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Barriers and opportunities for intensification of the coffee-banana agroecosystem of the Mt. Elgon in Uganda

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ABSTRACT

The world human population will reach 10 billion by the year 2050, yet of these 68% will be living in cities, posing serious threats to food and livelihoods security especially in low-income countries. This exponential population growth has and will continue to lead to an increased competition for limited land resources leading to expansion of agricultural lands and rural settlements into the natural landscape followed by mass deforestation and cultivation on mountain slopes, exacerbating landslides and soil loss. This challenge will call for development, innovation and adoption of intensified, efficient and sustainable agricultural production systems. However, evidence shows that only a few households manage the desired shift. At the same time, there are prevailing declines in crop yields in the Mt. Elgon partly due to increased soil degradation leading to recent conversions of forest land into crop land in the marginal mountain Elgon ecosystems. This study, using survey data from 500 farms, classified the intensification pathways of the coffee-banana farming system using core agricultural intensification surrogate indicators. Cluster analysis was used to classify, a stochastic frontier model to estimate technical efficiencies of the pathways and a logit model to assess the driving factors and barriers to agroecological intensification. Cluster analysis revealed two intensification pathways taken by farmers. We found that farmers lose about 50% and 30% of the maximum attainable coffee and banana output respectively due to inefficiencies, indicating existence of huge opportunities to increase yields. We found that the coffee variety grown and lack of access to credit pose opportunities for adoption of the agroecological pathways under study. This study contributes to the sustainable intensification debate by presenting evidence that farmers are trying to intensify, more so agroecologically, with less external inputs despite the numerous constraints faced and shows opportunities for increasing yields while reducing negative environmental impacts of agriculture.

Key words: Efficiency, intensification, logit, Mt . Elgon, Uganda

RÉSUMÉ

La population mondiale atteindra 10 milliards d'habitants d'ici 2050, avec 68% de personnes vivants en ville, ce qui constituent de sérieuses menaces pour la sécurité alimentaire et la survie, surtout dans les pays à faible revenu. Cette croissance exponentielle de la population est et continuera d'être à l'origine d'une flambée de concurrence pour des ressources en terres limitées, ayant pour conséquences l'expansion des terres cultivables, l'installation des populations rurales dans les espaces naturels, la déforestation massive et l'emblavure

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des pentes montagneuses. Tout ceci accentue l'érosion et les glissements de terrain. Ceci constitue un défi qui fait appel au développement d'innovation et d'adoption de systèmes de production intensive, efficients et durables. Cependant, il est démontré que très peu de ménages arrivent à se conformer aux changements nécessaires. Au même moment, une baisse de rendements agricoles se fait observer dans le Mont Elgon, due en partie à la dégradation grandissante des terres, conduisant à la conversion des forêts en terres agricoles dans les écosystèmes marginaux du Mont Elgon. La présente étude s'est fondée sur les données d'enquêtes collectées auprès de 500 exploitations agricoles, et classifié le processus d'intensification des systèmes agroforestiers à caféier et bananiers à partir d'indicateurs de substitution clés de l'intensification agricole. Une analyse de classification numérique a permis le regroupement des données. Le modèle frontière stochastique a permis d'estimer l'efficacité technique du processus et le modèle logit pour évaluer les facteurs déterminants et barrières de l'intensification agroécologique. La classification numérique a révélé deux processus d'intensification adoptés producteurs. Il a été révélé qu'en raison du manque d'efficacité, les producteurs perdent 50% et 30% du maximum du rendement escompté respectivement au niveau des plantations de café et de bananes. Ceci montre qu'il existe une immense possibilité pour améliorer les rendements. Il a été également révélé que la variété de café produite et le manque d'accès au crédit constituent des freins à l'adoption du processus agroécologique. La présente étude apporte une contribution à la question d'intensification durable en démontrant que les producteurs essaient d'intensifier les rendements de façon agroécologique, avec moins d'intrants extérieurs en dépit des contraintes, ce qui montre des possibilités pour l'amélioration des rendements agricoles tout en réduisant les impacts négatifs sur l'environnement.

Mots clés : Efficacité, intensification, logit, Mt . Elgon, Ouganda

INTRODUCTION

Throughout history, agriculture and natural resources have been used for the production of food, feed, fibre, fuel, and environmental goods globally. The question at hand is how to maintain or attain stable and higher yields without jeopardizing the long-term availability of the earth's resources (Perkins and Jamison, 2008). Demand for food is projected at 100%-110% increase by 2050 (IFPRI, 2017) which will have huge environmental impacts, justifying renewed calls for sustainable intensification and reduced extensification especially in poorer countries (Garnett and Godfray, 2012).

Research shows that agricultural growth especially in Sub-Saharan Africa (SSA) has been declining since 2007 from 3.5 % p.a yet projected to fall farther down to 2.1% p.a by 2030-2050 (Alexandratos and Bruinsma, 2012). Land use systems and decisions, which often result into altering ecosystem functions and socio-ecological systems are some of the causes of the observed declines (Domptail *et al.,* 2013). As land pressures due an increasing population globally and in Africa in particular continue to rise, the land management debate seems to have shifted to intensification.

In Sub-Saharan Africa, the traditional intensification pathway has been tightly linked to labour intensification; increasing yields via greater labour inputs (Boserup, 1965; Ruthenberg, 1971). This intensification pathway has often resulted into ecological degradation and soil exhaustion (Burton and White, 1984). The majority of farmers in SSA and many developing countries continue to rely on farming practices and systems that were developed in pre-industrial times, adapted to lower population densities (Pretty, 2008), yet 80% of African farms are smaller than 2 ha, without sufficient space for cropping and fallowing that are needed to intensify production in order to produce more food and feed (Pretty *et al.,* 2011). The question is whether to intensify using green revolution technologies such as inorganic inputs and machinery (Croppenstedt *et al.,* 2003) with their negative impacts on the environment (Snapp *et al.,* 2010) or intensify ecologically (Bommarco *et al.,* 2013; Tittonell, 2014). This study set out to assess the two approaches to find what is suitable for the farmers especially in the Mt Elgon ecosystem in Uganda.

Research in Uganda shows that the ongoing mass deforestation and cultivation on the slopes of Mt. Elgon due to a rapidly growing population is causing land use change and increased risk and frequency of landslides and soil loss (Jiang *et al.,* 2014). The increasing encroachment on the higher mountain areas has also exacerbated land degradation, soil and land cover loss, leading to reduced productivity and posing serious threats on food security (Mugagga *et al.,* 2012).

Since farmers are faced with reducing farm productivity that threatens their livelihoods, food and income security; they have to make a choice to either improve on their current production systems or adopt more productive and efficient systems. Improving smallholder agriculture efficiency in Africa has been one of the highly debatable issues in the recent years because increasing productivity is key in reducing poverty and hunger, better investment in agriculture technology and market access (Deininger and Byerlee, 2011). Millions of resource-poor farmers who have been left out from access or unable to afford modern agricultural technology can also benefit from new and tailor-designed agroecological systems that are compatible with the needs and aspirations of the poor (Altieri, 2002).

In this study we draw from previous efforts by Tscharntke *et al.* (2012) and Phalan *et al.* (2011) to classify intensification pathways in the coffee-banana farming system of the Mt. Elgon in Uganda. We make use of standard surrogate indicators of input and output intensification (Erb *et al.,* 2013; Smith, 2013). We based this study on the hypotheses that intensification pathways are shaped by household demography, farm characteristics and input availability and that resource-poor farms intensify by labour while richer ones intensify by capital, investing more in equipment and improved inputs. We further hypothesized that labour intensive agroecosystems are more efficient than capital intensive ones.

METHODOLOGY

The study was conducted in the neighbouring districts of Sironko and Kapchorwa in Mt. Elgon region in Eastern Uganda. This area is part of an extinct volcano with a maximum altitude of 4321 metres (Mugagga *et al.,* 2012) and lies within 1°8'43''N-1°23'04''N and 34°22'26''E-34°26'29''E. A list of coffee-banana growing households was obtained from the district personnel, working together with the Uganda Coffee Development Authority. Using excel, the list was entered and random sampling was used to generate a sample of 500 farmers who were interviewed using a structured pre-tested questionnaire. Coffee and banana harvests were obtained through farmer harvest recall per plot for the previous two seasons of 2015/2016 production year. Data were prepared, entered and analysed using SPSS 20.0 and Stata 14.0 software.

We used cluster analysis (CA) using 12 sustainable intensification (SI) indicator variables such as returns to inputs, yield, livestock intensity (TLU), family labour, altitude, access to farm machinery, soil and water conservation, and soil vegetation cover (fallow and shade tree cover) as spelt out by Delzeit *et* *al.* (2018), Erb *et al.* (2013) and Haileslassie *et al.* (2016) to classify the intensification pathways in the coffee-banana farming system. The Kaiser Meyer Olkin (KMO) measure of sampling adequacy was performed to address the question of independence and correlation of variables (Lattin *et al.,* 2003) and found to be less than 0.5, showing that the variables had a lot in common to warrant use of cluster analysis.

We found no collinearity among independent variables prior to running a stochastic frontier models since none of them had more than a threshold variance inflation factor (VIF) of 10. We estimated coffee and banana stochastic frontier production functions and later technical efficiency. The approach used by Batesse *et al.* (1996) and Batesse (1997) was used to address the problems of biased estimates as a result of zero values for some observations where some farmers do not apply inputs such as fertilizer or manure. The technical efficiency (TE) of the i^{th} farm was determined using the equation (1);

$$TE_i = \frac{Y_i}{\exp(X_i\beta)} = \frac{\exp(X_i\beta - \varepsilon_i)}{\exp(X_i\beta)} = \exp(-\varepsilon_i) \quad \text{.........} (1)$$

Equation (1) is an output-oriented measure of technical efficiency which takes a value between 0 and 1; indicating the magnitude of the output (of coffee or banana) of the i^{th} farm relative to the output that could be produced by a fully efficient farm using the same input vector. To understand the drivers of intensification pathway adoption, we also estimated a logit model specified as in equation 2;

$$P_i^h = \frac{exp\{\beta_{0i} + \sum_{k=1}^{k} \beta_k X_{ik}^h\}}{\sum_{j=1}^{j} exp\{\beta_{0j} + \sum_{k=1}^{k} \beta_k X_{jk}^h\}} \quad \text{.........} (2)$$

Where P_i^h is the probability that farmer h chooses intensification pathway i. To estimate the model, we maximised the likelihood function (joint probability that the observed choices are generated by the model) with respect to the estimable coefficients *β*.

RESULTS AND DISCUSSION

Classification of intensification pathways. A total of 12 indicator variables were included based on the criteria of sustainable intensification. Eight components were retained because they had eigenvalues greater than one. The eight PCs cumulatively explained 78% of the total variability in the dataset. Through cluster analysis, two pathways were characterised as conventional if a farmer used high amounts of fertilizer, manure and machinery or agroecological if a farmer practiced more fallowing, shading, manuring and had more returns to labour. Results of a t-test indicated that conventional coffee-banana farms significantly intensified in terms of machinery p<0.01, p<0.01, p<0.05. On the other hand, agroecological farms intensified significantly in terms of labour in coffee (p 0.10). These findings are in agreement with those of Altieri (2002) and Altieri (2009) who stated that agroecological systems can compete with the modern intensification systems by intensifying labour to manage soil fertility, regulate pests and building synergies for crop health. The agroecological farms were also found to apply some fertilizer (about 75 kg ha^{-1}) comparable to East Africa in 2015 with average of 84 kg ha^{-1} (Reij and Smaling, 2008).

Table 1 indicates that majority of coffee farms operated at efficiency levels within the 0.25-0.50 quartile while for bananas the majority operated in the 0.50-0.75 quartile band. This shows that farms were more efficient at banana than coffee production, indicated by a lower mean technical efficiency in coffee than in banana that is almost half. Results further indicated that on average, farms lost 50% of the maximum possible coffee output and 31% of banana output due to technical inefficiency while some farms lost over 90% of their coffee and banana output.

We however found that agroecological farms lost significantly ($p<0.10$) more coffee output than the conventional farms. Technical inefficiencies have been linked to productivity gains in African coffee production, which calls for interventions that help farmers to tap into such opportunities (Nchare, 2007).

Table 2 indicates that adoption of the agroecological intensification pathway relative to the conventional one was positively and significantly driven by the variety of coffee grown and access to credit. Adoption was found to be impeded by livestock intensity, amounts of fertilizer and manure. The odds of a farmer adopting the agroecological intensification pathway were 81% significantly (p 0.05) higher than for the conventional pathway if the farmer planted an improved coffee variety. Access to credit increased the odds of adopting the agroecological pathway by 3% (p 0.10) relative to the conventional. This is supported by the findings reported by Bagamba *et al.* (2007) which indicated that one way of increasing efficiency of coffee-banana production systems was to increase access to credit to facilitate investment in yield enhancing production technologies. However, the odds of adoption of the agroecological intensification pathway reduced with increased livestock (69%) and fertilizer (99%). Due to the smallholder nature of the coffee-banana farms in the Mt. Elgon, higher livestock rates will lead to exceeding carrying capacity, hence not sustainable in the long run.

If a farmer earned an off farm income, the probability of adopting the agroecological intensification pathway reduced by 0.03. Table 2 indicates that increasing livestock units, fertilizer and manure from the minimum to their maximum values, while keeping the means of other variables constant, the probabilities for adoption of the agroecological intensification pathway reduced drastically from over 96% to 0%. This is indicative of the fact that this pathway is driven by practices such as shading, fallowing and labour intensification. There was a high model predicted probability for the agroecological intensification pathway (94%) compared to 6% for the conventional pathway, hence farmers are more likely to practice the former. Altieri (2009) noted that agroecological pathways are favourable to the resource-poor farmers and future sustainability of small farms.

Table 1. Coffee and banana production technical efficiency estimates by intensification pathway

	Coffee			Banana		
Efficiency quartile (%)	Pooled sample (n=453)	Agroecological (n=388)	Conventional (n=65)	Pooled sample (n=453)	Agroecological (n=388)	Conventional (n=65)
<0.25	23.18	24.48	15.38	0.22	0.26	0.00
0.25-0.50	49.23	49.23	49.23	11.26	11.86	7.69
0.50-0.75	26.71	25.26	35.38	84.99	84.02	90.77
0.75-1.00	0.88	1.03	0.00	3.53	3.87	1.54
Mean TE[1]	0.39	0.38	0.42	0.61	0.61	0.63
Output loss due to inefficiency (%)	50.24*	50.84	46.70	31.12	31.40	29.40
Minimum loss (%)		19.21	20.38		13.81	18.59
Maximum loss (%)		99.48	99.31		84.34	57.11

[1]Intensification pathway average technical efficiencies for coffee and banana

Table 2. Factors for adoption of coffee-banana intensification pathways (logistic regression)

Dep var: Adoption (agroecological=1, conventional=0)	Coef.	Std. Err.	z	Odds ratio	Measure of change -+ 1/2	Predicted probability of change from min to max x=min	x=max
Coffee variety (Improved=1, Bugisu local =0)	1.57**	0.67	2.33	4.81	0.09	0.91	0.98
Household size	0.10	0.08	1.32	1.10	0.01	0.90	0.98
Elevation	-0.001	0.001	-0.91	1.00	-0.00	0.97	0.92
Age of household head	0.01	0.01	0.49	1.01	0.00	0.93	0.96
Farmer sex(1=male,0=female)	0.42	0.42	1.02	1.53	0.02	0.93	0.95
Credit access (dummy)	0.71*	0.42	1.69	2.03	0.04	0.92	0.96
Number of coffee and banana plots	0.05	0.09	0.58	1.05	0.00	0.93	0.98
Farmer has an off-farm job (dummy)	-0.46	0.39	-1.19	0.63	-0.03	0.95	0.93
Coffee yield (tons ha^{-1})	0.13	0.09	1.40	1.14	0.01	0.92	1.00
Banana yield (tons ha^{-1})	0.02	0.01	1.38	1.02	0.00	0.93	1.00
Tropical Livestock units (TLU)	-0.37***	0.09	-4.20	0.69	-0.02	0.97	0.00
Total annual fertilizer used (kg)	-0.01***	0.002	-6.15	0.99	-0.00	0.97	0.00
Total annual manure used (kg)	-0.0003***	0.0001	-4.00	1.00	-0.00	0.96	0.00
Total annual hired labour(man hours)	0.00001	0.00002	0.42	1.00	0.00	0.94	1.00
Unit price of coffee parchment (Shillings/kg)	0.0004	0.0003	1.28	1.00	0.00	0.91	1.00
Unit price of fresh banana (Shillings/kg)	0.0008	0.0008	1.06	1.00	0.00	0.93	0.99
Constant	3.13	2.10	1.49	22.89	0.00		
LR chi^2(16) = 179.10							
Prob > chi^2 = 0.0000							
Pseudo R^2 = 0.4638							
Pr(y|x) Conventional = 0.06							
Pr(y|x) Agroecological =0.94							

Significance: *** p<0.01, ** p<0.05, *p<0.10: The ML estimator was used because it is assumed consistent, efficient, and asymptotically normal. Test of the hypothesis that all of the coefficients except the intercept are simultaneously equal to zero; Chi^2 (15) = 69.41; Prob > chi^2 = 0.00 (Hypothesis rejected). We rejected the null hypothesis that the effect of credit access on agroecological intensification adoption is equal to the effect of coffee and banana prices (chi^2 (1) = 2.74; Prob > chi^2 = 0.0978); Mean predicted probability=0.86.

CONCLUSION

This study investigated two intensification pathways and the driving factors of their adoption, technical efficiency and coffee and banana yields in the Mt. Elgon highlands in Uganda. We found significant differences in terms of levels of intensification and efficiency between the conventional and the agroecological pathway. Estimating technical efficiency of and adoption of farming systems has policy implications since it helps to understand whether scarce resources are best allocated to improve productivity.

We conclude that there are high technical inefficiencies of agricultural production in the Mt. Elgon that are partly driven by levels of shading and altitude for bananas and fertilizer levels, altitude and genotype grown and labour intensity in coffee. The high inefficiency-related yield losses are indicative of huge opportunities to increase yields and improve the livelihoods of millions of farmers in the Mt. Elgon highlands.

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STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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