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ASSESSMENT OF THE DETERMINANTS OF ENVIRONMENTAL EFFICIENCY OF USING BIORATIONALS IN BANANA PEST MANAGEMENT IN THE LAKE VICTORIA CRESCENT, UGANDA

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ABSTRACT: *This research examined the factors affecting the environmental efficiency of biorationals in banana pest management in the Lake Victoria Crescent region of Uganda. Using farmers appraisals of the sustainability indictors, the Lot Quality Assurance Sampling Technique for participant selection and employing descriptive statistics alongside Categorical Regression with Least Absolute Shrinkage Selection Operator for data analysis, the study revealed several influential factors. Key findings indicated that education level, informal social networks, land ownership, farming experience, type of planting materials, and livestock presence significantly impacted environmental efficiency. Interestingly, farmers without formal education rated environmental efficiency higher than those with mid-level education, while increased farming experience correlated with lower efficiency ratings. Positive influences on environmental efficiency were associated with the "Munomukabi" social network and leasehold land ownership, whereas intercropping banana with coffee had a negative effect. The study concluded that informal environments, particularly those involving farmers with non-formal education and strong social networks, play a vital role in biorational use. Conversely leasehold landowners demonstrated higher efficiency ratings than those with "Mailo" land tenure. Furthermore, older farmers tended to be less environmentally efficient and preferred less labor-intensive practices.*

KEYWORDS: Biorational Use, Environmental Efficiency, Social Networks.

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INTRODUCTION

Bananas are a staple food and a major source of income for over 65% of the people in the Lake Victoria Crescent, Uganda (Lee, 2023; Ssekyanzi and Park, 2023). Globally, after India, Uganda is the world's second-largest producer of bananas. Ugandans consume between 250 and 440 kilograms of bananas annually. This is the highest in the world (Marimo *et al.,* 2019); (FAO, 2024). Currently, banana production is estimated at an average of 9.7, 12.4 and 20 t/ha respectively in the Southern, Central, Mount Elgon and South-Western regions of Uganda compared to potential yields of over 60 t/ha (Kapirir and Kabahenda, 2010; Nyombi, 2013; Lee, 2023). East Africa highland banana (EAHCB) production, however, is limited by high prevalence of pests and diseases and declining soil fertility, among other things, which contribute to the yield gap (Tinzaara *et al.,* 2009; Bakaze *et al.,* 2022). Banana farmers use biorationals to manage banana pests and to improve soil fertility (Mwine *et al.,* 2011; (Namaganda et al., 2018; Murongo *et al*., 2022). Previous studies have mostly assessed the effectiveness of biorationals and little research has been conducted to understand the environmental benefits and factors affecting the environmental efficiency of using biorationals in banana pest management (Veiga-Neto et al., 2018).

Biorationals are insecticides and bio-stimulants derived from natural resources, including minerals, microorganisms, plants and animals (Mwine, 2011).They are plant-based compounds such as quinones and alkaloids used to control insect pests while posing less risk to non-targets, for example human beings, animals, and the environment (Horowitz and Ishaaya, 2004).They are emerging as a major substitute for synthetic chemicals (Horowitz et al., 2009; Mwine et al., 2010).

Environmental sustainability refers to the ability of an environment to maintain ecological balance and support life indefinitely, while environmental efficiency focuses on optimising resource use and reducing environmental impact (Suh et al., 2014). Achieving environmental sustainability hinges on the importance of environmental efficiency. By enhancing resource utilisation, human ecological impact can lessen and pave the way for a more sustainable future. Environmental efficiency results in lower expenses, increased resource efficiency, and a diminished environmental effect. Consequently, by maximising resource use and minimising waste, we can foster a more sustainable and resilient environment for generations to come (Čuček et al., 2015). In order to achieve environmental sustainability, small-scale farmers turn to locally available resources and traditional agricultural practices which decrease dependence on synthetic inputs and encourage responsible resource use. This practice reduces pollution, preserves natural resources, and enhances biodiversity, resulting in more sustainable farming systems. Environmental efficiency relates to the interaction between agriculture and natural environmental processes and the outcome of the interaction. Particularly relevant to this aspect is farming that forms part of the ecosystem rather than being external to it and should therefore contribute to its sustainability, unlike most other economic activities.

In this study, environmental efficiency was assessed on the following sustainability indicators per respondents, namely: use of locally available resources, contribution to environmental sustainability, risks of pesticide residues to the environment, availability of water in dry season, ability to encourage crop diversity, level of earthworm biodiversity in top soil specifically focusing on to the surface-dwelling (epigeic) worms which live in the top layers of organic matter, and topsoil-dwelling (endogeic) worms residing in the top 20cm; energy use from

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crop residues and manure, products longevity in the production system, extent of pesticide risk to livestock and human and evidence of death of insect species in the system. The research focused on farmers in the Lake Victoria Crescent of Uganda who use locally sourced biorationals for banana production, with the goal of evaluating the environmental sustainability of these biorationals in controlling banana pests.

LITERATURE/THEORETICAL UNDERPINNING

The study employed two theories, i.e., the Cultural Ecological Theory (CET) and The General Utility Theory (GUT), to explore farmers' subjective choices regarding biorational use and their management techniques influenced by cultural contexts. The CET as described by Sutton and Anderson, (2004) posits that culture serves as a dynamic element within human ecosystems. Humans primarily utilise cultural inventions to create ecological niches, thereby reshaping existing biotic systems and developing new tools. These actions are guided by cultural knowledge, leading to the continuous creation of tools that optimise the interaction with the environment. Furthermore, the theory suggests that development arises from progressive cultural specialisation in response to environmental factors, indicating that the study of cultural ecology should extend beyond individual systems. The GUT as described by (Kuznar, 2000) on the other hand, posits that individuals evaluate decisions based on their ranked preferences and perceived risks. Decision makers consider potential success or failure and often rely on qualitative merits that are not easily quantifiable, leading to choices that enhance their overall happiness.

Methodology

Study Area

The study was conducted in the central region of Uganda in the districts of Mpigi, Lwengo Masaka, Kyotera and Kalungu (Figure 1) which are predominantly banana-growing areas. The area under study lies between 0° 19′ 0″ N and 32° 35′ 0″ E (0.316667, 32.583333) at an elevation of 1229 above mean sea level. The mean annual rainfall is 1000mm to 1200 mm. The rains are spread over two seasons between March and May and August and December. The average annual temperatures range between 22.5° C to 27 ^{0} C. The relative humidity is 80% to 95%. Average rain days per year are 127 with an average of 10.6 rain days/month (UBOS, 2024). The climate is favourable for the growth of bananas.

Sample Size

In each sub-county, one farmer who was using biorationals in banana pest control was purposively selected and nineteen other banana farmers were randomly interviewed. The targeted number of responders was 385 and was estimated using a formula by Kothari (2004).

Sample for unknown $N = Z^2 * P * (1 - P) / C^2$

Where:

N = sample size required

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P = estimated percentage picking choice of farmers (0.5)

C = confidence interval (0.08)

Z = estimated confidence level (1.96 for 95%)

At a 95% confidence level, 0.5 standard deviation, and a confidence interval of +/- 5%. $((1.96)^2 \times .5(.5)) / (.05)^2 = 385$ The actual number of respondents interviewed was 246. This was 63.8% of the estimated sample. At 63.8%, there was no new information which was being corrected, implying a point of circulation. According to Memon et al., (2020) a sample that is above 63 % is considered a relatively high sample size for a survey which assesses effectiveness of a technology**.** Triangulation with the sample correction factor found that the minimum sample size for this study, if the calculated sample was made the population size, was 198 respondents.

Sample Correction factor

$Ts = n\, x\, N / (n + N - 1)$ = (386*385)/ (385+385-1) = 193 farmers

Sampling Technique

We employed a multistage sampling procedure. Both probability and non-probability sampling were used to identify farmers who rely on biorationals for pest control. Farmers who use biorationals were identified by snowball sampling procedures and the 19 neighbouring farmers were picked at random using LQAST(Brown et al., 2014). Biorational users were compared to Integrated Pest Management (IPM), synthetic chemicals and cultural pest control method users (Sariot et al., 1999; Brown et al., 2014).

Data collection was conducted using questionnaires in addition to open-ended interviews. Physical visits were conducted to gardens which facilitated direct observation and recording of observable data from farms (Kuehne et al., 2017; Mensah et al., 2017)).

The measures of environmental efficiency included ten (10) sustainability indicators: the use of locally available resources, the contribution to environmental sustainability, the risks of pesticide residues to the environment, the availability of water during the dry season, the encouragement of crop diversity, the level of insect biodiversity in the topsoil layer (1 m), the energy use of crop residues and manure, the longevity of products in the production system, the extent of the risk of pesticides to humans and livestock and signs of the death of insect species in the garden (Runge and Gonzalez Valero, 2017).

Model used

Economic model

Environmental efficiency was assessed using Categorical Regression (CATREG).

The CATREG model assumes a classical linear regression model, applied to transformed variables:

$\phi r(y) = X\, jj = 1\, \beta j \phi j\, (xj) + e,$ .... *Equation (1)*

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With: -

- ϕry = the transformation of the response variable y
- xj= the number of predictor variables xj
- βj = the regression coefficient
- j the transformation of the jth predictor variable
- e =the residuals vector.

1. When equation one above is subjected to a loss function L,

Then $L(\phi r;\ \phi 1,\dots,\phi j;\ \beta 1,\dots,\beta j)\ =\ k\phi r(y)\ - X\ J\ j = 1\ \beta j\phi j\ (xj\ )k2, \dots$ *Equation (2)*

Where:

y = environmental efficiency is the function of sustainability indicators for ϕ_1 = The use of locally available resources, ϕ_2 = the contribution to environmental sustainability, ϕ_3 = the risks of pesticide residues to the environment, ϕ_4 =the availability of water during the dry season, ϕ_5 =the encouragement of crop diversity, ϕ_6 = the level of insect biodiversity on top soils, ϕ_7 = the energy use of crop residues and manure, ϕ_8 = the longevity of products in the production system, ϕ_9 =the extent of the risk of pesticides to humans and ϕ_{10} = livestock and signs of dead insect species. The Data management units (DMU) were the farms and the decision makers were the farmers. The study focused on biorational use under different banana management practices (pure, banana coffee, banana coffee agroforestry, and banana agroforestry). The output was environmental efficiency on a universal scoring scale of ten (10) (Runge and Gonzalez Valero, 2017) where: {1= "Extremely Low" …………………." 10 = "Extremely High"}. This was modified after transformation, as suggested by Wu et al., (2022) to a five-point Likert scale.

Statistical Model

The response variable:

$(Environmental\ Efficiency)$ = (Economic Input factors + Household characteristics + social-economic factors).

$Y_i\ (Environmental\ Efficiency) = \beta_0 +\ \beta_2 Education\ \ + B_3 Farm\ experience\ + B_3 Social\ Group + B_4\ Land\ tenure\ + B_5 B_n + \epsilon_{ij}$……………*Equation (3)*

Model selection

The process of model selection was carried out in three phases: first, factor analysis; second, a multicollinearity test; and finally, the estimation of the factors influencing environmental efficiency using Categorical Regression (CATREG).

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RESULTS/FINDINGS

The assessment of environmental efficiency indicators showed that the use of biorationals had the highest score for promoting energy usage, averaging 6.9 (Table 1). The capability of the system to provide raw materials for biorationals received a significant average rating of 6.7. In addition, the ability of these products to stay in the system to foster crop diversity and support environmental sustainability was rated between 6.4 and 6.45. Other factors, such as enhancing earthworm biodiversity and lowering pest risks, received lower ratings but were still above 5.5. The influence of biorationals on decreasing insect species mortality was rated the lowest, with an average of only 3.44, indicating that biorationals had minimal impact in this area.

Farmers' attitudes on environmental efficiency sustainability indicators of using biorationals in banana pest management in the Lake Victoria Crescent

The findings indicated that 32.1% of participants rated the use of raw materials for producing biorationals as high, while 27.3% rated it medium, 19.9% very low, 13.1% very high, and 7.8% low (Table 2) implying that farmer use biorationals because of the ease of getting raw materials from with their surroundings. In terms of environmental sustainability, 9.3% rated biorational use as very high, 41.9% as high, 33.7% as medium, 10.2% as low, and 4.8% as very low indicted that biorationals resulted in higher environmental sustainability (Table 2). Regarding the efficacy of biorationals in mitigating pest risks, 39.1% of respondents rated their effectiveness as high, while 9.3% considered it very high. The remaining responses included 21.1% rating it medium, 12.6% low, and 17.9% very low. Regarding biorationals' impact on water availability, 43.9% rated it medium and 28% high, with only 2% selecting very high. Additionally, 18.3% rated it low and 7.7% very low. In the same survey analysing crop diversity, 50.4% of respondents rated the promotion of this indicator as high, with 30.1% rating it medium and 6.5% indicating a very high rating; conversely, 8.2% rated it low, and 4.9% rated it very low. Regarding the enhancement of earthworm biodiversity through biorationals, 49.6% rated it medium, while 36.2% rated it high, and only 1.2% rated it very high. On the other hand, concerning increased energy use, 48.4% rated it high, 26.8% rated it medium, and 13% rated it very high; in this case, 8.1% rated it low, and 3.7% rated it very low (Table 2).

Principal Component Analysis

A factor analysis of environmental sustainability indicators revealed three dimensions among respondents utilising biorationals. Dimension one of promoting environmental sustainability demonstrated a strong correlation with indicators such as the source of raw materials (loading of 0.731), encouragement of crop diversity (0.687), and energy use (0.670) (Table 3). Dimension two focused on improving soil health and ecosystems, highlighting the reduction of pest risks (0.550) and human and livestock risks (0.519). Dimension three centred on habitat preservation, emphasising the reduction of insect species death (0.670) and increased water availability (0.596).

The analysis revealed that the first dimension related to environmental sustainability contributed 36.594% of the total variability, while the second dimension, focusing on improving soil health and fostering a balanced ecosystem, accounted for 13.383% (Table 4). Additionally, the third dimension, which emphasised habitat preservation and restoration, represented 11.290% of the overall variability in the model.

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Multicollinearity test of the independent variables to determine the factors which influence the environmental efficiency of using biorationals in banana pest management was conducted before the regression and it was found that all the variables had variance inflation factors below 10 inflations factors and therefore no serious problem of multicollinearity from the independent variables was found which would lead to instability of the regression (Table 5). A multicollinearity test is crucial in regression analysis because it helps identify and address the problem of high correlation between independent variables, which can severely impact the reliability and interpretability of a regression model (Banks et al., 2003).

Variables selection using Least Absolute Shrinkage and Selection Operator (LASSO)

Results of LASSO identified seven factors namely education, social groups, intercropping systems, farm experience, land tenure, and the presence of livestock, which influence the environmental efficiency of biorational use in banana pest management (Table 6).

Categorical regression for the determinants of environmental efficiency in the Lake Victoria Crescent

The results from the CATREG analysis demonstrated that various factors positively influence environmental efficiency. An increase in education level significantly raised environmental efficiency by 0.174 standard deviations ($p < 0.001$), accounting for 7.06% of total efficiency. Social group and marital status were also significant contributors, enhancing environmental efficiency by 0.145 and 0.147 standard deviations, respectively (both $p < 0.001$), contributing 9.3% and 3.9%. Intercropping 0.066 standard deviations ($p = 0.046$, 0.39% contribution) and farming experience 0.146 standard deviations ($p < 0.001$,3.06% contribution) further improved environmental efficiency, respectively. Land tenure, livestock presence, and planting materials also contributed positively, although to lesser degrees. Economic efficiency proved significant to enhance environmental efficiency by 0.053 standard deviations ($p < 0.05$), while human efficiency and social efficiency contributed 0.201 and 0.168 standard deviations, respectively. The covariate production efficiency had a minimal contribution despite not showing significant influence (Table 6).

Analysis of environmental efficiency based on educational attainment revealed that farmers with primary education experienced a decrease of 0.425 while O-level holders decreased by 0.321. Individuals with tertiary certificates and Diplomas had reduced ratings of environmental efficiency by 1.195 and 0.338 times, respectively. Notably, individuals lacking formal education and A-level holders exhibited increases in rating of environmental efficiency by 2.37 and 0.704 times, while university graduates increased it by 2.58 times. Furthermore, belonging to various groups influenced environmental efficiency; membership in "Munomukabi" an informal social network improved efficiency by 1.302 times and POWESA SACCO by 0.345 times, whereas the Parish Development Model SACCO, professional groups and having no group decreased it by 1.024, 0.198 and 1.332 times, respectively. Farming experience also played a significant role. Farmers with less than ten years had increasing efficiency of 0.906 times, while those with 20-30 years experienced a decrease of 1.445 times. Land tenure dynamics indicated that “Kibanja” ownership reduced efficiency by 0.224, whereas leasehold and freehold increased it by 7.293 and 1.740, respectively. Different farming methods varied in their impact on environmental efficiency; for example, intercropping bananas with coffee caused a reduction of 1.417 times, while banana agroforestry improved efficiency by 1.316. Regarding planting materials, micro propagated and sword suckers planting materials had

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enhanced efficiency by 0.739 times and 1.696 respectably and corms by 0.512 times, while maiden suckers decreased it by 0.750 times. Lastly, individuals without livestock showed a marked increase in efficiency by 2.017 times, compared to those with ruminants or non-ruminants.

DISCUSSION

The research findings indicated that farmers lacking formal education were 2.374 times more inclined to assess environmental efficiency positively compared to their counterparts. This finding was closely linked to findings about social networks which quantified the social network "Munomukabi" positively by 1.302 times. As regards environmental efficiency, a more plausible explanation for the observed high efficiency among farmers with no formal education, belonging to the Munomukabi social network, and their superior environmental efficiency ratings could be linked to the importance of Indigenous Knowledge (IK) in banana production, which is deeply intertwined with social values (Lee, 2023). According to Akullo et al., (2007) Indigenous Knowledge (IK) significantly contributes to the cultivation of banana (Matooke) in Uganda, affecting aspects such as variety selection, management practices, planting timing, mulching, and pest and disease management. This finding is supported by the Cultural Ecological Theory that formed the basis of this research, suggesting that humans mainly rely on cultural innovations to establish ecological niches, thus altering current biotic systems and inventing new tools (Sutton and Anderson, 2004). IK systems in traditional African communities have been used to safeguard natural resources from overexploitation, thereby preventing potential disasters (Eneji et al., 2012). This provides a valid justification for the higher environmental efficiency ratings among farmers with no formal education and their reliance on IK. For farmers who have a moderate level of education, the unfavorable view of environmental efficiency might indicate that this level of education allows them to seek information beyond their social circles and comprehend labels on synthetic pesticides, resulting in a greater reliance on these chemicals. This may lead them to prefer rapid and seemingly more effective synthetic solutions rather than organic methods (Kouamé et al., 2022). However, the observation that farmers with no formal education exhibit high environmental efficiency contradicts previous findings suggesting that education levels boost information acquisition and, consequently, efficiency. Nevertheless, this aligns with the Cobb-Douglas production function, which asserts that the relationship between education and production is not straightforward (Cobb and Douglas, 1923; Orlando, 2023). In this study farmers with higher education as well as farmers with no education had higher ratings of environmental efficiency, which was also supported by the results on biorational use: that individuals with advanced education were significantly more inclined to utilise biorationals compared to other educational categories.

As regards study findings which exhibited low efficiency with lower education levels and mid-career education with tertiary certificates and diplomas, positive ratings of environmental efficiency increase with university education. This may be attributed to increased awareness of the usage of synthetic pesticides by farmers with mid-career education and difficulty in the use of IPM strategies. However, farmers with university education tend more to have healthy concerns related to their farming practices (Zachariou et al., 2019). A study conducted by Magali and Stenger, (2022) revealed that individuals with higher education have greater

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awareness of environmental issues and effective strategies for addressing them. Another related study showed that farmers' level of education affects their capacity to handle environmental challenges and promote sustainability (Kangogo et al., 2021). Additionally, less educated farmers tend to be more susceptible to the negative impacts of environmental issues compared to their more educated peers, making them more inclined to adopt locally accessible mitigation strategies using indigenous knowledge (IK). Other studies had established that misuse of synthetic pesticides is more commonly linked to individuals with lower educational qualifications. In this study 63% of banana farmers had either a primary education or none at all (Andersson and Isgren, 2021).

Concerning farming experience, the length of time the farmer had been farming was inversely related with how important they rated environmental efficiency. Banana producers under the age of twenty were more likely to assess environmental sustainability positively, with the rating reducing with the number of years of agricultural experience. After 20 years of farming, negative coefficients were attained, and they reached as the number of years grew. Above the 20 years of farming experience, farmers were significantly less likely to rate environmental efficiency favourably. During the course of the study, it was found that the current biorational management practices are labour intensive and so as the years increase, farmers facing labour shortages or high labour costs are more likely to resort to labor-saving technologies like the use of synthetic pesticides.

About social groups, it was found that social membership among farmers was significantly ($p < 0.001$) related to environmental efficiency sustainability assessment. A study by Severo et al. (2019) found that most people gain information about environmental sustainability when they interact with others in social networks. With this regard, results of this study were in agreement with (Barnes et al., 2016). that social networks play a significant role in environmental outcomes and in advancing environmental sustainability. Social networks also increase improved resource use efficiency. In this study, belonging to a cooperative and saving society raises one's rating of environmental sustainability by 0.612. However, environmental efficiency ratings of farmers in Parish Development Model (PDM) groups were lower than that of other farmers in rating environmental efficiency positively. Also, environmental efficiency was scored 1.4 times lower by farmers who did not belong to any group. According to the elevator effect theory, people's support for environmental preservation and other social benefits is influenced by their social identities(Brieger, 2019). In view of this, Briefer (2019) postulates that social identity raises people's support for environmental protection above their personal demands and toward those of society as a whole. Special interest would be in a government-led programme (PDM) that is scoring low in terms of environmental efficiency. There is a need to analyses the technologies disseminated and integrate issues about environmental sustainability in the future in PDM.

An important link between land tenure and environmental efficiency was also present ($p < 0.05$). Compared to other land tenure types, 'Bibanja' owners rated environmental efficiency 0.224 times lower. The environmental sustainability and utility ratings of Freehold was 1.74 times in favour, and Leasehold was even higher by 7.29 times. Rented farms were environmentally inefficient by 4 times lower. This study finding on environmental efficiency of Leasehold and Freehold landholders is consistent with a study conducted by (Walker et al., 2023) which found that deforestation on degazetted land in Uganda decreased when landowners got assurance of occupancy. About the findings on "Bibanja" and Mailo land

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ownership, this study postulates that Bibanja and Mailo landholders have overriding land rights which may exacerbate land conflict and environmental degradation.

Results indicate that planting materials influenced environmental efficiency by 0.13 standard deviations and the choice of sword suckers had a positive rating of 1.6 times, followed by farmers with micro propagated planting materials with a rating of 0.739 times. Planting bananas from maiden suckers was found to result in a reduced environmental efficiency rating of 0.7 times. The study findings were in agreement with studies in Ghana and the Philippines by Mensah et al. (2017) and (Bales and Brillon, 2010), giving preference to sword suckers as planting materials for bananas over maiden and peppers. However, because employing suckers that are directly taken from a mother plant is limited by poor multiplication rates and a propensity to spread pests and diseases, which results in decreased banana yield, farmers may instead choose to use tissue-cultured materials (Tumuhimbise and Talengera, 2018). The finding suggests that prior to cultivation, a thorough understanding of the banana crop's appropriateness and adaptability is required by farmers. The correct banana cultivar or variety seed to be grown in relation to the environment and season must then be chosen. Crops must be carefully chosen to represent the ecosystem's ability to support them without having a negative impact on the environment. To guarantee the preservation of environmental resources and sustainable production intensification, farmers may turn to newer methods which reduce losses, like the micro propagated planting materials and macropropagation from corms.

Furthermore, of the four covariates which were assessed in the model, two were found to significantly contribute to environmental efficiency, that is economic efficiency and human efficiency. According to Zhu, (2024)the management of environmental issues is greatly affected by factors related to human efficiency and economic efficiency. The development of human capital, especially through formal and informal education and awareness, is essential for promoting sustainable practices and technologies. Economic efficiency, which encompasses investments in eco-friendly technologies and strong environmental regulations, is vital for achieving a balance between economic development and environmental preservation and ensures resource use efficiency (Kumar et al., 2020).

IMPLICATIONS FOR RESEARCH AND PRACTICE

The primary takeaway from the research is that indigenous knowledge (IK) is crucial for achieving environmental sustainability. This indicates that integrating IK into environmental management and conservation strategies can result in more efficient and sustainable biorational use in banana pest management.

Indigenous social network work plays a significant role in knowledge dissemination among banana farmers. These informal networks, like “Munomukabi”, grounded in common cultural values and community connections, enable the sharing of important information concerning banana farming, pest management, and sustainable agricultural practices which play a significant role in environmental conservation.

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CONCLUSION

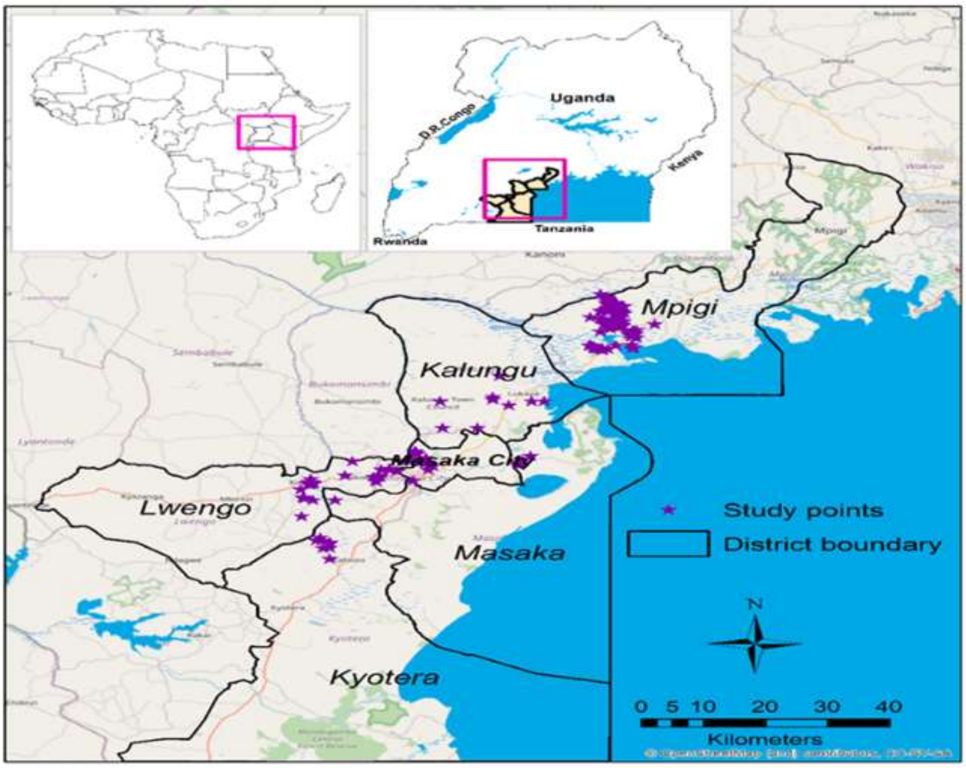
The study on the assessment of the determinants of environmental efficiency of using biorationals in banana pest management in the Lake Victoria Crescent, Uganda, emphasises the importance of informal learning and social networks in banana pest management, especially among farmers lacking formal education. It reveals that farmers with leasehold land demonstrate greater environmental efficiency, while older farmers tend to be less motivated to adopt innovative, labor-intensive farming practices.

FUTURE RESEARCH

There is a need to identify the predisposing factors which stimulate adoption of technologies in informal social networks that should be explored further. As farmers grow old, they are more likely to turn to less labor-intensive synthetic pesticides. Government should support local innovators to develop and marketable biorational products that are both effective and easier to use than synthetic options, potentially easing the labour burden on farmers.

FIGURES

Figure 1: Map showing the distribution of banana producers in the study area (source: Survey data 2023-24)



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TABLES

Table 1: Descriptive statistics of the Environmental Efficiency Sustainability Indicators against different pest control methods. (Source: Survey data 2023/24)

Environmental sustainability Indicators	N	Mean	Median	Mode
System encourages energy use	246	6.91	7	8
Products' longevity in System	246	6.45	7	8
Encourage crop diversity	246	6.44	7	7
Promote environmental sustainability	246	6.43	7	8
Preserve earthworm biodiversity	246	5.95	6	7
Reduced risk to pests	246	5.74	6	8
Use raw local material for biorationals	246	5.67	6	7
Increase water availability	246	5.55	6	6
Reduce risks to human and livestock	246	5.19	5	7
Reduce death of insect species	246	3.44	3	2

Table 2: Banana Farmers' rating of environmental efficiency sustainability indicators transformed to five Likert scale (Source Surrey data 2023/24)

Response on environmental efficiency indictors	Freq/%	Very Low	Low	Medium	High	Very High
Source of materials to make biorationals	Freq	49	19	67	79	32
	%	(19.9)	(7.8)	(27.3)	(32.1)	(13.1)
Increase environmental sustainability	Freq	12	25	83	103	23
	%	(4.8)	(10.2)	(33.7)	(41.9)	(9.3)
Reduce Pest risks	Freq	44	31	52	96	23
	%	(17.9)	(12.6)	(21.1)	(39.1)	(9.3)
Improves waiter availability	Freq	19	45	108	69	5
	%	(7.7)	(18.3)	(43.9)	(28)	(2)
Encourage crop diversity	Freq	12	20	74	124	16
	%	(4.9)	(8.2)	(30.1)	(50.4)	(6.5)
Increase earthworms'	Freq	9	24	122	89	3
	%	(3.2)	(9.7)	(49.6)	(36.2)	(1.2)
Increase energy use	Freq	9	20	60	119	32
	%	(3.7)	(8.1)	(26.8)	(48.4)	(13)
Reduce death of insect species	Freq %	1 (0.4)	26 (10.6)	37 (15.0)	80 (32.5)	102 (41.4)
Reduce risks to human and livestock	Freq %	45 (18.2)	47 (19.1)	66 (26,.8)	81 (33)	7 2.8)
Product stay for long	Freq %	7 (2.9)	25 (10.2)	97 (36.5)	108 (43.9)	16 (4.7)

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Table 3: Dimensions for environmental efficiency sustainability indicators on biorational use in the Lake Victoria Crescent (Source survey data 203/2024)

Environmental sustainability indictor s	Component		
	1	2	3
Environmental sustainability	0.779		
Use of raw materials for biorationals	0.731		
Increase crop diversity	0.687		
Encourage energy use	0.67		
Reduce pest risks	0.664	0.55	
Product stay in system long	0.66		
Reduce risks to humans and livestock	0.646	0.519	
Increase earthworm diversity	0.437	-0.601	0.378
Reduce death of insect species		0.396	0.67
Increase water availability			0.596

Table 4: Principal components in environmental efficiency indicators (Source: survey data 2023/2024)

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings			
	Total	% of Variance	Cumulative %	Total	Total	% of Variance	Cumulative %
1	3.659	36.594	36.594	3.659	36.594	36.594	2.630
2	1.338	13.383	49.977	1.338	13.383	49.977	2.261
3	1.129	11.290	61.266	1.129	11.290	61.266	1.236
4	.839	8.390	69.656				
5	.695	6.947	76.602				
6	.635	6.345	82.948				
7	.542	5.420	88.367				
8	.535	5.349	93.716				
9	.320	3.202	96.918				
10	.258	2.581	100.000				

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Table 5: Multicollinearity to test for inter-association or inter-relation between two or more independent variables.

Variable	Tolerance	VIF
Gender	0.754	1.327
Marital status	0.787	1.271
Education	0.685	1.461
Farming experience	0.43	2.323
Household size	0.739	1.353
Source of Incomes	0.85	1.176
Type of farm	0.688	1.453
Land ownership	0.811	1.233
Planting martials	0.844	1.186
Pest control method	0.411	2.433
Fertility management	0.665	1.505
Age of respondents	0.482	2.075
Land size	0.638	1.566
Acreage of banana	0.653	1.533

Table 6: Least absolute shrinkage and selection Operator LASSO Coefficient tables

Coefficients					
	Standardized Coefficients		df	F	Sig.
	Beta	Estimate of Std. Error			
Education	.137	.065	6	4.407	.000
Marital status	.000	.023	0	.000	.
Social Group	.109	.060	4	3.325	.012
Intercropping system	.035	.059	3	.352	.788
Farm experience	.208	.075	4	7.772	.000
Gender	.000	.010	0	.000	.
Land tenure	.228	.074	4	9.642	.000
Type of farm	.000	.016	0	.000	.
Presence of livestock	.003	.043	3	.005	.999
Planting materials	.041	.059	3	.486	.692
Pest control	.000	.042	0	.000	.
Fertility management	.000	.011	0	.000	.
Household size	.000	.026	0	.000	.
Land Ownership	.000	.010	0	.000	.

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Size of land	.000	.021	0	.000	.
Banana Acreage	.000	.020	0	.000	.
Dependent Variable: EVEF					

Table 7: Categorical Regression of Factor Influencing Environmental Efficiency of Using Biorationals in Banana Pest Management in Lake Victoria Crescent

Independent variables	Standardized Coefficients	df	f	Sig.	Correlations		Tolerance	
					R	R^2	After Transformation	Before Transformation
Education	0.185	6	16.702	0.000	0.306	0.321	0.908	0.781
Farming Experience	-0.14	1	6.322	0.013	-0.419	-0.225	0.748	0.741
Social group	0.167	4	10.838	0.000	0.328	0.284	0.859	0.867
Land tenure	0.138	4	7.938	0.000	0.313	0.247	0.931	0.862
Intercropping system	0.062	3	2.531	0.059	0.01	0.115	0.944	0.896
Presence of Livestock	0.092	3	4.628	0.004	0.202	0.167	0.922	0.934
Planting materials	0.056	3	1.929	0.126	-0.009	0.102	0.908	0.849
PE	0.12	4	0.894	0.469	0.595	0.167	0.545	0.52
ECEF	0.34	4	23.521	0.000	0.709	0.442	0.573	0.471
HEFF	0.205	5	7.068	0.000	0.598	0.273	0.524	0.51
SOIEFF	0.11	4	1.29	0.275	0.555	0.159	0.585	0.51
Dependent Variable: EVEF		R	0.851	R^2:	0.727	ADJ R^2: 0.668		

Table 8: Quantification of factors influencing environmental efficiency of using biorationals in banana pest management in the Lake Victoria Crescent

Variable	Category	Frequency	Quantification
Environmental efficiency	Very low	29	-1.694
	Moderately Low	47	-1.017
	Medium	62	-.050
	Moderately high	70	.883
	Very high	29	1.319
Education	None	20	2.374
	Primary	94	-.424
	O-Level	70	-.321
	A Level	13	.704

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	Certificate	14	-1.195
	Diploma	10	-.338
	University	10	2.580
Farming experience	0-10	68	.906
	10-20	64	.860
	20-30	28	-1.445
	above 30years	77	-.989
Social group	Munomukabi	55	1.302
	POWESA SACCO	87	.345
	PDM	18	-1.024
	Professional group	10	-.198
	No group	61	-1.332
Land tenure	Kibanja	162	-.224
	Mailo	38	-.597
	Leasehold	2	7.293
	Freehold	28	1.740
	Rented	1	-4.264
Intercropping pattern	Pure	49	.947
	Banana Coffee	87	-.113
	Banana Agroforestry	39	1.316
	Banana Coffee Agroforestry	62	-1.417
Presence of livestock	Ruminants	34	.578
	Nonruminant	102	.328
	Both	74	-1.290
	None	21	2.017
Planting materials	Micro propagation	21	.739
	Sword sucker	48	1.696
	Maiden sucker	145	-.750
	Corms	23	.512

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