transformed the landscapes of south-western Uganda through sustainable and regenerative climate smart agriculture, agroforestry and appropriate production environment. The study was guided by three objectives: (a) examining the barriers in management of sustainable and regenerative climate smart agriculture; (b) assessing the capacity of the stakeholders; and (c) analysing climate change adaptation measures in managing climate-smart and regenerative agriculture. Findings reveal that farm-level production barriers can be removed by, among others, building stakeholder capacity; appropriate site-matched on-farm integrated agroforestry; and introducing small-scale irrigation technology. To minimize the prevailing global climate change experienced in the study region, farmers need to use climate-smart information, agro-forestry, soil and water conservation techniques, grow appropriate banana cultivars, and acquire agricultural knowledge and skills through farm school training.

Keywords: Overcoming barriers, Sustainable management, Regenerative climate smart agriculture, Agroforestry and Environment.

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1.0 Background and context

The Great Lakes region in East Africa is the largest banana-producing and consuming region in Africa (AATF 2009). In Uganda, banana is one of the most important food crops where annual per capita consumption exceeds 135 kg (FAO 2013a) and main staple for nearly 60% of the population. The major banana- growing areas in East Africa include south-western and central Uganda (AATF 2009). The South-western region, is the home of the Banana Industrial Research and Development Centre (BIRDC), where the study was carried out.

Studies conducted by Feed the Future (FtF) have revealed that drought stress is a major constraint in banana production in the region (Van Asten *et. al.,* 2011). Optimal banana production requires ample soil moisture due to its permanent green vegetation and shallow root system (Robinson, 1996). Although banana can survive water stress for long periods, low soil moisture and extended exposure to extreme temperatures (above 35°C) can reduce production (Thornton and Cramer, 2012). In the East African highlands, where annual rainfall is below 1100 mm, drought-induced yield reduction on rain-fed bananas can reach up to 65% compared to wetter areas (Van Asten *et. al*., 2011).

Banana agricultural production in Uganda, responds to climate change management from mitigation and adaptation perspectives (FAO, 2009). Agricultural production contributes almost one-quarter of global human-induced greenhouse gas (GHG) emissions, according to the Food and Agriculture Organization, but discussions about mitigation tend to focus overwhelmingly on the energy and transport sectors. Consequently, climate-related research on food production in developing countries is mostly centred on attainment of sustainable yield (Fay *et al.*, 2015).

Potential changes in rainfall availability and the impacts of temperature affect crop productivity, raising concerns about the impact of climate change on banana production and food security in Uganda. As the global population is expected to increase by 25 per cent to almost ten billion by 2050, crop production will need to increase by up to 70 per cent to feed the population (FAO, 2009). If current trends are not addressed, the majority of the world's population could face food and water shortages, hence the need to mitigate climate change effects to meet the food demands of the changing population. The good news is that technologies and practices for better water management and climate-smart agriculture (CSA) exist, where water is delivered directly to the roots of the plant as opposed to flooding the fields (Thornton, 2016).

BIRDC's underlying theory of change is that rural farmers with access to science-led processing and value addition enterprises will be able to access profitable market chains that supply local, regional and international markets, resulting into increased household incomes. It is against this background that the project supported farmers to form cooperatives to meet the production from 6-7 tonnes per acre per year to 50-60 tonnes per acre per year under optimized agronomic practices.

This paper provides a grounded analysis of how to overcome barriers in sustainable climate-smart agriculture focusing on the East African Highland Banana variety. Furthermore, it shows how transformations in technology adoption can calibrate policy niches to market arenas to leverage technology for the benefit of the rural farmers in Uganda. The paper is organized as follows: after the introduction, the research is contextualized to the current debates on sustainable climate-smart and regenerative agriculture. The objectives and the theoretical underpinning are presented for ease of reference. Thereafter, the paper elucidates the method and the details of the study area giving the research design, data collection, data analysis and ethical considerations. The results, discussion, conclusion and recommendations are finally presented in relation to the research idea initially developed for the study.

1.2 Research objectives

This paper has the following objectives:

i. Examine barriers to sustainable banana production.

ii. Assess the capacity of stakeholders to share information on banana production value chain.

iii. Analyse adaptation measures for sustainable management of climate-smart agriculture, agroforestry and environment project.

1.3 Conceptual framework under BIRDC

The strategic components of the banana value chain under BIRDC are premised on the over-arching theme of "elevating the banana crop value and economic contribution through science driven agro-industrial processing leading to export promotion of gluten-free banana flours, import substitution of flour for the bakery and confectionary industry, and socio-economic transformation of the banana farming communities (Fig. 1).

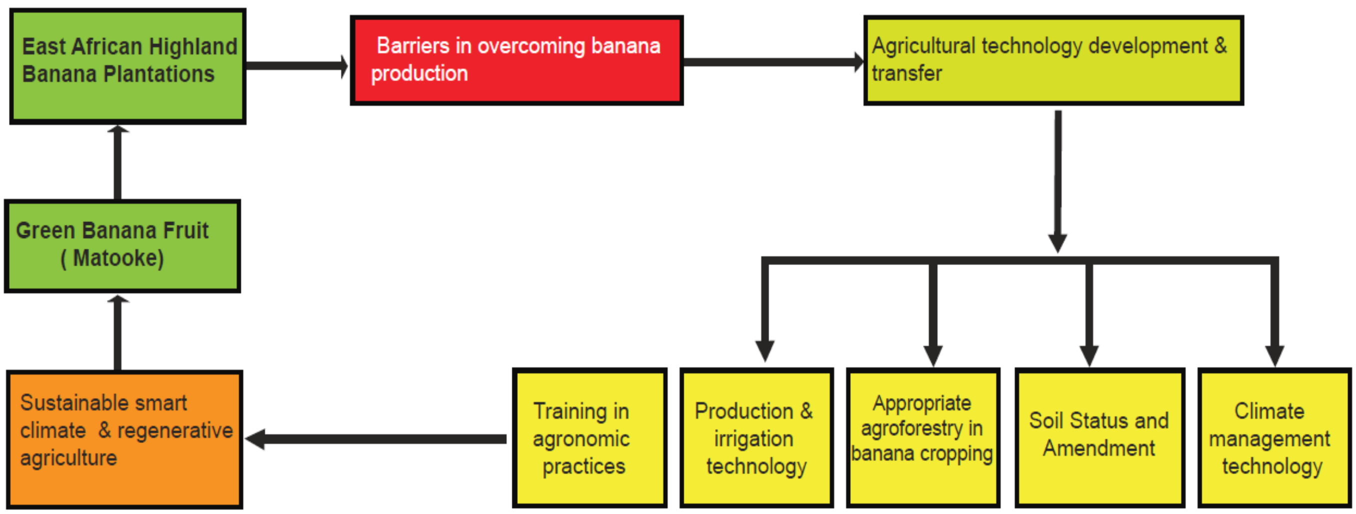


Figure 1: Conceptual framework adapted from the Banana Value Chain under BIRDC.

It is anticipated that sustainable climate smart and regenerative agriculture will result from agricultural technology transfer, farmer training in good agronomic practices, maintaining soil health, provision of water for production, employing appropriate agroforestry practices, and optimizing use of climate information through forecasts and climate early warning systems.

2.0 Theoretical underpinning

2.1 Overcoming barriers to agricultural productivity

Increase in human population puts pressure on land leading to decrease in its fertility which is compounded by global climate change effects. This calls for novel approaches to boost agricultural production (Zhang et al., 2020).

Zake et al. (1994) reported that agricultural modernization requires use of machines, fertilizers and practices such as agroforestry, planting cover crops, use of mulch and small-scale irrigation. Without these inputs, agricultural productivity is compromised.

Land fertility varies from location to location in the tropics (Robinson and Gala´n Sau´co, 2010) besides other barriers to improvement of agricultural productivity. For instance, identification of soil types is important in matching farming system to sites. Moreover, subsistence farmers accumulate knowledge over time (Emma et al., 2020 and Moris, 2010) on soil preparation, planting and management of crops, harvest and post-harvest handling, and farm management These are supplemented by tech-based skills including irrigation, use of pesticides, improved techniques of cultivation, harvest storage and transport (Tsouvalis, et al., 2000).

The basic premise of sustainable development is that through planning the effectiveness of these joint interactions can be improved for the benefit of individual stakeholders (World Bank, 2019). Trust, power, and social capital are inherent to social

2.2 Climate adaptation measures and Theory of Change

In order for BIRDC to overcome the barriers to management of climate-smart regenerative banana-based agroforestry that is environmentally sound, the paper refers to Pringle and Thomas' (2000) narrative on climate-smart agriculture and theory of change (Toc).In their view, planning should demonstrate how change can be achieved.

ToC was relevant for BIRDC because it helped focus design and overcome the barriers in sustainable management of the banana productivity in the southwestern project area in Uganda. Emphasis was on how to make the change happen by considering the context under which the banana project was operating, enhancing the linkages across Climate Change Adaptation (CCA) sectors and scales in the project area, and implementing an iterative and flexible activities with the relevant stakeholders, which allows to respond to changes in the social, political, or natural environment – leadership participation, defining and analyzing the problems and defining the critical impact pathway to address the problem, clarify on the appropriate interventions, identification of assumptions and barriers and Identify indicators and thresholds through monitoring and evaluation (M&E).

3.0 Study area, materials and methods

3.1 Study area

The research presented in this paper is framed around the East African Highland banana cultivation in Uganda (Fig 3), but predominantly grown in Central and South-western Uganda in the Greater Bushenyi districts (Fig. 4). The initiative to add value to bananas (cooking banana) and exploit the niche markets evolved out of persistent alarming statistics in the banana production sector, of increasingly high production volumes, high post-harvest losses, very low export volumes and subsequent insignificant contributions of the banana sector to the GDP. The underlying problem identified was that cooked banana is predominantly eaten in Uganda and the Great Lakes regions.

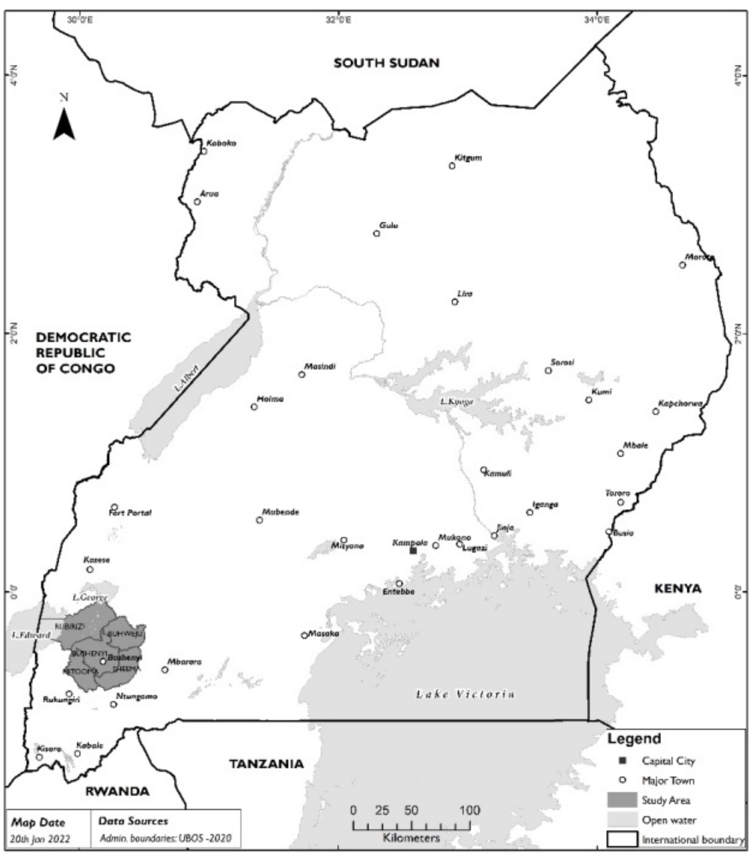


Figure 3: Map of Uganda showing the study area

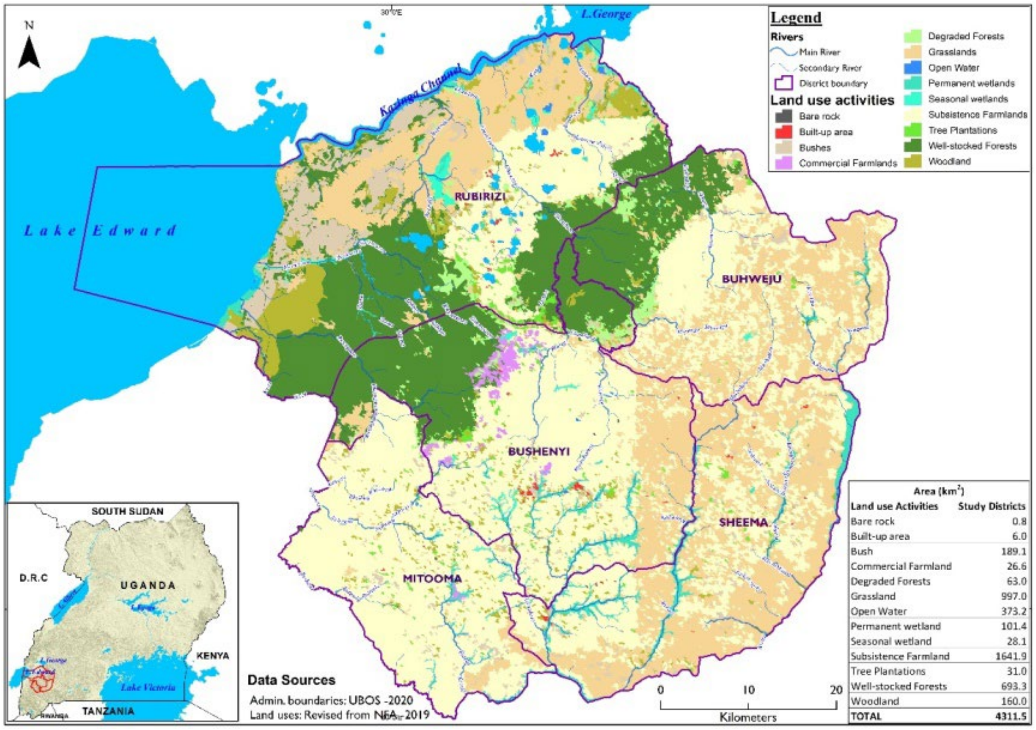


Figure 1: The study area in the Greater Bushenyi districts of Mitooma, Bushenyi, Sheema, Buhweju and Ribirizi districts.

Subsequently, increases, in local consumer demand above population growth seemed unlikely given that per capita consumption is ready by far the highest in the world. Consequently, targeting the fresh banana market as a growth strategy would easily hit a dead end, particularly given Uganda's landlocked situation. The processed banana market has therefore been envisaged to constitute a viable alternative for the accelerated market growth given the wide potential range of products that have been generated by research to date. With the above background, it was necessary to invest in overcoming barriers, through research and collaboration with the different stakeholders in the banana value chain, to sustainably manage climate smart agriculture, agroforestry and environment in which the communities reside.

The main objectives was to introduce a Model banana value addition industry through a state - of -the -art industrial platform that leverages university academic research and technical leadership in realizing optimum benefits for the primary stakeholders (the rural farmers), while assuring product market strength and competitiveness. The latter was to be achieved by establishing a strong research, training and technology development and transfer mechanism between university researchers and rural entrepreneurs.

The BIRDC driving philosophy is enshrined in the corporate mission, "*to be the centre of excellence for farmer-focused banana industrial development through strategic public-private-partnerships*" and the vision is "*a world-class banana research and innovation, business and investment development centre for value added products by 2024/25.*"

The objectives that relate to overcoming barriers in sustainable management of this predominant Agroforestry site include: 1) to identify and categorize the knowledge levels of the different actors in the banana production chain from the farm to processing, 2) to identify how the stages in the banana production chain are interlinked, 3) to investigate the extent to which PIBID has implemented knowledge management (KM) practices such as knowledge creation, sharing and retention through the assessment of existing KM enablers, and 4) to develop a model that interlinks the different actors to ease information access and sharing.

3.2 Materials and methods

The research involved the use of a GPS and mapping software – ArcMap version 10.5 and five (05) summarized questionnaires designed to capture data from farmers and other stakeholders such as Local Government leaders, BIRDC workers, technicians, managers and policy-makers.The research used a cross-sectional design employing uantitative and qualitative research methods to collect data(McCormick and Schmitz, 2001). Semi-structured questionnaire and question check list guided key informant interviews. Data were collected on farmers' profile, land use, production, productivity and marketing. The baseline household survey involved 1,119 respondents randomly sampled from the five districts in the Greater Bushenyi districts. The leaders of the 21 banana cooperatives were also interviewed. The interviews were both at home and on-farm.A calibrated Geographical Positioning System (GPS) was used to map households and banana plantation boundaries. The Garmin GPS receivers were set to Geographical Coordinate System positioning format (decimal degrees) with World Geodetic System (WGS) of

1984 as the datum parameter, and measurement units in meters. GIS ArcMap v10.5 was used to extrapolate the spatial distribution of land uses.

The attributes for each household and banana plantation was recorded. Additional data on were collected on workers in banana-growing processing, managers in banana-growing processing, policy-makers and technicians. Respondents were selected using ‘snowball’ technique. District Commercial/Production Officers (DPO), Community Development Officers (CDO) and Village Chairpersons provided information on policy at the district levels.

In terms of quality control measures and to ensure accuracy in data collection, one person in every district was trained and the questionnaire pre-tested before embarking on the full survey.

The research complied with ethical regulations. Respondents were not induced to answer questions and interviews were based on informed consent. Each respondent was informed about the purpose of the study (UNISA, 2016) and that the interview was voluntary.

Soil core samples from the Greater Bushenyi districts were collected at depths 0–15 and 15–30 cm from banana rows at 50-cm intervals and then thoroughly mixed to give one composite sample with three replicates per treatment. The soil was air-dried at room temperature and then passed through a 2-mm sieve for chemical analysis. Soil pH was determined using 1 mol L-1 KCl suspension (1:5 soil:solution, v/v). Soil nutrients were determined according to Bao [41]. Soil organic matter content (SOM) was determined using the 0.8 mol L-1 K2Cr2O7 oxidation-reduction titration method. Available nitrogen (AN) was determined by alkaline hydrolysis and diffusion. Available phosphorus (Olsen P) was assayed spectrophotometrically. Available K+ was determined by flame photometry after extraction with 1 mol L-1 NH4OAc. The soil datasets were acquired from FAO data portal at a scale 1:100000. The legend of the FAOUNESCO system was adopted to assist in the further classification/grouping of soil types

3.3 Data analysis

Questionnaire responses were edited, coded and entered in SPSS to create data file ad generate statistical summary.

Normality and homogeneity of variance of all data were checked before performing analysis of variance in SPSS16.0 for Windows (SPSS Institute, Inc., Cary, NC).The data collected with the GPS were downloaded into a laptop computer. The points were verified using the data collection templates. Data from the questionnaires were cleaned for inconsistencies, especially for household and banana plantation locations. Secondary GIS administrative datasets and base maps were also utilized during data cleaning and analysis. The cleaned data were captured and exported to ESRI ArcGIS desktop software version 10.5 for geo-processing and spatial analyses.

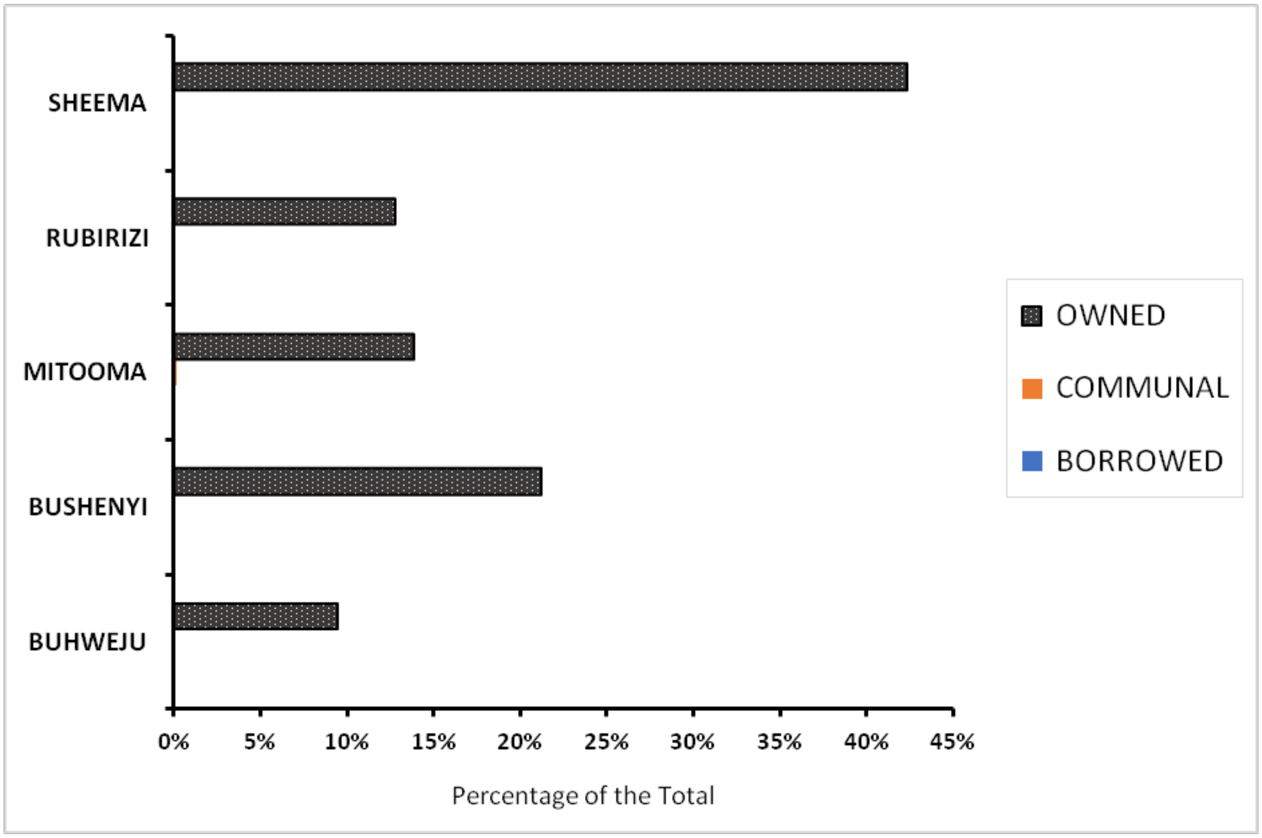
Variation in climate parameters mainly Cumulative Rainfall (CRF) and Land Surface Temperature (LST) was analyzed and the trend determined. Climate archived data covering the Greater Bushenyi districts was obtained and provided by the U.S. Agency for International Development (USAID) Famine Early Warning Systems Network (FEWS NET). The data includes the observed changes in rainfall and temperature for the whole country, based on an analysis of a quality-controlled, long-time series of station observations throughout Uganda.

4.0 Results

4.1 Barriers to sustainable banana production

4.1.1 Nature of land ownership

Land tenure systems in the study districts is a barrier because it affects farmers' long-term decisions to invest on land. Land was owned individually, communally or borrowed (Graph 1). Individual ownership means that a banana plantation was planted on land which is owned by the farmer. 'Communal' means that farmers had banana plantation planted on land owned by family or clan members. 'Borrowed' is when a farmer plants a banana plantation on land which he/she does not own, and the land - is often borrowed from another person. Most of the farmers (40%) owned land in Mitooma, Rubirizi, Sheema, Bushenyi and Buhweju districts while 2% of the farmers in Rubirizi, Sheema and Buhweju districts owned land individually, communally and borrowed.



Graph 1: Household land ownership in the project areas.

4.1.2 Soil characteristics and spatial distribution

Spatially, Bushenyi District contains Acric ferralsols soils covering most parts of the district and small patches of Histosols in the south. Buhweju District is uniformly covered by both the Dystric, regosols and Acric ferralsols. The northeastern part of Buhweju District contains mainly Dystric regosols soil. Rubirizi, is composed of Luvic andosols, Leptic andosols, Lixic ferralsols soils. Parts of the district are covered by lakes while Mitooma District is covered by Luxic ferralsols, Acric ferralsols to a large part and small patches of Histosols. Dystric regosols, Acric ferralsols, Lixic ferralsols soils uniformly Sheema District.

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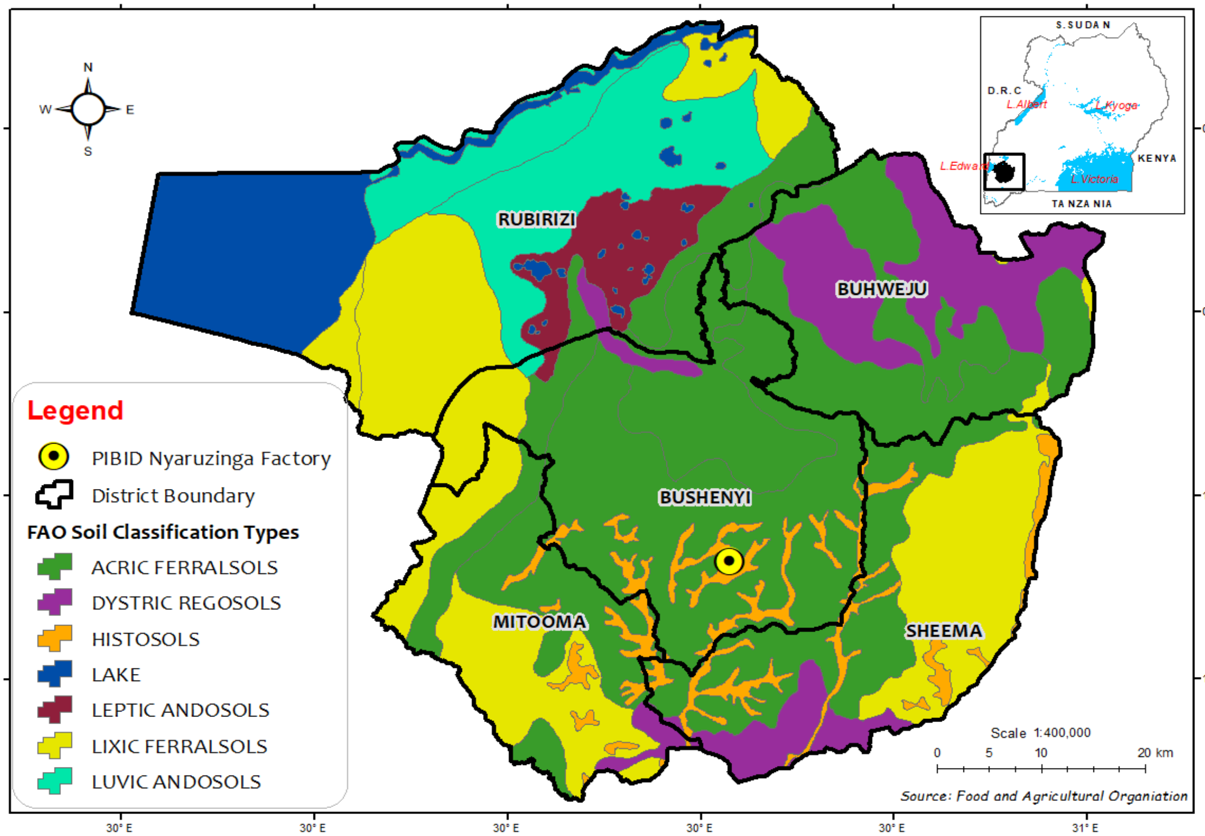


Figure 5: Spatial distribution of soil types in the BIRDC project area.

Results of the soil analysis for the period 2000 to 2021 are presented in Table 1.

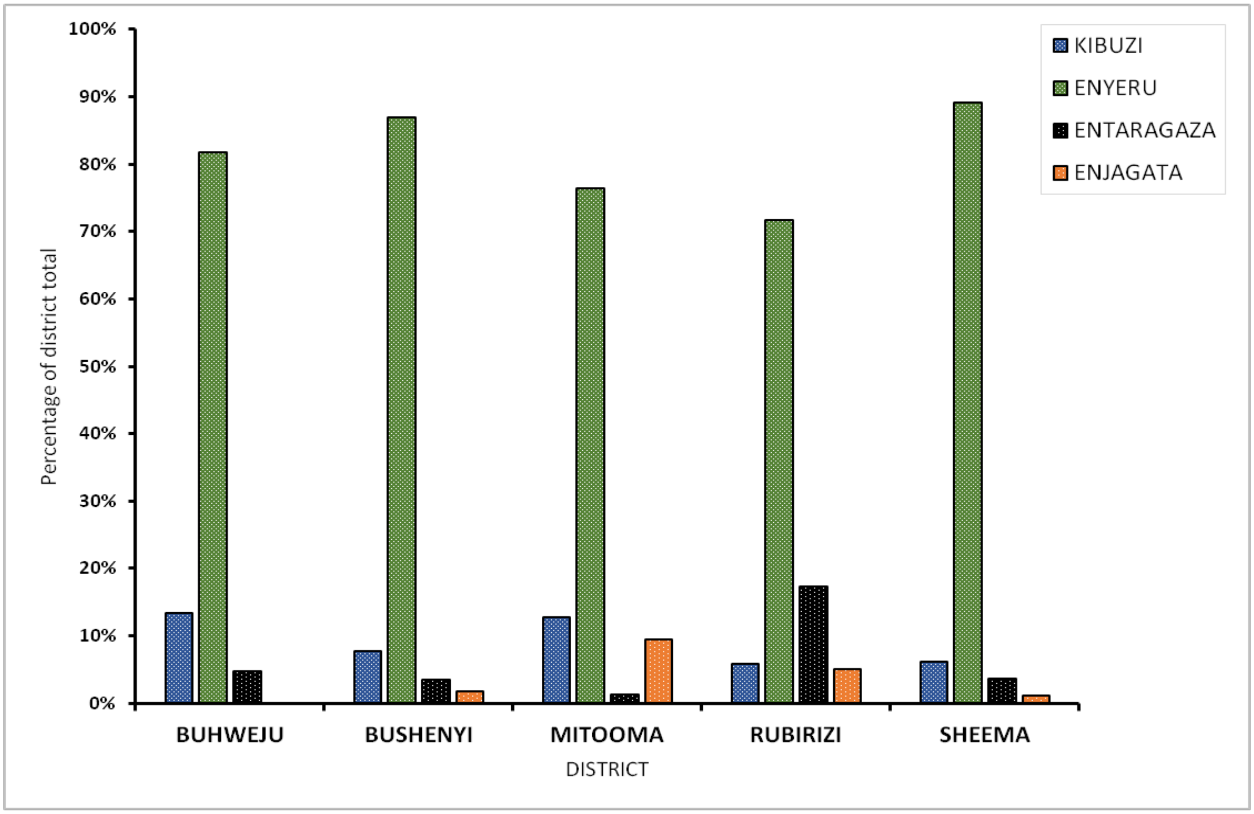
Table 1: Results for selected soil nutrients from the Greater Bushenyi districts

S/N	Parameter	Root zone (50-60 cm)		Outside root zone (100 cm)		Banana optimal requirement	Soil amendment
		0-15 cm	15-30cm	0-15 cm	15-30cm		
1.	pH	5.05	4.93	4.77	4.71	5.5- 6.5	Liming
2.	Exchangeable Potassium kg/ha	81	68	52	35	1500	Application of NPK fertilizer
3.	Total Phosphorus	4.6	4.4	4.6	4.2	10	**8-10-8** **(NPK)** chemical fertilizer or organic composted

	(mg/lit)						manure.
4.	Available Nitrogen	10.7	9.7	7.6	7.1	8	
5.	Soil texture						Organic composted manure
6.	Organic matter (%)	9.15	5.14	9.49	5.17		Apply SOM
7.	Organic carbon (%)	1.83	1.12	1.87	1.15	≥1.2	Apply SOC

4.1.3 Type of cultivars planted

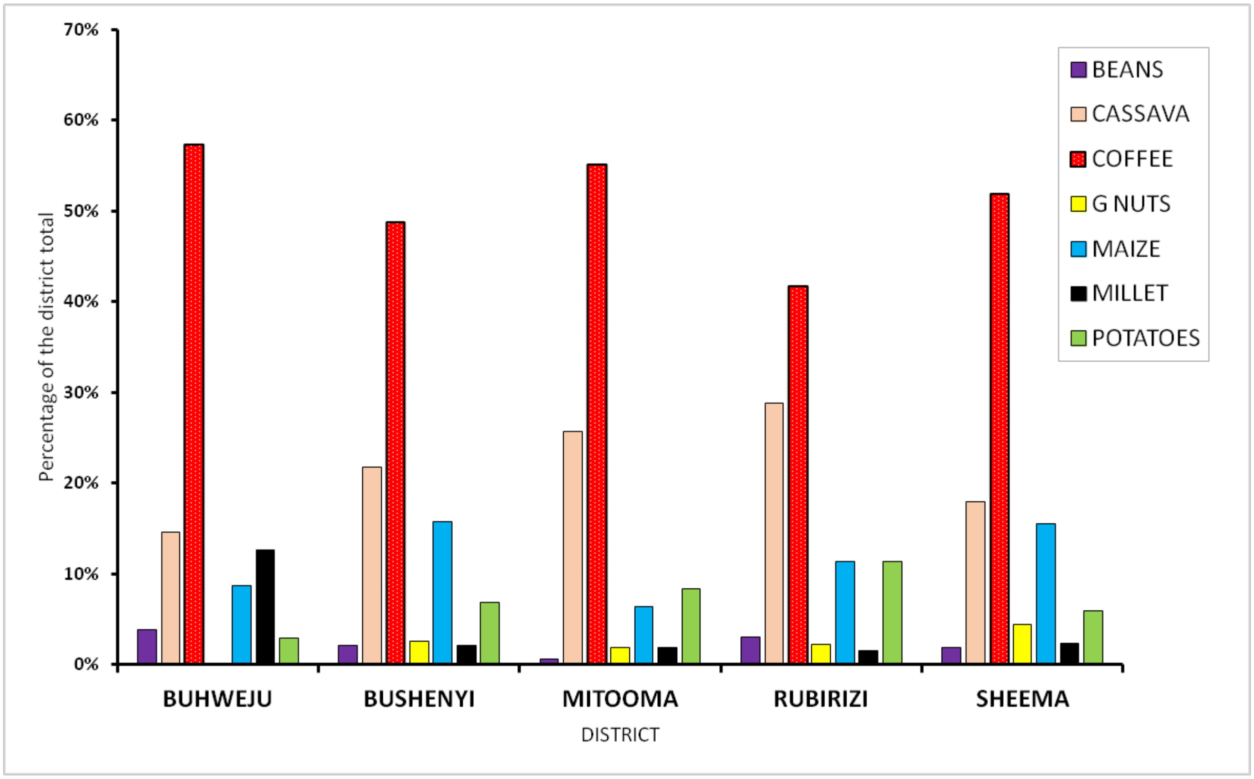
Banana cultivars respond differently to climate change, to agronomic operations, diseases, etc. Therefore, planting the right cultivars can increase productivity and production of banana. The cultivars planted were so competitive, especially *Enyeru* tplated cultivar in all the districts. In Sheema *Enyeru* scores approximately 89%, Buhweju scores 81.73%, Bushenyi scores 87.01%, Mitooma scores 76.35% and Rubirizi 71.74%. *Entalagaza* dominates more in Rubirizi District after *Enyeru* at 17%. In Bushenyi, Mitooma, Sheema and Buhweju districts *Entalagaza* is less than 5%. In Buhweju District, *Kibuzi* scores 13%, Mitooma 12%, and less than 10% in Bushenyi, Sheema and Rubirizi districts. *Embwazirume, Bukumu, Entalagaza* cultivars scored less than 10% in all districts (Graph 2).



Graph 2: Cultivars grown in the project districts.

4.1.4 Intercropping with bananas

Beans, cassava, coffee, G-nuts, maize, millet, potatoes, yams, among others are grown with banana. Coffee-growing ranked highest, cassava ranked second and maize ranked third in all districts of Greater Bushenyi districts (Graph 3).



Graph 3: Crops grown with banana.

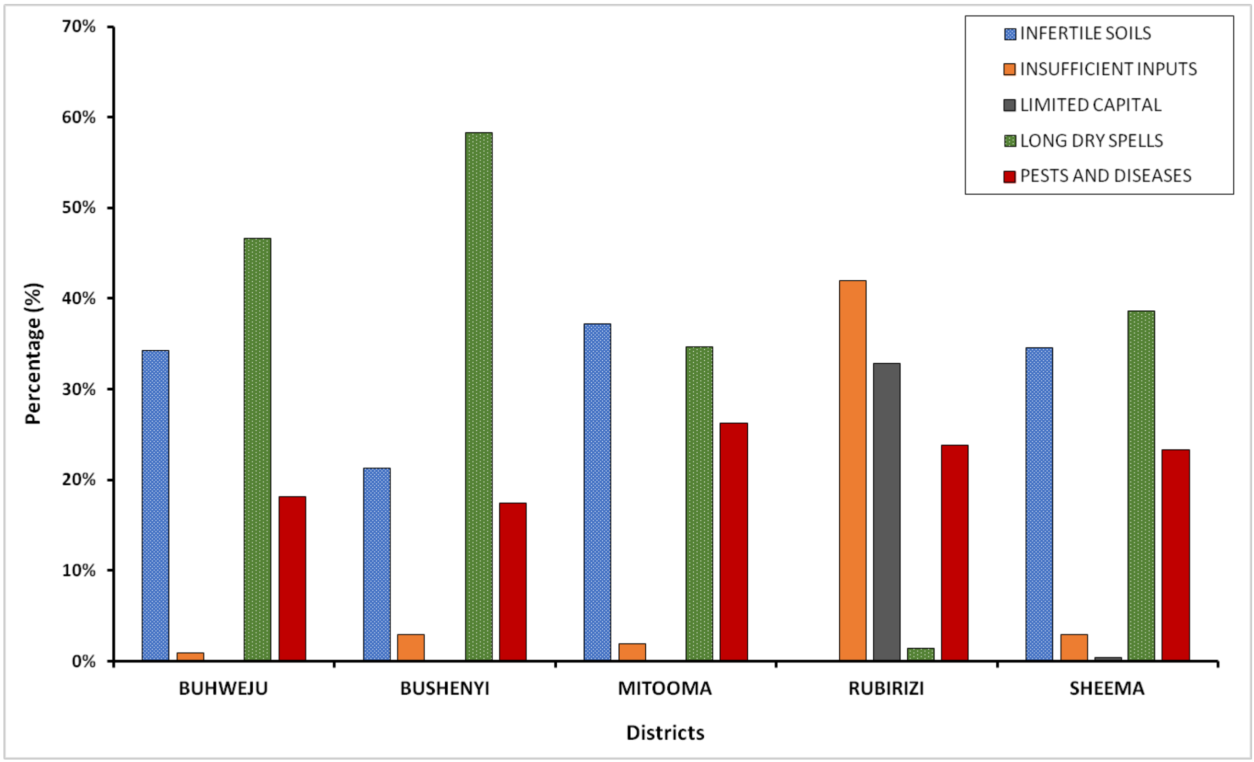
Spatially, coffee was more grown in all the sub-counties apart from Sheema Central Division in Sheema District where maize was more dominant. Coffee had the highest spatial coverage of 50%, cassava 22% and maize 14% in all the districts. Such districts would be prone to hunger if banana plantations succumb to diseases.

4.1.5 Climate variability

Uganda is characterized by bimodal rainy seasons which cover most of the country and a unimodal rainy season that is experienced mainly in Karamoja in the northeast. The first rainy season starts from March to July and the second rainy season in mid-August to December. Seasonal trends of rainfall in the districts follow this same pattern in the first and the second seasons.

4.1.8 Adaptation to challenges farmers face

The challenges identified included: long dry spells (climate change), pests, and disease, insufficient inputs, limited capital, among others, and price fluctuations (Graph 5).



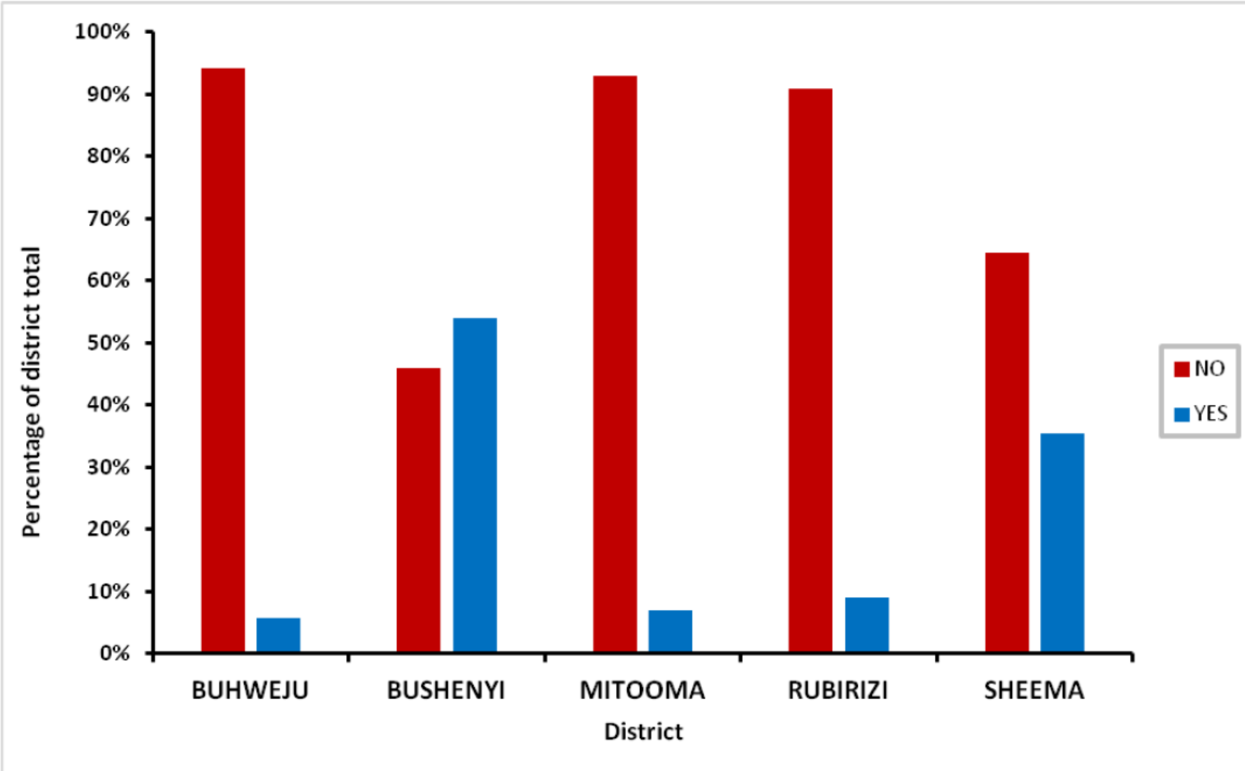
Graph 5: Percentage of main challenges that banana farmers are experiencing

The long dry spell affects farmers in Buhweju District (47%), Bushenyi District (58%), and Sheema District (39%) unlike in Mitooma and Rubirizi districts. Apart from Rubirizi District where soils are fertile compared to any other districts, infertile soils are a major constrain to banana production in Mitooma district (37%), Sheema District (35%), Buhweju District (34%) and Bushenyi District (21%). Insufficient inputs, compost organic maater or fertilisers such NPH or CAN and capital are common in Rubirizi District. Pests and diseases are common in Mitooma District (26%) and Rubirizi and Sheema districts (23%). Bushenyi and Buhweju districts had less problems of pests and diseases (17%) and (18%) respectively.

4.2 The capacity of the different stakeholders and capacity of sharing information and interlinkage of knowledge stages in the banana production chain

BIRDC is working with the Local Government District Commercial/Cooperative Officers to collectively sensitize the banana farmers about the need to work as associations. This empowers the farmers to have a common voice for a two-way communication with BIRDC. In establishing the 21 banana co-operatives, BIRDC has been accessing the farmers either through their leaders or at the general meetings. BIRDC is currently carrying out participatory rural appraisal (PRA) and transect walks at community levels. The cooperative leaders, local government representatives and farmers discuss the importance of CSA to the banana agro-industry and how to develop and support the cooperatives. The transect walks facilitate meeting the farmers at household level. Occasionally, BIRDC invites representatives from the Ministry of Trade, Cooperatives and Industries to talk to the banana cooperative leadership and during the monthly training of trainers (ToTs).

The ToTs are intended to educate farmers on how to manage and maintain banana plantation with a focus on how to improve the productivity and incomes in the changing climatic conditions by adopting improved farming practices. In Buhweju, Rubirizi and Mitooma districts, about 90% of the farmers have never been trained, although 10%were slightly trained. Some training was conducted in Sheema and Bushenyi districts with a percentage of approx 35 and 54 respectively (Graph 6).



Graph 6: Agricultural training conducted by PIBID Production team.

Among the sub-counties and parishes visited, 71% of the farmers have never been trained by the BIRDC production team while 29% were trained in all the districts.BIRDC has expertise to support its activities to improve farmer practicesto increase resilience to climate change (Table 2).

Table 2: Capacity of human recourse in sustainable smart climate smart and regenerative agriculture at BIRDC

S/N	Specialist	Description
1.	Agronomists:	Responsible for the selection of the cultivars and guiding farmers on all agronomic and tending operations from banana planting to harvesting
2.	Agroforestry Specialist	Responsible for identifying the right agroforestry species to be planted with the bananas in terms of spacing, boundary planting, line planting or cluster planting, especially in areas prone to wind. The Agroforestry specialist selects the right fruit trees that are suitable for the sites
3.	Soil Scientists	Responsible for soil sample collection and analysis.

		From the analysis, recommendations are provided on the required macro and micro nutrients required to make the soils suitable for banana cultivation and to promote climate resilience.
4.	Entomologist:	Responsible for pests and disease advice and management when such issues arise such as Banana Bacterial Wilt (BBW
5.	Quality Controller at farm gate level:	Responsible for on-farm guidance during and after harvesting to recommend which 'banana fingers' will be transported to the agro-processing plant.
6.	Environment/climate change specialist	Responsible for the environment impact assessments, including climate and biodiversity related, both upstream and down-stream impacts and mitigation measures are evaluated especially for sites that have wetlands or sites with steep terrain.
7.	Cooperatives/Outreach	Receives training trained in cooperative/group formation or associations, and is responsible for imparting that training to other farmer members
8.	Plant ecologists	Responsible for guiding the Production Section on the processing plant site to match not only suitable banana crops, but also is a general expert on advising on other produce intercropped with the banana
9.	Disaster management (wind/storm specialists	Responsible for guiding the team on climate and disaster management such as post wind damages after hail storms and related restoration measure
	Irrigation specialist	These technologies are implemented specific to the source of water and farmer needs. Some interventions involve digging of deep wells, others look at wetland abstraction and water for production using a formalised irrigation system constructed by BIRDC
	Climatologist	For climate forecasting and early warning information

4.3 Adaptation measures for that would lead to sustainable management of climate smart agriculture, agroforestry and environment

BIRDC has optimized banana production outside the rainfall seasons usingirrigation technology as presented in Table 3. Irrigation is used during March and April (first season) and from September to December (second season) when there is sufficient moisture.

Table 3: Irrigation of banana plantations from January to December 2020

S/N	Month	Water delivered (m^3)	Total rainfall (mm)	Equivalent in m^3	Comment
1.	January	1,280	123.7	1,237	
2.	February	710	106.6	1,066	
3.	March	nil	145.6	1,456	Enough moisture
4.	April	nil	102.2	1,022	Enough moisture
5.	May	1,080	77.8	778	
6.	June	2,430	58.1	581	
7.	July	3,520	51.8	518	
8.	August	1,830	58.1	581	
9.	September	nil	300.6	3,006	Enough moisture
10.	October	nil	207.9	2,079	Enough moisture
11.	November	nil	166.4	1,664	Enough moisture
12.	December	nil	188.8	1,888	Enough moisture
	Total	**10,850**			

4.3.1 Integration of agroforestry

BIRDC has over the years planted agroforestry tree species presented in Table 4.

Table 4: Agroforestry tree intercropped with banana

Tree species	Number planted						
Calliandra spp	1200	1500	5000	1005	2014	5117	4011
Grevilea robusta	500	156	122	69			
Pine					3731	2315	80
Whistle pine				1018	462	297	
Maurithius					2556	503	12

thorn		
Avacado	150	70
Citrus	700	348
Papaya	150	83
Terminali brownii		284
Cashew nuts		300

4.3.1 Knowledge sharing and collective internal governance

The project has created new knowledge to increase banana yields from 5-7 tones per ha to 50-60 tons per hectare per year. This has been due to the innovations in spacing, cultivar uae, improved agronomic practices, weed management, disease/pest control, irrigation and knowledge sharing by farmers (Fig 10).

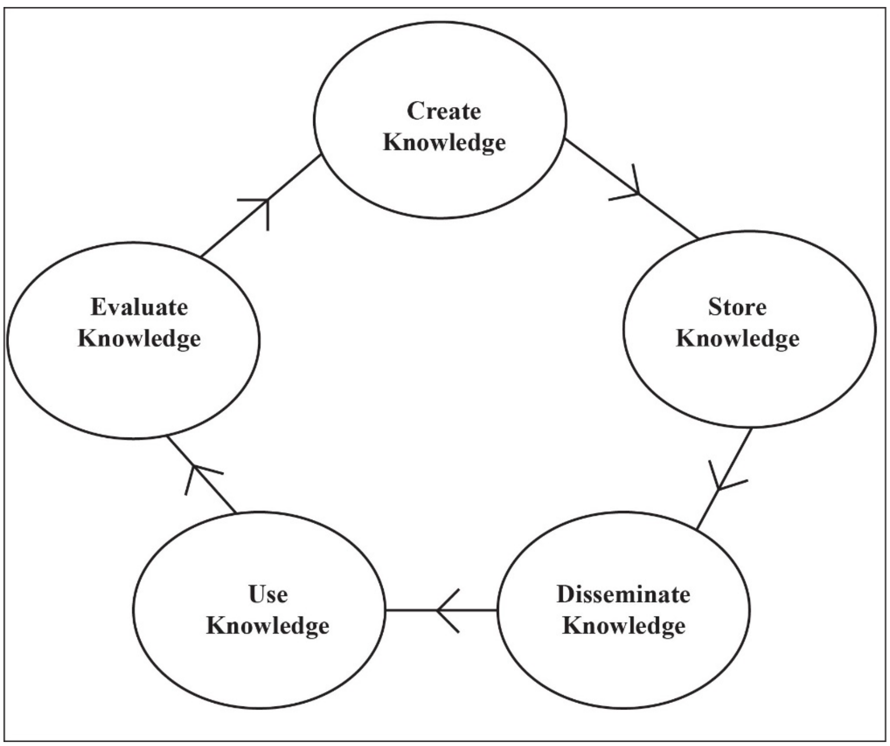


Figure 10: Knowledge management process used by the project. Source: Leung, Lau and Tsang, 2013.

The training, demonstration at the BIRDC site, and timely sharing of information enhanced banana productivity (Fig. 11).

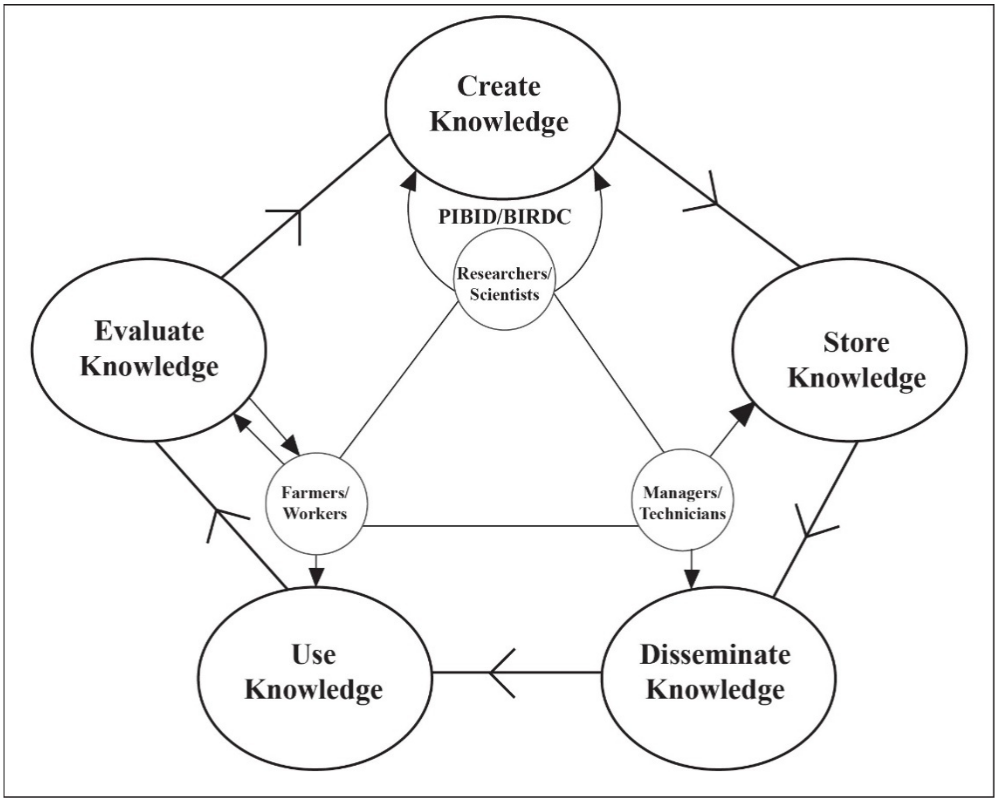


Figure 11: Integration of the BIRDC Model of farmer's knowledge sharing. Adapted from Leung, Lau and Tsang (2013).

5.0 Discussion

This paper contributes to the ongoing development of literature by demonstrating how reforms can be packaged in agriculture in Uganda. The findings have identified enabling conditions and examined the barriers in the banana production value chain to maintain the value addition through agro-processing in south-western Uganda. Second the application of technology has gone beyond the proof-of-concept to application. Here, the state played a critical role in the early stages of technology introduction to the country in the absence of which the banana agro-processing industry would probably not have emerged to the extent that it has. The third was an enlargement of the solution space to stakeholder interests. The timely flow of funds to the entity helped overcome lethargy in the taking the appropriate and timely actions. Furthermore, the policy innovation space was opened to the actors beyond the local government and the symbiotic relationship with other research organisations established. To some extent, this depended on the established human resource structure in the project. Thus, one of the main roles of the central government has been to provide an open-ended market assurance to convince the stakeholders to invest in production capabilities and facilities.

The application of different adaptation techniques in the banana production areas aims to improve soil health, water conservation, livelihood crop diversification or intercropping and the capacity of local institutions (FAO, 2014). In addition, effective management of land, water and soil resources provide a safety net to the vulnerable groups (Paavola, 2008). It is evident from the findings that banana is affected by heat stress caused by increased evapotranspiration and variability in rainfall.

The role of the banana farmers requires continuous training, awareness raising and demonstration. The banana farmers through the **Tooke Cooperatives** facilitate the creation of multi-stakeholder platforms for innovation diffusion amongst farmers.

The findings present an interesting example of the emergence of more complex networks of polycentric governance linking farmers, the BIRDC structure and governments in which the their roles are clearly defined. While some scholars have investigated the role of agricultural orgnisations in addressing environmental problems (Levy and Newell, 2005), they have focused mostly on the global scale. This paper has extended the research to more micro-level interventions although the motivations of the various stakeholders did not stem primarily from environmental concerns.

Banana is a high water demanding crop and vulnerable to climate change effects such as droughts. Given the limitation of irrigation in Uganda, a considerable amount of water needed in the banana production needs further investigation. BIRDC has explored this technology and should be scaled up to several farmers in the project area. Currently, the project works with 5,389 farmers. It is projected to reach 50,000 farmers.

6.0 Conclusions and recommendations

This paper synthesizes ways of overcoming barriers in management of climate-smart and regenerative agriculture in a banana cropping region in Uganda, and the impacts of climate change on bananas. A review of literature reveals that moderate temperature rise is beneficial for highland bananas, but higher increase in temperature negatively impacts on yield. Banana production is rain-fed and small-scale irrigation is a crucial step in ensuring future production and food security. Farmers need to be supported to acquire irrigation systems for banana production. Continuous Training/sensitization, banana cultivar selection, soil and water conservation measure are important in maintaining the banana crop productivity and building resilience against climate change.

The scientific management of banana has traditionally emphasized intensive management operations focused on increased production, mostly the banana fruit. The findings from this research suggest that there are alternative factors that need to be considered in future management of the banana crop characterized by a set of fundamental principles, including an emphasis on training, appropriate site-matched agroforestry (diversity) and avoidance of intensive site-preparation methods by introducing cover crops and mulch. This wider adoption of alternative practices is currently hindered by ecological, economic, logistical, informational, technology, cultural, and historical constraints, which can be overcome.

Development and adoption of drought tolerant banana cultivars is one of the options to cope with the changing climate. Furthermore, promoting the transitioning from mono-culture by adopting agroforestry coping measures such as nutrient recycling of leached nutrients through leaf decomposition and mulching needs to be supported through training, sensitization and demonstration.

Liming and organic fertilizer are considered to be important tools for the amelioration of acid soils in the study area. The use of organic amendments as an alternative to wholly or partly replace synthetic fertilizers is recommended to increase soil fertility and crop yields.

Several soil management strategies have been used to improve soil quality for higher yields and quality of banana. Lime application is the most common method used to increase yield and quality of crops in acid soils.

Organic amendments such as organic manures and composts are effective in ameliorating soil acidity and enhancing soil quality. The application of organic manures or organic amendments modifies the structure of the soil microbiome, enhance soil quality and increase total soluble solids.

As food production is also impacted by other factors such as land-use changes, disease incidence, and market demand, future research studies should take these factors into consideration when studying the effects of climate change on crop production. In addition, there is a need to incorporate uncertainty of climate models into consideration. This will provide better information in regard to the impacts of climate change in the South-western Uganda and the country as a whole.

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