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Assessment of agricultural intensification and determinants of the relative choice of land management systems in East African wetlands

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ABSTRACT

Wetlands play critical ecological and economic functions through ecosystem services they provide. Despite this importance, wetlands in many regions of the world and particularly East Africa are increasingly facing anthropogenic pressure compromising their sustainability. Agricultural production is one of the key activities driving wetland degradation. The impact of agriculture on the wetlands is not straightforward and can be better understood through studying specific activities within distinct agricultural land use management systems (ALUMS) and the level of risk they pose to wetlands. The purpose of this study is to assess the level of intensification across three agricultural land use management systems (ALUMS) in East African Wetlands and identify the drivers of farmers' choices of the ALUMS. The study utilizes cross-sectional data collected from 1053 wetland dependent farm households in Kenya, Uganda and Tanzania. Results indicate that there were higher rates of agricultural intensification in upland irrigated and wetland land use systems compared to the rain fed only system. The most prevalent choice of ALUMS was the one involving a combination of upland rain fed and wetland production depicting wetlands as a diversification and risk management strategy by farmers around them. The choice of the wetland dependent systems was significantly driven by commercialization, land scarcity and household socio-demographic factors. To guide sustainability in the use of wetlands in the long run, we develop various postulates that can point to potential policy options that will guide wetland users towards this objective.

Key words: Agricultural intensification, agricultural land use management, East Africa, wetlands

RÉSUMÉ

Les zones humides jouent des rôles écologiques et économiques essentiels à travers différents services écosystémiques fournis. Malgré cette importance, les zones humides dans nombreuses régions du monde, et en particulier de l'Afrique de l'Est, sont de plus en plus confrontées aux pressions anthropiques, ce qui compromet leur durabilité. La production agricole est l'une des principales activités entraînant la dégradation des zones humides. L'impact de l'agriculture sur les zones humides peut être mieux compris avec des études spécifiques au sein des systèmes de gestion de l'utilisation des terres agricoles et leur niveau de risque. Le but de cette étude est d'évaluer le niveau d'intensification de trois systèmes de gestion de l'utilisation des terres agricoles dans les zones humides d'Afrique de l'Est, et d'identifier les déterminants du choix des agriculteurs. L'étude a

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utilisé des données transversales collectées auprès de 1053 ménages d'exploitants agricoles tributaires des zones humides au Kenya, en Ouganda et en Tanzanie. Les résultats indiquent que les taux d'intensification agricole étaient plus élevés dans les systèmes d'utilisation des terres irriguées et humides dans les hautes terres que dans le système pluvial. Le choix le plus courant parmi les systèmes de gestion de l'utilisation des terres agricoles, a été celui associant la production pluviale à celle de zones humides, décrivant les zones humides comme une stratégie de diversification et de gestion des risques par les agriculteurs. Le choix des systèmes dépendants des zones humides était fortement influencé par la commercialisation, la rareté des terres et les facteurs sociodémographiques des ménages. Pour une durabilité dans l'utilisation des zones humides à long terme, nous développons divers postulats qui peuvent indiquer des options politiques potentielles qui guideront les utilisateurs des zones humides vers cet objectif.

Mots clés: Intensification de l'agriculture, gestion de l'utilisation des terres agricoles, Afrique de l'Est, zones humides

BACKGROUND

Wetlands play an important role in providing ecosystem services in support of ecological functions and livelihoods. East African wetlands have continued to face anthropogenic pressures that can be attributed to growing population density, climate and market dynamics. In most cases, the increasing utilization of wetlands for providing ecosystem services is in conflict with ecological functions (Turner *et al.,* 2000). Crop production is one of the main uses of wetland resources, mainly land and water. Intensive use of wetland for agricultural purposes is a key threat to sustainable management of wetlands and may compromise the capacity of the wetlands to play their critical ecological functions, especially in the long run (Dixon and Wood, 2003). Africa is still experiencing the highest rates of population growth in the world and this trend will continue at least up to 2050 (Population Reference Bureau, 2017). For the agricultural sector to satisfy the increasing demand for food, farmers either increase productivity under the current area or expand farming to potential areas such as wetlands or a combination of both strategies. Unregulated wetland exploitation can however compromise their ecological functions and therefore there is need for reconciling food production with wetland conservation. The impact of agriculture on wetland health and the risk of wetland degradation depend on agricultural practices which are distinct across the land use management systems (ALUMS).

Three ALUMSs may be distinguished within the East African wetland areas: upland rain fed (URF), upland-irrigated (UIRR) and wetland (WET). The upland rain fed system is where farmers depend on rainfall. The upland irrigated system is characterized by cultivation of upland parcels located close to the wetlands with irrigation water drawn from the wetland. The wetland system involves clearance of wetland vegetation and substantial drainage to create crop land on marshes, disrupting normal hydrological and ecological functions of wetlands. In some cases, the reclamation is irrevocable but in other circumstances, flooding may occur during certain periods of the year making it impossible to grow crops. Under such circumstances, farmers may combine wetland cropping with upland cropping to spread the risk. As a diversification strategy, farmers crop on upland fields during the rainy season but return to wetlands during the dry seasons. It is the practices associated with each of these systems that may indicate to what extent each system may negatively impact on the wetlands. This is because the ALUMS reflect the risk management strategy of the farmer and also the potential impact of wetland cultivation on the wetlands.

The current study sought to identify the extent of agricultural intensification across the agricultural land use systems in East African Wetlands and determine the drivers of farmers' choices of the agricultural land use systems. It is guided by two research questions: 1. What are the levels of agricultural intensification in the three ALUMSs in East African Wetlands? 2. What drives the choice of agricultural land use management systems and particularly what is the relative importance of population density, markets and household characteristics in these choices?

METHODOLOGY

The study was conducted in Kenya, Uganda and Tanzania representing three wetland types: highland flood plains, lowland flood plains and inland valley bottoms. The Kenyan site, Ewaso Narok wetland is a highland floodplain located along the Eng'are Narok River, within the Laikipia District at 0 19'0" N and 36 36'0" E and an altitude of approximately 1700 m.a.s.l. Flooding only occurs during the rainy season, rendering most part of the wetland inaccessible. The Ewaso Narok catchment receives an average annual rainfall of 840 mm ranging between 450 and 1090 mm. The Kilombero valley wetland is a lowland flood plain stretching over a distance of 250 km along the banks of the Kilombero River, in the south-central parts of Tanzania located at 8 45'0" S and 36 0'0" E and an altitude of 239 m.a.s.l. The valley consists of a seasonally inundated floodplain, an alluvial fan which is also seasonally flooded with run-off during the rainy season, with an average annual rainfall of approximately 1418 mm. In Uganda, the study was conducted within Kampala and Wakiso districts in 14 parishes representing an urban-rural gradient. Namulonge Research Station, the center of the study area, is located at 0 31'17.99" N 32 36'32.39" E at an altitude of 1,160 m.a.s.l. The weather around the study sites is generally wet throughout the year with maximum rainfall of 170 mm in April and a minimum of 55 mm in January. The temperatures also fluctuate with a maximum of 28.8 ^{0}C in January and a minimum of 15.2^{0}C in July.

The primary data were obtained through a cross-sectional survey among 1053 randomly selected farm households located near the target wetlands in Kenya (350), Uganda (399) and Tanzania (304). The sample size was determined using the Kothari (2004) formula while ensuring a reasonable precision and confidence level. Within each wetland, a sampling frame was generated composed of all the households who were engaged in farming within and around the wetland.

To address the first objective parametric and non-parametric descriptive analysis methods were used to describe the agricultural land use management systems and assess the relationship between relevant variables. The determinants of the household's choice of agricultural land use management system were identified using a multinomial logistic regression (MNL) model. MNL was preferred because the dependent variable is multinomial and data are individual specific and the values of the independent variables are assumed to be constant among all the alternatives in the choice set. Seven ALUMs were identified but only five had a significant number of farmers: Wetland only, upland rain fed only, upland irrigated only, upland irrigated combined with wetland and upland rain fed combined with wetland, as illustrated below.

Model 1: Comparing a combination of upland rain fed and wetland category with upland rain fed system only.

$$(1)\quad \log\left(\frac{\Pr(Y=URFW)}{P_r(URF)}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \varepsilon_1$$

Mode 2: Comparing a combination of wetland and upland irrigated system with upland rain fed system only.

$$(2)\quad \log\left(\frac{\Pr(Y=UIRRWET)}{P_r(URF)}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \varepsilon_2$$

Mode 3: Comparing a wetland only system with upland rain fed system only.

$$(3)\quad \log\left(\frac{\Pr(Y=WET)}{P_r(URF)}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \varepsilon_3$$

Model 4: Comparing the upland irrigated system with upland rain fed system only.

$$(4)\quad \log\left(\frac{\Pr(Y=UIRR)}{P_r(URF)}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13} + \varepsilon_3$$

where P_r is the probability that household *i* chooses land use management strategy *j*, X_1-X_{13} are exogenous and endogenous explanatory variables which are described in Table 1; β_1-β_{14} are the coefficients to be estimated and ε_1- ε_4 are the error terms.

The marginal effects associated with each of the explanatory variables were estimated using Equation 5.

$$(5)\quad \delta_j = \frac{\partial P_j}{\partial x_i} = P_j\left[\beta_j - \sum_{k=0}^{K} P_k \beta_k\right] = P_j[\beta_j - \bar{\beta}]$$

There is simultaneity between commercialization and choice of land use management systems, included in models 1-5. To control for endogeinity, we applied the control function approach (CFA). Distance to the nearest output market was used as the exogenous IV for agricultural commercialization and participation in off-farm income regeneration activities for household wealth status.

RESULTS AND DISCUSSIONS

Table 1 presents descriptive statistics for selected variables which depict agricultural intensification across the three land use management systems in the three wetlands. Agricultural intensification was measured through four parameters: Quantity of inorganic fertilizer used, size of land parcels, labour use per unit of land, and land use intensity measured through the length of period the land was left fallow.

Fertilizer use was highest in the upland irrigated land use system and lowest in the rain fed system. The rate of fertilizer application seems to increase with decreasing production risk. The higher rates used in the upland irrigated system can possibly be explained by the fact that farmers are able to control for the risks associated with water scarcity or flooding. The average quantity of manure applied is lowest in the wetland system. Pesticide use was highest in the wetland plots in Tanzania, followed by upland irrigated plots in Kenya and wetland fields in Uganda. Use of mineral fertilizers and pesticides within and around wetlands has been identified as one of the leading factors contributing to wetland degradation (Vymazal and B ezinová, 2015). Table 2 presents a comparison on changes in the rates of fertilizer application at different levels of

Table 1. Description of variables used in the Models

Variable Name	Description	Unit of Measure
Y	Category of farmer based on ALUMS choice	5 category multinomial
X1	Commercialization Index	Index (0-1)
X2	Household Welfare	Index (0-1)
X3	Distance to the market	Km
X4	Population density	Persons/Ha
X5	Group membership	Dummy (Yes=1)
X6	Gender of household head	Dummy (Male=1)
X7	Age of the household head	Years
X8	Education level of the household head	Years
X9	Number of adult household members	Number
X10	Land owned in upland locations	Ha
X11	Livestock ownership	Tropical Livestock Units(TLU)
X12	Distance from the home to the wetland	Km
X13	Distance to nearest piped water	Km
X14	Agricultural wages	Euro

population density.

Land sizes in wetland fields averaged 0.2 ha in Kenya and Uganda and 1.4 ha in Tanzania. The smaller sizes of wetland plots relative to the rain fed plots in Kenya reflects the pressure on wetlands as a result of increased demand for land. In Uganda, plots sizes were equal across the three land use types while in Tanzania wetland plots were the largest. The smaller land sizes reflect higher degrees of land fragmentation which are mainly driven by population density. At lower population density, there is a small difference between land allocated to crop production in the two locations. As population density increases the gap widens with relatively higher preference for wetland plots. As population density increases, plot sizes in the upland locations were declining more rapidly compared to those in the wetlands.

Land use intensity was higher in the wetland plots compared to upland plots in the three countries. The longer periods of dry spells in upland plots was responsible for the longer fallow periods. Reduced fallowing is associated with population driven land pressure where farmers have to engage in all year round farming cycles in wetlands. The average number of crops in the wetland system was 5 in Kenya, 3 in Uganda and 2 in Tanzania. In Kenya, there was high crop diversity in the wetland system compared to all the other systems while in Uganda and Tanzania higher diversity was found in the upland rain fed system. Crop diversification and variation in cropping patterns are important risk management strategies among households in East African rural areas. The rain fed system is used mainly for subsistence purposes in Kenya and Uganda, while wetland and upland irrigation are used for commercial purposes. Local vegetables, mainly those in the Brassica family (Cabbages, Kales and Spinach) were the mostly grown commercial crops in the wetlands while staple cereals had the least commercialization index within the wetland system.

Table 3 presents the multinomial logistic regression results estimated using Equations 3-6. The marginal effects for the referent land use management systems are interpreted relative to the upland rain fed system (base category), which has the least risk to wetlands. These results show what drives farmers to engage in agricultural activities that expose wetlands to risk. The coefficients of X_1 and X_2 and their p-values were used to test the hypothesis that endogenous was present. Based on these parameters, we conclude that indeed commercialization was endogenous but household welfare was not.

The preference for the upland irrigated/wetland system over the upland rain fed system was significantly influenced by various factors. The marginal effect of the commercialization index was positive and significant implying that commercially oriented farmers are more likely to diversify their production by including wetland plots in their portfolio. Producing within the wetlands or engaging in irrigation on plots at the fringes of wetlands provides an opportunity for increasing yields and reducing variances and therefore irrigation is an effective risk management strategy for commercial farmers. Female farmers were more likely to engage in a system that combines upland rain fed production with wetland production. The older farmers get, the less they are likely to diversify. This could be explained by the rigorous labour intensive activities required in wetland fields which may be hard for aged farmers. Farmers who have large parcels of land in upland locations were less likely to engage in a combined upland / wetland land use system. This implies that land scarcity in the upland locations could be driving farmers into wetlands. The marginal effect for the distance from the wetland to the homestead was positive, implying that farmers who engage in wetland utilization are not necessarily those who are located closer to the wetlands. Distant farmers also tend to gain access to wetlands, putting more pressure on wetlands.

The wetland only system was significantly influenced by the distance from the homestead to the wetland, household education level and agricultural wage rate. Higher agricultural wage rates would still encourage engagement in wetland cultivation compared to upland rain fed production system. The only reason this would be possible is when there is a possibility of using family labour. This is a possibility considering the positive marginal effect of the number of household members. The effect of household education level on the probability of choosing the wetland only system over the upland rain fed system was negative, implying that the more educated farmers were, the less likely they were to engage in wetland production.

The coefficient of commercialization index and distance to piped water had a positive effect on the probability of farmers choosing the upland irrigated land use management system. The probable explanation to the first result is partly because commercially oriented farmers are more likely to choose a system where they can produce through-out the year and avoid the risk associated with erratic rainfall and flooding. The upland irrigated system satisfies these requirements and therefore is favored by commercial farmers. Group membership, had a negative effect implying that farmers producing through the upland irrigated system were less likely to cooperate with other farmers. Such farmers would rather concentrate on individual benefits and less on collective benefits, a trait that could work against collective action in wetland conservation initiatives. Household labour supply measured by the number of adult household members had a negative effect on the probability of choosing the upland irrigated system over the upland rain fed system. Given the possibility of mechanized land preparation, the system is comparatively

Table 2. Level of Agricultural Intensification Across the three Land Use

	Kenya						Uganda						Tanzania					
	UR		WET		UIRR		UR		WET		UIRR		UR		WET		UIRR	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Qty. of Fertilizer Applied (Kg/Ha)	147.1	281.6	229.5	313.1	277.1	299.7	57.5	107.1	128.2	187.2	204.0	196.3	62.7	48.0	79.3	55.2	114.3	91.4
Qty. of Manure Applied (Kg/Ha)	3457.1	6494.7	2313.6	2900.0	3511.7	2587.8	4518.5	15425.0	3926.4	5645.9	4197.7	2471.6	0.0		0.0		294.0	
Commercialization Index	0.7	0.2	0.8	0.2	0.8	0.1	0.7	0.3	0.8	0.2	0.8	0.2	0.7	0.2	0.6	0.2	0.6	0.2
Plot Size (Ha)	0.4	0.5	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.2	0.2	0.1	0.5	0.6	1.4	2.1	0.4	0.4
Number of Crops grown	4	2.8	5	2.9	4	2.4	6	3.4	4	2.1	3	4.8	3	1.5	2	1.5	1	0.95
Labour (Mandays/Ha)	6	28.9	70	119.6	18	40.2	29	23.6	56	58.7	5	12.6	38	24.4	43	44.3	11	4.6
Wages (Eur/Manday)	2.3	2.01	2.0	0.29	2.0	0.41	2.9	4.12	2.2	1.99	2.64	1.52	3.5	0.87	3.7	1.88	2.0	1.4
Months wetland left fallow Annually	-	-	3.7	2.19	-	-	-	-	2.4	2.30	-	-	-		3.1	1.78	-	-
Months Upland left fallow Annually	4.7	1.43	-	-	3.8	2.01	1.9	2.41	-	-	-		6.3	2.41	-	-	-	-
Percentage Using Pesticides	- 30	31	-	60	-	-	24	43	-	0	-	0	-	70	-	-	-	
Value of crops produced (Eur/Ha)	129	211.9	329	574.8	507	972.4	282	329.4	567	637.2	87	126.7	172	338.8	134	157.3	131	101.6

UR= Upland Rain fed; WET=Wetland; IRR=Upland Irrigated

Table 3: Multinomial Logistic Regression Results

	UR and WET MODEL			WET and UPIRR MODEL			WET MODEL			UPIRR MODEL		
	β	SE	dy/dx	β	SE	dy/dx	β	SE	dy/dx	β	SE	dy/dx
Commercialization Index	1.72***	0.286	0.14	1.5*	0.89	0.03	0.5	0.77	-0.049	2.5***	0.45	0.09
Household Welfare	0.27	1.368	0.04	10.0	9.27	0.09	8.6	9.18	0.095	-2.4	3.53	-0.23
Distance to the nearest Tarmac road	0.67***	0.030	0.006	0.07***	0.02	0.002	0.08***	0.03	0.006	0.06*	0.01	0.01
Population density	0.01**	0.005	0.01	-0.5	147.38	-0.004	-0.5	49.44	-0.005	-0.1***	0.02	-0.001
Group membership	-0.19	0.198	0.01	-0.4	0.61	-0.02	0.1	0.54	0.026	-1.1***	0.30	-0.06
Gender of household head	-0.72***	0.245	-0.07	-0.004	1.21	-0.04	1.2	1.10	0.069	-1.0***	0.44	-0.05
Age of the household head	-0.02***	0.007	-0.002	0.01	0.02	0.001	0.0	0.02	-0.00002	0.02***	0.01	-0.002
Education level of the household head	-0.07***	0.022	-0.01	-0.1**	0.04	-0.0004	-0.1*	0.04	-0.00003	-0.1***	0.02	-0.001
Number of adult household members	-0.02	0.043	-0.002	0.1	0.13	0.0004	0.1	0.12	0.001	0.005	0.07	-0.002
Land owned in upland locations	-0.33***	0.121	1.02	-116.2	19046.78	-0.05	-129.2	7629.84	-2.329	-0.4**	0.18	0.94
Livestock ownership	-0.01	0.010	0.00	0.001	0.03	-0.0003	0.01***	0.01	0.001	0.0	0.01	0.001
Distance from the home to the wetland	0.12***	0.045	0.02	0.2*	0.13	-0.003	0.3	0.13	0.009	-0.1*	0.08	-0.02
Distance to nearest piped water	-0.01	0.010	-0.002	-0.001	0.03	-0.0003	0.01**	0.03	0.0003	0.0	0.01	0.002
Agricultural wages	0.03	0.036	0.01	0.8**	0.36	0.01	0.8	0.35	0.012	-0.4**	0.18	-0.03
Constant	3.93***	0.717		1.0	2.30		0.4	2.11		6.5**	1.08	

*,**,*** coefficients are statistically significant at 0.1, 0.05 and 0.01 levels, respectively.

less labour intensive and therefore may not be constrained by lower household labour supply. Further, the distance to markets had a positive effect on the probability of choosing the upland irrigated system. In a situation where there is improved infrastructure the distance to markets may not be limiting factor because it may be overcome by other indicators of market access such as better information flow and quality of transport infrastructure. Market access has been found to enhance agricultural intensification through irrigation and use of fertilizers and pesticides (Asselen *et al.,* 2013) and also drive global patterns in deforestation and urbanization (Verburg *et al.,* 2011). These trends have a bearing on intensive wetland agriculture. Farmers who cultivate directly in the wetlands are not necessarily those who have settled close to wetlands. This may be because the rights to access wetlands are not necessarily tied to settlement but rather may be governed by other sets of (informal) rules. In Kenya for instance, although the wetland is a public resource, over the years the users have crafted informal access rights which are regulated by local elders.

Road infrustructural quality measured through the distance to the nearest tarmac road had a positive and significant effect on the choice of all the models. Improved infrastructure is considered to facilitate access to markets and therefore a drive for wetland conversion and intensive use (Verburg *et al.,* 2011). In the current study however, households that were located in remote locations furthest from good quality roads were found to also engage in farming practices with higher risk on wetlands. Since tarmac roads link rural villages to distant markets, these results indicate that there is substantial local demand for food commodities around wetlands which drive farmers into the wetland and irrigated crop production systems. Also, the returns from wetland agriculture may offset the transaction costs associated with poor infrastructure.

CONCLUSIONS

The current study has identified various postulates that may support policies that incentivize wetland users to reduce agricultural induced wetland risks. Some of these include: access to markets and drive towards agricultural commercialization will accelerate wetland degradation. Policy should focus on creating incentives for efficient commercial production and minimize effluents from inputs into wetland systems. Wetland degradation is not only caused by people living close to the wetlands. There is need for better regulation on who can access wetlands and how the wetland fields should be utilized. Poor infrastructural development may not necessarily imply better management of wetlands since local demand and subsistent production are already driving wetland use. Further, returns from wetland production are large enough to off-set the transaction costs associated with poor road infrastructure.

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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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