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BENEFITS AND DRIVERS OF FARM MECHANISATION IN RUZIZI PLAIN, EASTERN DEMOCRATIC REPUBLIC OF CONGO

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ABSTRACT

Farm mechanisation plays a major role in the agricultural sector, as it facilitates achievement of energy-intensive operations. In developing countries, policies and technical constraints have greatly affected the development of a coherent agricultural mechanisation system, that is accessible to farmers, especially the poorest. This study aimed to identify the socioeconomic factors that have driven the use of different sources of farm power in family farming in Ruzizi Plain in Democratic Republic of Congo. A random sample of 190 smallholder farmers and 30 technicians were surveyed in 2014 and 2015 in six areas of Kamanyola, Luvungi, Luberizi, Sange, Kiringye and Kiliba. Results showed that mechanisation in the Ruzizi Plain involved a range of sources of farm power, including draft animals, tractors and rototillers. Factors such as gender, attitude of the head of a household, farm productivity and profitability and non-farm incomes played a crucial role in the choice of whether or not to mechanise. Maize profitability was higher under mechanisation (US$ 535.46 ha^{-1}) compared to non-user farms (US$ 7.73 ha^{-1}). For cassava, however, there were no significant differences in profitability between mechanised and non-mechanised farms. Other benefits of mechanisation included better working conditions, reduction in the duration of farming operations, and the expansion of cultivated land parcels.

Key Words: DR Congo, farm power, profitability, South-Kivu

RÉSUMÉ

La mécanisation agricole joue un rôle majeur dans le secteur agricole, car elle facilite l'aboutissement d'opérations à forte intensité énergétique. Dans les pays sous-développés, les politiques et les contraintes techniques ont fortement affecté le développement d'un système de mécanisation agricole cohérent, accessible aux agriculteurs, en particulier aux plus pauvres. Cette étude visait à identifier les facteurs socioéconomiques qui ont conduit à l'utilisation de différentes sources d'énergie agricole dans l'agriculture familiale dans la plaine de Ruzizi en République démocratique du Congo. Un

échantillon aléatoire de 190 petits exploitants et 30 techniciens a été interrogé en 2014 et 2015 dans six zones de Kamanyola, Luvungi, Luberizi, Sange, Kiringye et Kiliba. Les résultats ont montré que la mécanisation dans la plaine de Ruzizi impliquait une gamme de sources d'énergie agricole, y compris les animaux de trait, les tracteurs et les motoculteurs. Des facteurs tels que le sexe, l'attitude du chef de ménage, la productivité et la rentabilité agricoles et les revenus non agricoles ont joué un rôle crucial dans le choix de mécaniser ou non. La rentabilité du maïs était plus élevée sous mécanisation (US$ 535.46 ha-1) par rapport aux exploitations non utilisatrices (US$ 7.73 ha-1). Pour le manioc, cependant, il n'y avait pas de différences significatives de rentabilité entre les exploitations mécanisées et non mécanisées. Les autres avantages de la mécanisation comprenaient de meilleures conditions de travail, la réduction de la durée des opérations agricoles et l'expansion des parcelles de terres cultivées.

Mots Clés: RD Congo, énergie agricole, rentabilité, Sud-Kivu

INTRODUCTION

Despite the immense potential of its agricultural sector, the Democratic Republic of Congo (DRC) exhibits poor food security indicators that call for short-, medium- and long-term solutions, capable of gradually increasing the average annual crop production above that of the demographic increase (MINAGRI-DRC, 2010). The use of mechanisation is one component of productivity improvement, provided that it is used in a coherent programme (Kumi and Taiwo, 2014; Mergeai, 2016; Sims and Kienzle, 2016). Access to an appropriate source of farm power facilitates the implementation of energy-intensive operations such as tillage, improves the performance of technically demanding operations such as sowing and weeding, increases the area under cultivation, and valorises human labour, which becomes available for less arduous or more productive tasks (Side and Havard, 2015; Amare and Endalew, 2016; Sims *et al.,* 2016).

The Ruzizi Plain has favourable physical conditions for agricultural mechanisation, such as low topographical constraints as well as considerable arable land which is estimated to be approximately 80,000 hectares (Wanders and Mwangalalo, 2010). This makes agriculture the main activity of the population located in the area, and provides jobs to most households. However, agricultural productivity in the Ruzizi Plain remains low (Walangululu *et al.,* 2012) and represents approximately one third of the average yield recorded in Asia and Latin America (FAO-UNIDO, 2008; NEPAD, 2013). This is partly due to the low use of mechanisation and other agricultural inputs by farmers, who rely on agricultural implements such as hand hoes for farming operations, despite their limitations (Bishop-Sambrook, 2005; Sims *et al.,* 2012). Further, the chores associated with manual labour in agriculture and its related low income make the agricultural sector unattractive for the youth, causing them to leave rural areas for urban centres, and, therefore, rendering the agricultural labour force inaccessible and much more expensive in the rural areas (Kumi and Taiwo, 2014; Furaha *et al.,* 2014; Otchia, 2014; Sims and Kienzle, 2015). This is particularly true in the Ruzizi Plain, where the labour is often imported from the neighbouring countries such as Burundi and Rwanda to cope with the labour shortage.

The programme to modernise agriculture in the Ruzizi Plain, implemented by the Congolese Government and its partners, aimed to alleviate this labour problem and increase agricultural productivity, as well as contribute to food security and poverty alleviation in rural areas (MINAGRI-DRC, 2010; IFDC-Catalist, 2011). However, the dissemination programme did not favour smallholder farmers, and surprisingly reduced their access to modern agricultural farm power, mainly motorised implements (Houmy, 2008; Otchia, 2013).

Nevertheless, family farming in the region by the resource-poor farmers has many advantages. It is an effective means of eradicating poverty and malnutrition, and in the majority of developing countries; it feeds the communities by providing up to 80% of their food (Dioula *et al.,* 2013; Laplante, 2014; Side and Havard, 2015; Sims and Kienzle, 2016).

The purpose of this study was to: (i) analyse the socio-economic factors dictating the use of different sources of farm power on family farms; (ii) ascertain whether the advantages of mechanisation, recognised by agricultural cooperatives and large-scale farmers, have also had an impact on family farming undertaken mainly by the poorest; and (iii) identify major constraints to agricultural mechanisation in the Ruzizi Plain in eastern DRC.

METHODOLOGY

Study site. This study was conducted in eastern DRC, South-Kivu province, in the Ruzizi Plain, which has favourable topography for mechanisation. This plain extends over three countries (DRC, Rwanda and Burundi), but only the Congolese part (which is approximately 80,000 ha of land) was covered in this study. This area is located between the foothills of the Mitumba Mountains (to the west) and the Ruzizi River (to the east), covering a distance of approximately 85 km from north to south and a width of approximately 15 km (Wanders and Mwangalalo, 2010; Walangululu *et al.,* 2012).

Agriculture and livestock farming are the main economic activities of the population. Of the 80,000 ha that constitute the Ruzizi Plain, 14,000 ha are occupied by approximately 45,000 farmers whose main activity is agriculture, and the remainder is covered with pastures (35,000 ha) and marshes (30,000 ha) (Walangululu *et al.,* 2012).

The soils are sandy, with a mixture of recent alluvial materials. Rice, maize, cassava, groundnuts, beans, soybeans, tomatoes and other vegetables are the main crops in the area (IFDC-Catalist, 2008). This plain has a semi-arid Aw4 climate, according to the climatic classification of Koppen Wladimir and is located at a low altitude (779 to 1000 m above sea level). It has annual precipitation ranging between 800 and 900 mm (Muhigwa, 2006; Balagizi *et al.,* 2010; AgMerra database).

Data collection. A survey was carried out on 190 smallholder farmers and 30 technicians (and/or owners of equipments), who were randomly selected in six zones, namely, Kamanyola, Luvungi, Luberizi, Sange, Kiringye and Kiliba. To set definitive criteria for respondents and the sample size per zone, a pre-survey was conducted to identify the main agglomerations where each type of farm power is used and its relative importance. A two-part questionnaire (one for smallholder farmers and one for technicians) was administered. The main questions concerned the socioeconomic characteristics of households that may influence the efficiency of mechanisation, sources of farm power and factors dictating their use. The impact of mechanisation on farm productivity and profitability of major staple crops, as well as its effects on working conditions were also discussed with farmers. Major technical constraints to mechanisation with respect to sources of farm power and zone as experienced by farmers were inventoried. Technicians were interviewed mainly on their qualification, availability of machineries spare parts, duration of farming operations, rental and maintenance costs, technical characteristics of the equipment, and the fuel consumption.

Data analysis. Descriptive analysis was performed on qualitative socioeconomic and technical data; while the analysis of variance was done on quantitative data, using Statistix 8.0 software (USDA and NRCS, 2007). Logistic analysis (Gujarati, 2004; Wooldridge, 2009) was used to determine the factors that

led to the use of mechanisation by smallholder farmers in the Ruzizi Plain with Eviews 5.1 software (McKenzie and Takaoka, 2007). The binary logistic distribution for the adoption decision can be specified as:

$$P_i = \frac{1}{1 + e^{-z_i}} \quad \text{Eq. ..... (1)}$$

Where:

P_i is a probability of choosing mechanisation for the i^{th} farmer and ranges from 0 to 1, e represents the base of natural logarithms and Z_i is the function of a vector of n explanatory variables and which is expressed as follows:

$$Z_i = \beta_0 + \sum \beta_i X_i \quad \text{Eq. ..... (2)}$$

The explicit binary logit model as used in this study can be expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + \mu \quad \text{Eq. .....(3)}$$

Where:

Y represents the probability for an individual i to adopt mechanisation (1 if the farmer adopt and 0 if otherwise); X_i are the explanatory variables including the characteristics of the farmer and farm attributes; β_0 is the intercept; $\beta_{(1\text{-}k)}$ are the coefficients for the respective variables in the logit function and u is error term (Greene, 2003).

The choice of independent variables used in this study was based on literature review and socio-economic theory governing the adoption of agricultural innovations as well as a pre-survey conducted in the study area. Variables included in the logit model were of two types; technical and socioeconomic. Technical variables comprised the ease of access to equipments, cost of equipment rental, farm productivity, mode of access to equipment, quality of plowing and total production. The socioeconomic variables included gender, non-farm incomes, age of the head of the household, farmer's experience, field-to-house distance, workforce (presence of affordable hired labour), household size, level of education of the head of the household, highest level of education within the household, the head of household's main activity, the mode of access to agricultural land and the total farm size.

The profitability of the two major staple crops (cassava and maize) was assessed by the difference between the production (expressed in monetary value) of the farm's previous harvest and the total cost incurred in its production. The estimation of the total cost incurred in production included the cost of inputs such as seeds and fertilisers, land preparation, sowing, weeding, harvesting, post-harvest operations and transport. To evaluate production, the total quantity harvested from farmer field was estimated in terms of 50 kg bags produced per "Carré" or per hectare (1 "Carré" = 625 m^2; 1 ha = 16 "Carrés"). The selling prices on the local markets were used to estimate the value of the total farm production.

Analysis of variance (ANOVA) allowed comparison of the means with respect to the sources of farm power used to carry out cultural operations. Fisher's least significant difference (LSD) test allowed separation of means whenever significant differences were observed.

RESULTS

Socio-economic characteristics of households. Table 1 shows the socio-economic characteristics of farming households in the Ruzizi Plain that may have a positive or negative influence on the use of mechanisation on their farms. In the Ruzizi Plain, family farming is more commonly practiced by poorly educated people (with illiterate people occupying up to 41.1%), the rate of membership in agricultural cooperatives is very low (24.4%). Monoculture is dominant

TABLE 1. Socio-economic characteristics of household farmers in the Ruzizi plain, eastern DR Congo

Variables	Modality	Proportion (%)
Level of education	Without formal education	41.1
	Primary education	25.6
	High school	28.9
	University	4.4
Membership in agricultural cooperatives	Member	24.4
	Non-member	75.8
Mode of acquisition of agricultural land	Inheritance	32.2
	Purchase	21.1
	Leasing	46.7
Cropping system	Monoculture	58.9
	Intercropping	41.1
Chemical fertiliser	Access	2.2
	No access	97.8
High yielding varieties	Access	15.0
	No access	85.0
Main crop	Maize	51.1
	Cassava	48.9
Access to farm power	Access	54.4
	No access	45.6
Access to storage facilities	Access	23.7
	No access	76.3
Access to agricultural credit	Access	0.0
	No access	100
Market satisfaction	Satisfied	0.0
	Not satisfied	100

(58.9%), especially for cereals (maize, rice, sugar cane); while grain legumes are mainly intercropped with tuber crops (cassava-groundnut, cassava-soybean) and cereals (maize, sorghum).

Mineral fertilisation of soils is virtually non-existent (2.2%); while 85% of households do not have access to improved varieties of the different staple crops and, therefore, rely on landraces, which are often lower yielding and poorly adapted to mechanisation. Cultivation of staple commodities (cassava and maize), with a low rate of market participation is dominant in family farming, which rarely uses industrial and export crops. Rice, the main cash crop, is still largely under manual cultivation.

None of the surveyed households had been trained in terms of mechanisation, and most of them had limited access to agricultural credit that could facilitate access to modern agricultural farm power. In the Ruzizi Plain, it was the market that determines the price of

agricultural products, at the expense of producers, and this price fluctuates considerably with the harvest period. Low prices of agricultural products are mainly due to a lack of adequate storage and processing facilities.

Sources of farm power for agricultural activities. Mechanisation in the Ruzizi Plain can be referred to as a set of possible sources of farm power, including draft animals and motorised equipments such as tractors and tillers. Manual labour remains the most commonly used for farming activities, due to the lack of a complete mechanisation chain and/or lack of expertise required for the use of other accessories (seeders, fertiliser and pesticide spreaders, etc.).

On mechanised farms, modern farm power is used exclusively for land preparation (opening, plowing, harrowing and burial of residues) and for transport. Other farming activities are still performed by hand, using family labour and/or hired labour depending on the farm size. In the analysis of the sources of farm power, manual labour was not taken into account as it remains present on all farms, in spite of the presence of other forms of mechanisation.

The source of farm power in the Ruzizi Plain varies with zones (Table 2). Except for the manual labour, the tractor is the only source of farm power used for cropping operations in Luvungi, Kiliba and Kamanyola where topography is favourable, and this mainly for cassava and maize crops. Rototillers are only found at Luberizi and Kiringye in the marshes and along rice perimeters.

Animal traction is only used at Sange where draft animals (trained cattle) are available. At Sange, this source of farm power is used by 41.8% of the households using mechanisation, while the majority (58.2%) use tractors, which they consider to be faster and more efficient than the traditional draft animal practiced in that area for many years.

Drivers of the use of different sources of farm power. The use of mechanisation in farming operations depends on several factors, including economic, social and technical, among other factors. The key factors identified by the logit model are presented in Tables 3 - 5 for tractors, tillers and draft animals, respectively. Increases in yield (P=0.0084), off-farm incomes (P<0.001), gender (P = 0.0082) and the attitude of the head of the household (P=0.0430) influence the probability of tractor use on family farms (Table 3). The prediction test of the second estimate of the logit model shows that these explanatory variables influenced the use of tractor up to 88.00%.

The results in Table 4 show that the use of tillers for farming in the Ruzizi Plain is significantly influenced by the attitude of the head of the household towards mechanisation (P = 0.0107), off-farm incomes (P = 0.0006) and gender (P = 0.0007). The second estimate of the logit model shows that these variables contribute significantly to the use of tillers in family farms, by up to 82.00%. The other variables had no significant influence on tiller use.

TABLE 2. Farm power sources other than humans used in the Ruzizi plain, eastern DR Congo

Zones	Sources of farm power	Proportion (%)
Kamanyola	Tractor	100
Kiliba	Tractor	100
Kiringye	Rototiller	66.7
	Tractor	33.3
Luberizi	Rototiller	72.7
	Tractor	27.3
Luvungi	Tractor	100
Sange	Draft animal	41.8
	Tractor	58.2

TABLE 3. Estimated logit model of variables driving the use of tractors as a power source in farming operations in Ruzizi plain, eastern DR Congo

Variables	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-5.775084	2.232675	-2.586621	0.0097***
Ease of access to farm power	-1.265917	0.867826	-1.458722	0.1446
Mode of acquisition of land	1.105516	0.721861	1.531481	0.1257
Leasing cost of farm power	0.641228	0.848713	0.755529	0.4499
Head of household's main activity	2.372224	1.226068	1.934822	0.0430*
Production increase	1.118788	0.777668	1.438644	0.1503
Yield increase	2.165519	0.821467	2.636159	0.0084**
Mode of access to farm power	0.883405	1.071432	0.824509	0.4097
Quality of plowing	1.106362	0.944010	1.171980	0.2412
Gender	-2.944629	1.113826	-2.643706	0.0082**
Off-farm incomes	4.277057	1.027819	4.161292	0.0000***
Age	-0.017934	0.029048	-0.617391	0.5370
Experience in farming	0.036566	0.035926	1.017797	0.3088
Field-to-house distance	-0.002256	0.006863	-0.328664	0.7424
Workforce	-0.801348	0.616899	-1.298993	0.1939
Household size	0.093821	0.113612	0.825795	0.4089
Education level of head of household	-0.087005	0.262391	-0.331585	0.7402
Highest level of education within the household	0.045968	0.289113	0.158996	0.8737
Total Production	0.000158	0.000241	0.654200	0.5130
Cultivated area	1.80E-05	4.61E-05	0.390844	0.6959

* = Significant, ** = highly significant, *** = very highly significant at the P-value threshold of 5%

It should be noted that tillers and draft animals were more commonly used in rice cultivation, i.e., by 32.30 and 16.10% of the rice farmers, respectively. Nevertheless, the Chi-square test showed no statistical relationship between cultivars and/or cultivated species, and the source of farm power used to carry out the farming operations. The use of draft animals in family farming as a source of farm power was significantly and positively influenced by off-farm incomes (P=0.0001) and the increase in yield (P=0.0185) (Table 5). The results of the prediction test of the logit model estimate of factors influencing the use of draft animals as a source of farm power were influenced up to 85.00% by these two variables (Table 5).

Gender and agricultural mechanisation. Women increasingly adopted the use of different sources of farm power in farming operations more than men counterparts (Table 6). With respect to tractors, women constituted 68.9% of users, compared to only 29.1% of men. For manual cultivation, women constituted only 24.4% of users, compared to 65.5% of men. Rototillers were more commonly used by women than by men, i.e., 4.4% *versus* 3.6%. A similar trend was observed for draft animals, i.e., 2.2% versus 1.8% for women and men, respectively.

Agricultural mechanisation and working conditions. The duration of work depends significantly on the source of farm power used for cropping operations (P<0.001), but was not influenced by location. The results showed that it takes an average of 19.3 hr or 5 working days to plow 1 ha if draft animals were used. However, if a tiller was used, it takes an average

TABLE 4. Estimated logit model of variables driving the use of rototillers as a source of power in family farming in the Ruzizi plain, eastern DR Congo

Variables	Coefficient	Std. Error	z-Statistic	Prob.
Constant	-4.949176	2.093995	-2.363509	0.0181*
Easy access to farm power	0.562507	0.751131	0.748879	0.4539
Mode of acquisition of land	0.787636	0.661854	1.190045	0.2340
Leasing cost of farm power	-0.052537	0.713335	-0.073650	0.9413
Farmer as the household head	3.066315	1.201185	2.552742	0.0107*
Production increase	-0.473680	0.692338	-0.684175	0.4939
Yield increase	-0.064845	0.699214	-0.092740	0.9261
Mode of access to farm power	0.104859	1.242127	0.084419	0.9327
Quality of plowing	0.500372	0.849269	0.589180	0.5557
Gender	-4.055291	1.192073	-3.401880	0.0007***
Off-farm incomes	4.041876	1.178778	3.428870	0.0006***
Age	0.007000	0.038629	0.181201	0.8562
Experience in farming	0.023929	0.040797	0.586533	0.5575
Field-to-house distance	0.003905	0.007541	0.517843	0.6046
Workforce	-0.468252	0.645056	-0.725909	0.4679
Household size	0.045962	0.123243	0.372933	0.7092
Education level of head of household	-0.202226	0.276137	-0.732340	0.4640
Highest level of education within the household	-0.092947	0.301957	-0.307815	0.7582
Total Production	0.000275	0.000281	0.979142	0.3275
Cultivated area	6.78E-06	5.11E-05	0.132836	0.8943

* = Significant, ** = highly significant, *** = very highly significant at the P-value threshold of 5%

of 5.5 hr compared to only 1.6 hr per ha if a tractor is used (Table 7).

Table 8 shows that the total farm size owned by households in the Ruzizi Plain varied significantly with the zone ($P<0.001$) and significantly influences the decision whether to use mechanisation ($P<0.001$). It was observed that households using a tractor to carry out farming operations had larger farms. These households had an average of 18,333 m^2 (1.8 ha) at Kamanyola and 10,000 m^2 (1 ha) at Kiliba, Kiringye, Luvungi and Sange. Those who used a tiller own an average of 1 ha at Kiringye and 15,000 m^2 (1.5 ha) at Luberizi. On the other hand, those using draft animals owned an average of 0.2 ha, mainly at Sange.

Economic profitability of mechanisation. Farm productivity varied significantly with the use of mechanisation ($P<0.001$) and the crop under cultivation (Table 9). Consequently, the profitability was higher with use of mechanisation (US $ 535.5 gain ha^{-1}) for maize compared to non-user farms (US $ 7.7 gain ha^{-1}). For cassava, on the other hand, there were no significant differences in profitability between farmers using modern sources of farm power and those relying exclusively on manual cultivation. Maize crop profitability was, therefore, more sensitive to mechanisation effects than cassava crop profitability.

Technical constraints. Results in Table 10 show that the level of training of technicians in Ruzizi Plain was low, regardless of sources of farm power. It was observed that none of the technicians assisting farmers to perform farming operations using draft animals had

TABLE 5. Estimated logit model of variables driving the use of draft animals in family farming in the Ruzizi plain, eastern DR Congo

Variables	Coefficient	Std. Error	z-Statistic	Prob.
Constant	0.660199	1.437411	0.459297	0.6460
Easy access to farm power	-0.265791	0.608411	-0.436861	0.6622
Mode of acquisition of land	-0.816149	0.588559	-1.386690	0.1655
Leasing cost of farm power	0.596416	0.661591	0.901487	0.3673
Farmer as the household head	0.704118	0.766284	0.918873	0.3582
Production increase	-0.034957	0.699528	-0.049973	0.9601
Yield increase	1.823826	0.774302	-2.355447	0.0185*
Mode of access to farm power	1.112878	0.886641	1.255161	0.2094
Quality of plowing	-1.007368	0.735573	-1.369500	0.1708
Gender	-0.252792	0.712681	-0.354706	0.7228
Off-farm incomes	2.522028	0.650986	-3.874169	0.0001***
Age	0.033827	0.044281	0.763922	0.4449
Experience in farming	-0.054574	0.046540	-1.172603	0.2410
Field-to-house distance	0.011980	0.007972	1.502669	0.1329
Workforce	0.676283	0.717960	0.941952	0.3462
Household size	-0.208771	0.134158	-1.556154	0.1197
Education level of head of household	0.225006	0.314477	0.715493	0.4743
Highest level of education within the household	-0.240732	0.334311	-0.720083	0.4715
Total Production	-5.76E-05	0.000307	-0.187949	0.8509
Cultivated area	-4.19E-05	5.58E-05	-0.751078	0.4526

* = Significant, ** = highly significant, *** = very highly significant at the P-value threshold of 5%

TABLE 6. Influence of gender on the use of mechanisation in the Ruzizi plain, eastern DR Congo

Gender	Sources of farm power	Proportion (%)
Women	Draft animal	2.3
	Manual	24.4
	Rototiller	4.4
	Tractor	68.9
Men	Draft animal	1.8
	Manual	65.5
	Rototiller	3.6
	Tractor	29.1

been formally trained. The trend was the same for tillers for which only a quarter of technicians were formally trained, but did not complete the training programme. For tractors, on the other hand, approximately 26% of technicians assisting farmers in farming operations were trained but only 13% successfully completed the training programme. Table 11 indicates that the greatest constraint pertaining to the use of draft animals as perceived by technicians and owners of equipments was the lack of qualified personnel (40%) and absence of spare parts (37.5%). For tractors, the absence of spare parts was the greatest constraint (59.3%). The trend was the same for tillers (45%). The greatest

TABLE 7. Influence of the farm power source on working duration (hr ha^{-1}) in the Ruzizi plain, eastern DR Congo

Sources of farm power	Kamanyola	Kiliba	Kiringye	Luberizi	Luvungi	Sange	Overall mean
Draft animal	-	-	-	-	-	19.3±3.6	19.3±3.6[a]
Rototiller	-	-	7±0.0	4±0.0	-	-	5.5±1.7[b]
Tractor	2.1±1.4	1.7±1.0	1.2±0.8	1.6±0.9	1.4±0.8	1.5±0.0	1.6±1.0[c]

a, b, c : Means followed by the same letter are not significantly different at the 5% P-value threshold

TABLE 8. Influence of cultivated area (in m^2) on the choice of farm power source used in the Ruzizi plain, eastern DR Congo

Sources of farm power	Kamanyola	Kiliba	Kiringye	Luberizi	Luvungi	Sange	Mean (m^2)
Draft animal	-	-	-		-	2,109±572	2,109±572[b]
Rototiller	-	-	10,000±0.0	15,000±0.0	-	-	12,500±2,887[a]
Tractor	18,333±7,177	10,000±0.0	10,000±0.0	2,187±442	10,000±0.0	10,000±0.0	11,087±3,767[a]
Mean (m^2)	18,333±7,177[a]	10,000±0.0[b]	10,000±0.0[b]	8,594±7,402[b]	10,000±0.0[b]	8,500±3,078[b]	10,451±4,328

a, b, c : Means followed by the same letter are not significantly different at the 5% P-value threshold

TABLE 9. Influence of the use of mechanisation and main crop grown on the cost of plowing, the total cost of production and the production obtained (presented as a value) in the Ruzizi plain, eastern DR Congo

Main crop	Cost of plowing (CF ha^{-1})	Production cost (CF ha^{-1})	Outcome (CF ha^{-1})	Benefit (CF ha^{-1})
Non-users				
Maize	132,816.7a	389,550.0a	396,666.6c	7,116.6c
Cassava	125,241.7a	392,025.0a	706,383.3b	314,358.3b
Users				
Maize	83,552.5b	375,215.0a	867,837.5a	492,622.5a
Cassava	80,255.0b	387,051.5a	725,005.0b	337,953.5b

a, b, c: Means of variables followed by the same letter are not significantly different at the 5% probability threshold according to the LSD(least significant difference) test. CF = Congolese francs. During the survey period, US$ 1 was equivalent to 900 Congolese francs.

TABLE 10. Level of training for technicians with respect to different farm power sources in Ruzizi plain, eastern DR Congo

Types of farm power	Level of training	Proportion (%)
Draft animals	None	100.0
Rototiller	A3	25.0
	None	75.0
Tractor	A2	13.0
	A3	13.1
	None	73.9

A3 = Low level of education (short cycle: Primary education + 5 years); A2 = successful completion of secondary humanities education (long cycle: Primary education + 6 years)

constraint experienced by technicians in the Ruzizi Plain regardless of zones was the difficulty of finding spare parts (51%). In addition, there are regular breakdowns (26.9%) and high fuel costs (26.9%) (Table 12).

DISCUSSION

Influence of farmers' socio-economic characteristics on mechanisation. Most of smallholder farmers' socio-economic characteristics in the Ruzizi Plain were not favourable to farm mechanisation (Table 1).

Firstly, farmers in the Ruzizi Plain were poorly educated and, therefore, slow to understand and engage in agricultural innovations. Many studies have previously shown that adoption of agricultural innovations increases with farmer education level (Abdulai and Huffman, 2005; FAO and UNIDO, 2008; Adégbola *et al.* 2008, Sauer and Zilberman, 2009; Gregory and Sewando, 2013; Dontsop-Nguezet *et al.,* 2016; Mondo *et al.,* 2019). They explained that trend by the fact that producers with a high education level had a propensity to get information on new technologies that may be profitable, and which translate into a higher probability of engaging in new technologies. It can as well be explained by the fact that most of educated farmers in rural areas are targeted by non government organisations (NGOs) and are more involved in farmers' associations (Mondo *et al.,* 2019).

TABLE 11. Major constraints encountered by technicians or owners of agricultural equipments in the Ruzizi plain, eastern DR Congo

Sources of farm power	Major constraints	Proportion (%)
Draft animal	Shortage of qualified personnel	40.0
	Regular outages	22.5
	Absence of spare parts	37.5
Rototiller	Absence of spare parts	45.0
	High fuel cost	20.0
	Regular outages	15.0
	Shortage of qualified personnel	20.0
Tractor	Absence of spare parts	59.3
	High fuel cost	19.8
	Regular outages	20.9

TABLE 12. Constraints to mechanisation in different zones of the Ruzizi plain, eastern DR Congo

Constraints	Kamanyola	Kiliba	Kiringye	Luberizi	Luvungi	Sange	Mean
Absence of spare parts	43.5	53.4	67.8	62.8	41.3	37.3	51.0
High fuel cost	13.4	36.7	32.2	37.2	18.4	23.5	26.9
Regular outages	35.9	9.9	-	-	30.7	30.9	26.9
Shortage of qualified personnel	7.2	-	-	-	9.6	7.9	8.2

While working on farm mechanisation in Mali, Houmy (2008) clearly demonstrated that slowness to adopt mechanisation was in part due to low education. He explained that education increases the level of understanding and the ability to apply and disseminate instructions from extension services.

In addition, the rate of membership in famers' cooperatives/associations was very low in Ruzizi Plain, reducing the exposure of farmers to new agricultural innovations. It was widely demonstrated that membership to farmers organisations was crucial to boost farmers adoption of new technologies. This is because farmers' associations promote access to information about innovation through other members (Marra *et al.,* 2003), as well as facilitates the contact of farmers with support structures or extension workers, who have innovative information (Ainembabazi *et al.,* 2015; Wossen *et al.,* 2017).

Smallholder farmers have limited/no access to financial credit in the Ruzizi Plain, which limits access to mechanisation as this innovation is capital-intensive. As reported by several studies, access to credit is important in adoption of agricultural innovations, as it makes factors of production accessible to producers, and thus improves their living conditions (Ouédraogo, 2003; Allogni *et al.,* 2004). Wossen *et al.* (2017) revealed that the impact of extension services on poverty reduction and cooperatives on technology adoption is significantly stronger when smallholders access credit.

The limited access to financial credit as well as the absence of government subsidies on farm inputs (Furaha *et al.,* 2016) could also explain the low use of other factors of production such as improved varieties and chemical fertilisers. Unfortunately, it would be difficult to take full advantage of farm mechanisation without other agricultural inputs and adequate farming practices as it is being done by smallholder farmers in the Ruzizi Plain (Aune *et al.,* 2019).

Furthermore, the intercropping system largely used in family farming for staple food crops in Ruzizi Plain is not easy to mechanise due to the additional labour required and the added complexity of management (e.g. harvesting and handling of mixed grain) (Fletcher *et al.,* 2017).

Sources of farm power and factors dictating their use. The rate of utilisation of agricultural mechanisation and the choice of the source of farm power to be used for farming operations in the Ruzizi Plain, differed from one area to another due mainly to natural factors such as soil and topography and availability of farm power sources in the farmer vicinity (Table 2). For example, rototillers were mostly used in marshes for rice cultivation where tractors and draft animals were not suitable; while animal traction was only practiced where draft animals were available. This supports findings by Sims and Kienzle (2016), who demonstrated that mechanisation in sub-Saharan Africa is by nature site-specific and thus, generalisations are always difficult to make.

Regardless of the farm power, four factors dictated the decision on whether to mechanise. These are the farm productivity and profitability, off-farm incomes, gender and the attitude of the head of the household (Tables 3-5). It is obvious that any agricultural technology with potential to improve yield and income in the short-term is easily adopted by farmers, even for the most sceptical (Adekunle *et al.,* 2016).

Findings from the present study agreed with the positive relationship between off-farm incomes and agricultural innovation uptake by households in South-Kivu as established by Dontsop-Nguezet *et al.* (2016). In this study, we realised that farmers with income-generating jobs, other than agriculture use more machines in cropping operations because they did not have enough time for farming and, thus substitute this with mechanisation. Additionally, they have sufficient financial means to pay the costs related to mechanisation.

This study showed that women use more farm mechanisation than men due to several reasons, as detailed in the section below on gender and farm mechanisation. These include their perception of farming operations as a burden because they have also to carry out housework (Van Eerdewijk and Danielsen, 2015). In addition, their high participation in agricultural cooperatives (Mushagalusa *et al.,* 2020) makes them informed on new innovations and facilitates access to financial and technical subsidies by NGOs. Another key reason is that mechanisation in Ruzizi Plain was mostly promoted on subsistence crops traditionally practiced by women (Doss, 2002).

Although men used less farm mechanisation than female counterparts, their attitude as head of household was crucial. We realised that households, where men had agriculture as the main economic activity, adopted more farm mechanisation than those where men were not much involved in farming activities. This supports the general assumption that in Africa, men ultimately bear direct or indirect influence on women decision. For instance, Adekunle *et al.* (2016) showed that in Kenya, agricultural development planners have been reported to target men deliberately for agricultural training, arguing that men are the household heads, and therefore, the major decision makers for productive resources and also because tasks traditionally performed by men, such as land

preparation, harvesting, and processing are the easiest to mechanise.

Gender and farm mechanisation. As highlighted in the section on drivers of mechanisation, gender was a key factor which influenced the likelihood of using mechanisation in the Ruzizi Plain. Women were more inclined to use mechanisation than their male counterparts (Table 6). Most of the time, women were obliged to balance their labour between farming activities and housework, which is not always easy; therefore, mechanisation was a good alternative to carry out field work. Van Eerdewijk and Danielsen (2015), who analysed gender issues with respect to the demand for farm power, concluded that women considered tillage and land preparation, weeding, post-harvest operations and transport as farming activities that contribute to their labour burden, and therefore, they prefered mechanisation for their execution. Amare and Endalew (2016) reached a similar conclusion that the introduction of medium or low level mechanisation implements and technologies enabled lighten burden of women, who contribute most of the labour for agricultural production in Ethiopia, and released them to be used for other on, off and non-farm activities. We are tempted to assume that the same perception of farming activities as a burden for women who have to carry out other family tasks could have attracted the Ruzizi Plain women to farm mechanisation.

In addition, in Ruzizi Plain, women are more active in agricultural cooperatives than men and thus, they can easily access information, credit, financial and technical assistance from non government organisations (NGOs) promoting mechanisation. In fact, a recent study by Mushagalusa *et al.* (2020) showed that, women constitute more than 60% of members in agricultural cooperatives and associations in the South-Kivu. These would increase their likelihood of adopting agricultural technologies, including mechanisation (Mergeai, 2016). Jeremiah *et al.* (2007) reported that the contact of farmers with community-based organisations (CBOs), NGOs and farmer groups are very instrumental in facilitating the delivery of agricultural innovations to farmers and thus facilitate their adoption.

The low interest of men may be attributed to the fact that in the Ruzizi Plain, mechanisation is mainly used on staple crops with low market participation. Previous experiences showed that men were usually attracted to cash crops than women who were more attached to subsistence crops (Doss, 2002; Hill and Vigneri, 2014; Zakaria, 2017). In addition, rice which is the main cash crop attracting men in this area is still largely under manual cultivation and thus, men do not perceive direct interest of turning to mechanisation.

Effects of mechanisation on working conditions and land expansion. The source of farm power used had a significant influence on the working duration and, therefore, the timeliness of operations (Table 7), which is important for a yield increase of up to 70% (Verma, 2006). It was also observed, that there was a positive relationship between farm size owned by the households and choice of farm power (Table 8); which supports previous reports on mechanisation. For example, Bishop-Sambrook (2005) showed that in sub-Saharan Africa, families owning 1 to 2 ha use mainly draft animals for farming; while those owning more use preferentially tractors. On the other hand, Mergeai (2016) concluded that farmers with abundant land have greater ease of access to harnessed or even motorised cultivation, probably due to their more eligibility to financial loans and subsidies than the one with smaller plots. An economic analysis on farm power by Aune *et al.* (2019) in Mali showed that animal traction is the most appropriate mechanisation below six ha; while above this land size, it becomes increasingly interesting for the farmers to invest in motorised implements.

In regions where land is available, mechanisation based on human energy is a serious handicap to the extension of cultivated land (Bishop-Sambrook, 2005). This is particularly true for the Congolese side of the Ruzizi Plain where Furaha *et al.* (2016) showed that contrary to neighbouring countries like Rwanda and Burundi which were currently facing scarcity of lands, only 22.4% of available lands for the Congolese side were exploited. This made it possible to increase crop production both by expanding surfaces (which required unambiguously promotion of mechanisation) and by increasing productivity per unit area (by promoting adequate agronomic practices) in the Ruzizi Plain to improve food and income security indicators in the area.

Benefits of mechanisation. The cost incurred in production depended significantly on the source of farm power used as well as the grown crop (Table 9). The cost decreased when motorised services were used in agricultural production; while the productivity increased in mechanised farms (Table 9). Similar trends in smallholder farming were reported in India, and which were attributed to the improvement in timeliness of operations, which reduced farm and post-harvest losses, provided better quality work and more efficient utilisation of inputs, as well as the effects of economies of scale (Singh, 2005; Verma, 2006). In Mali, Aune *et al.* (2019) showed that use of mechanisation results in earlier and uniform crop establishment, facilitate microdosing application, timelier weeding, higher yields, better economic return and reduced labour demand.

Previous reports on the opportunity of mechanisation in the Ruzizi Plain showed that manual farming is constrained by several factors including the complete invasion of the region by weeds, the high wages for the labour force, limited transport options (Wanders and Mwangalalo, 2010; Breman and Akonkwa, 2012) and the scarcity of labour force as young people prefer to work in non-agricultural sectors (Furaha *et al.,* 2014). Therefore, use of mechanisation is less costly than hiring people for farming activities. Referring to weeds for example, Wanders and Mwangalalo (2010) showed that the rhizome weeds that have invaded the Ruzizi Plain cannot be removed by hand; by contrast, a tractor equipped with a rigid-toothed harrow is capable and more effective.

In addition to decreasing the production cost, farm mechanisation improved the productive capacity of smallholder farms and consequently, their income (Singh, 2005; Verma, 2006; Girard and Dugué, 2010; Reid, 2011; Amare and Endalew, 2016). For example, the use of tillers in Nigeria resulted in an overall yield increase of approximately 70% for some crops (Faleye *et al.,* 2012).

While analysing the economic benefits of mechanisation on the two major staple crops (maize and cassava) in Ruzizi Plain, we found that maize crop profitability was more sensitive to mechanisation effects than cassava. This would be due to the extra cost incurred, especially for ridging, mounding and post-harvest operations needed for cassava but that are less important in maize production. The reported profitability for maize is likely to be due to an improvement in plowing quality that positively affects the development and productivity of this crop, as opposed to a reduction in plowing costs. Ouedraogo (2005) showed that under harnessed crop conditions, deep plowing (15 cm deep or more) of less depleted Ferralitic soils at the beginning of the growing cycle allows a yield increase of more than 50% for rice, 25-46% for maize, 11-23% for groundnuts, and 15-36% for sorghum in Burkina Faso. This can be explained by the fact that mechanisation has a positive effect on soil tillage and, therefore, affects the quality of the soil by loosening it, allowing better long-term infiltration and infiltrability of water into the soil, as well as effective root development and, therefore, the effective management of soil water. Reid (2011), analysed productivity

due to mechanisation in the United States since the mid-1800s, and concluded that improved labour efficiency, higher production input efficiency, improved timeliness of operations, and the implementation of more sustainable production systems were the four major factors that explained the contribution of mechanisation to the agricultural sector.

Major technical constraints to mechanisation. Several reports on farm mechanisation indicate that the scarcity of agricultural mechanisation specialists in producer-support structures and at research levels is a serious handicap for information dissemination, the training of manufacturers and users, and technological innovation (Adekunle *et al.,* 2016; Amare and Endalew, 2016). This is a serious constraint to efficiency of farm mechanisation in the Ruzizi Plain as the Congolese Government introduced motorised equipments, including high capacity tractors before adequate training of technicians and other beneficiaries. Although the government did not have a coherent mechanisation programme, it bought equipments and distributed them to individuals, organisations and agricultural cooperatives with limited or no experience in farm mechanisation. This resulted in common constraints as highlighted by technicians and owners: regular breakdowns, absence of spare parts, shortage of qualified personnel and high fuel cost. Adekunle *et al.* (2016); Amare and Endalew (2016) reported similar trends in other parts of Africa, and asserted that mechanisation as implemented in African countries is not adapted to socioeconomic and technical realities of farmers, and the government structures, leading to low impacts or in some cases worsened beneficiaries livelihoods by increasing debts, cost of fuel and repair of equipments, unemployment and disparity in incomes. Therefore, the introduction of mechanisation in a given area should be initiated locally by empowering small-scale and local actors to produce agricultural implements and processing machineries adapted to local reality and that could be modified and repaired locally without or with limited external inputs.

CONCLUSION

It can be concluded from this study that (i) the source of farm power used in Ruzizi Plain in the DR Congo differs from one area to another and is dictated by accessibility and topography; (ii) the factors that influenced the use of motorised farm power (tractors and tillers) are gender, off-farm incomes, the attitude of the head of the households toward technological innovation, and yield increases; (iii) the use of draft animals is influenced by farm productivity and off-farm incomes; (iv) the cost of production decreases when mechanisation is used compared with when only waged labour is used, and (v) the greatest constraint for technicians is the inaccessibility of spare parts and their low level of training. From these results, agricultural mechanisation can provide an opportunity to improve the welfare of the households in the Ruzizi Plain as it increases the income of users by offering them the possibility to increase the yield and the cultivated area as well as provides good working conditions.

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