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PROMOTING PRODUCTION AND MARKETING OF ROOT CROPS IN SOUTHERN AFRICA IN A CHANGING CLIMATE USING INTEGRATED AGRICULTURAL RESEARCH FOR DEVELOPMENT (IAR4D) PATHWAY

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ABSTRACT

Climate change is expected to have adverse impacts on smallholder farmers whose livelihoods depend on rain-fed agriculture. In fact, climate change is expected to continue to pose a serious threat to agriculture in southern Africa as annual rainfall amounts are expected to decline and temperatures are expected to increase. Studies show that the impacts will depend on the extent of smallholder farmers' adaptation in response to climate change and variability. However, despite numerous extension efforts and repeated past maize crop failures, smallholder farmers in southern Africa continue to show preference to maize over other drought resistant crops. The low rate of adoption of drought resistant crops in response to the changing climate has been blamed on the linear non-participatory manner in which agricultural research and development efforts are organised. The present study seeks to establish whether reorganising research and development in an integrated manner known as Integrated Agricultural Research for Development – (IAR4D) would contribute towards the adoption of drought resistant crops and also improve household incomes. The study used cross-sectional household survey data collected from Zimbabwe, Mozambique and Malawi to determine the local average treatment effect of adopting drought resistant crops (in this case root and tuber crops) on household income. A multistage sampling technique was used to sample 600 households from the three countries. The data was collected as part of an end-line survey in the proof of IAR4D concept from conventional, treatment and control sites in each of the three countries. Results from the analysis show that smallholders in IAR4D villages which produced and sold root and tuber crops had higher household incomes than farmers who did not produce and sell these crops. The results also show that smallholder farmers who participated in IAR4D activities adopted roots and tuber crops to militate against the effects of climate change and variability. The study concluded that IAR4D could effectively deal with institutional and technical issues that constrain smallholders from adapting to climate change and variability. Furthermore, climate change adaptation strategies could be easily promoted using an integrated agricultural research for development approach.

Key words: Climate, adaptation, marketing, agriculture, innovations Roots and tubers, Southern Africa, IAR4D

INTRODUCTION

Southern Africa is going to be among the regions hardest hit by the effects of climate change and variability [1, 2, 3]. While the impacts of climate change cut across many sectors, agriculture remains the most susceptible due to the predominance of rain-fed agriculture. In fact, various studies show that climate change is already having strong adverse impacts on poor smallholder farmers who derive their livelihoods from rain-fed agriculture in the region [2, 4, 5]. Boko *et al*. [6] predict that in southern Africa, mean annual temperature is going to rise; the frequency and intensity of cyclical droughts would increase while the overall rainfall pattern will decrease. Studies show that the changing climate is already negatively impacting on rain-fed per capita food production, household food security and poverty reduction efforts in southern Africa [5, 6]. Most southern African economies hinge on rain-fed agricultural production with the sector contributing 30-40% of the Gross Domestic Product and providing livelihoods to over 70% of the population [5, 7]. Smallholder farmers in southern Africa are vulnerable to climate change because of low adaptive capacity and the presence of multiple stressors such as endemic poverty, dysfunctional market institutions, soil fertility decline and complex climate systems [8]. Literature shows that decrease in rainfall as a result of climate change will increase food insecurity [9, 10,11]. As such, failure to manage climate change by developing countries will be met with a sharp decline in food production, famine and unprecedented setbacks in the fight against deepening poverty. This evidence suggests that smallholder farmers can only be less vulnerable to the effects of climate change if they adapt.

A number of climate change adaptation strategies are being considered and proffered to farmers in southern Africa to reduce the impact of climate change on smallholder farmers [9, 12, 13]. The cropping systems based climate change adaptation strategies are largely centered on improving water use efficiency to deal with a drier climate [14]. Farmers have to adapt their cropping systems towards more drought tolerant crops. Root and tuber crops, which are more drought tolerant, present a potentially feasible adaptation strategy. However, maize continues to dominate regional farmers' cropping system despite repeated maize harvest failures in the recent past. As noted by Mapfumo and Giller [14], smallholder farmers commit over 80% of arable land to maize while the remaining 20% is shared amongst legumes, root tubers and small grains. This research seeks to establish whether there is scope among smallholders to improve livelihoods through the increased production and marketing of root and tuber crops.

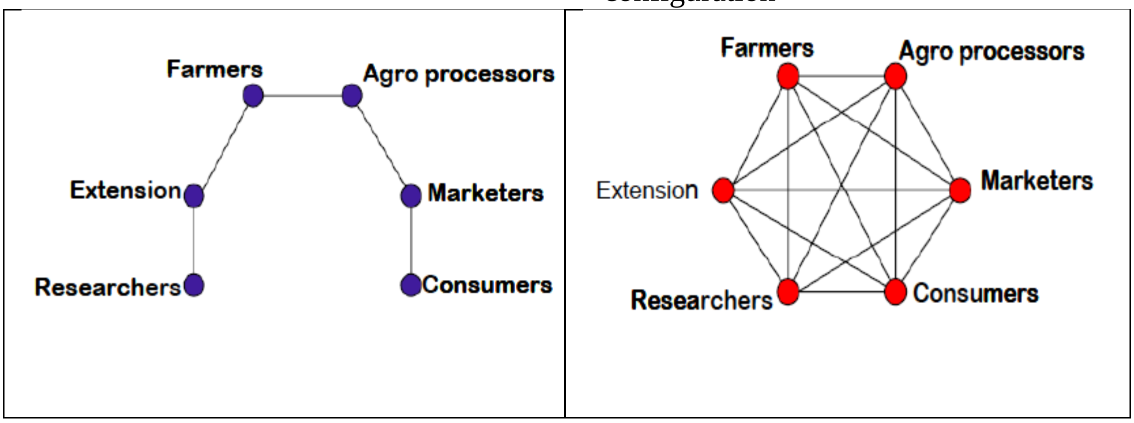
Studies have shown that root and tuber crops such as sweet potato and cassava easily adapt to marginal environments that characterise farming systems in southern Africa [15, 16, 17]. These crops are resilient to moisture stress and hence provide food in areas with short rainy period and prolonged drought where other crops cannot survive [18, 19]. Despite the importance of root and tuber crops in reducing household vulnerability to food insecurity caused by drought, their importance relative to cereals remains low. Root and tuber crops are grown on a small scale as secondary crops by most farmers in southern Africa. Although there is a growing recognition among policy makers and scientists of the importance of root and tuber crops in enhancing household food security and income, efforts to promote the crops have been fragmented. As Mertz *et al*. [20]

noted, the livelihoods of smallholder farmers in marginal drought-prone areas remain precarious despite huge investments in agriculture research and development (ARD) and other efforts designed to promote drought resistant crops. According to Hawkins *et al.* [21] failure of ARD to uplift the livelihoods of farmers is attributed to the way agricultural research and development was organized. Innovation follows a linear path that begins with researchers, who pass on information to extensionists, who in turn pass it to farmers. Other commodity value chain actors, such as suppliers, agro-processors, and micro financiers and commodity buyers would have their separate programmes designed to maximise their benefits from smallholder agricultural sector. The major challenge with the ARD approach is that there was no continuous feedback between researchers and final users of the research information. It also failed to bring synergies between and among the various stakeholders and actors along the commodity value chain [21].

According to Hawkins *et al*. [21], it is not surprising that such fragmented non-participatory and linear approaches to agricultural research and development (as shown in Figure 1a) fail to improve smallholder farmers' income. In this approach to agricultural development, research is the purview of trained scientists, who pass their innovation to farmers through agricultural extension officers. Agro-processors simply buy what the market offers and they do not have a say on the product quality and quantity. Sub Saharan Africa Challenge Programme [22], therefore, recommended the adoption of an Integrated Agricultural Research for Development (IAR4D) approach to promoting innovations that are likely to improve the smallholder farmers' food security and livelihoods and provide benefits for stakeholders along the value chain as shown in Figure 1b.

1a. ARD actors in a linear configuration

1b. IAR4D actors in network configuration



Source: [22]

As put forward by Nyikahadzoi *et al*. [23] and Binam *et al*. [24], the IAR4D concept uses Innovation Platforms (IPs) to embed agricultural research and development organisations in a network to undertake multidisciplinary and participatory research. The IAR4D approach overcomes the shortcomings of traditional approaches and generates greater impact from agricultural research for development (AR4D) leading to improved rural livelihoods, increased food security and increased benefit for the commodity value chain actors.

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Dantas [25] argues that the IAR4D approach should be embedded in an innovation platform with all relevant actors for a specific value chain. An innovation platform is defined as a formal or an informal coalition, collaboration, partnership and alliance of public and private scientists, extension workers, farmers association, farmers, private firms (agro-processors, marketers and financiers), non-governmental organisations and policy makers who communicate, cooperate and interact [22]. Innovation platform actors bring different competences to the team and also have incentives to bring about mutual change for their own benefit and also that of the farmers. In an Innovation Platform, there is direct and continuous interaction, communication and knowledge sharing among the IP actors. This facilitates quick and continuous feedback from end users (farmers) at all stages of research for development. It also ensures the timely integration of new knowledge into the innovation process using experiential learning, monitoring and evaluation and the continual feedback [21, 22]. In the process, Innovation Platform actors identify and address any institutional, economic, technological and social constraints that might affect production of root and tuber crops. These actors on the value chain are motivated by the belief that improving smallholder farmers' adaptive capacity will generate welfare benefits for all members of the platform [26]. Proponents of the IAR4D approach argue that interactions among platform actors should yield mutual benefits for the actors such as uptake of technologies, improved input demand, increased yield, improved produce supply, higher incomes and finally improved adaptive capacity of smallholder farmers [21, 22, 23]. A properly composed innovation platform allows learning and knowledge sharing among the platform actors at each stage of the value chain and generates innovations. This should trigger the necessary behavioural change at individual actor level that facilitates the adoption of productivity enhancing technologies that are being promoted. This paper seeks to establish the effect of taking up IAR4D innovations of promoting the production and marketing of root and tuber crops in southern Africa. The paper assesses the appropriateness of Integrated Agricultural Research for Development in promoting the production and marketing of root and tuber crops. It then suggests institutional arrangements that can be improved in order to effectively enhance smallholder farmers' adaptation to climate change and variability.

MATERIALS AND METHODS

The study used a quasi-experimental design to compare outcomes (smallholders' incomes) under IAR4D and under the control which is the non-IAR4D. This involved the experimental district, which received the IAR4D intervention treatment, and control groups, which did not receive treatment. The control districts (non-IAR4D) were selected using stratified random sampling method. In the IAR4D district, five villages were selected. These were sampled from the 'clean' villages. Clean villages refer to villages in which there is absence or very minimal level of any agriculture developmental intervention in the last 2-5 years [22]. From the control district, five clean and five conventional villages were selected. In each of the selected villages ten households were randomly selected for monitoring and impact evaluation. Following this approach, the study used a sample size of 600 households. Conventional villages are villages with projects identifying, promoting and disseminating technologies in the last 2-5 years [22]. In this study, one panel data set collected from Zimbabwe, Malawi and Mozambique

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after three years of project implementation of the IAR4D proof of concept was used. The household data were collected in October 2011 using a structured questionnaire that sought information on general household characteristics, awareness and use of improved technologies, access and use of improved agricultural inputs, marketing of agricultural produce and interaction among key stakeholders in the IAR4D district.

In this paper, the interest was in measuring the causal effect of IAR4D activities (D), on income (Y). It was of interest to note how income was influenced by IAR4D activities. In this case, the aim was to find out how IAR4D-induced activities *D*, causally affect income *Y*, that is, how an exogenous variation in *D* would change the variable *Y*. For each unit in the sample D € {0, 1} which indicates whether the unit received the treatment of interest IAR4D-induced activities ($D_i = 1$) or did not ($D_i = 0$, the control group). $Y_i(1)$ and $Y_i(0)$ denote the two potential outcomes as a function of treatment. They represent the outcome household i would get if he/she received treatment or did not, respectively.

The study employed an exogenous variation in a binary variable Z to learn about the effect of D on Y with Z € {0, 1}. Variable *Z*-is a vector that represents the incentives created by IAR4D that affect only *D* but not *Y*. Then an exogenous variation in *Z* induces an exogenous variation in *D* and thus overcomes the endogeneity of *D*. Such a variable Z is called an instrumental variable. Informally, the role of an instrument is to induce a change in the behaviour of the treated in a way that it will have an effect on the outcome variable (Y). Integrated Agricultural Research for Development activities are aimed to encourage smallholders to participate in the production and marketing of root and tuber crops. The study found that farmers' participation in marketing drought resistant crops such as root and tuber crops was an instrument for improving farmers' income.

Participation in root and tuber crops marketing research embodies capacity building in their production, strengthening of farmer organisations in organization development, networking with other partners along the commodity value chain and provision of product markets. Then $D_1 = 1$ for a particular individual means that such an individual is exposed to the technologies (for example, better methods of growing roots and tubers and easy access to commodity markets) through IAR4D activities. On the other hand $D_0 = 0$ means that the smallholder is not exposed to IAR4D activities. The treatment status indicator variable can be expressed as $D = Z.D_1 + (1 - Z).D_0$. In practice, we observe Z and D (and therefore D_z for individuals with $Z = z$), but we do not observe both potential treatment indicators.

The actual or realised value of the endogenous variable is

$$D = Y(Z) = \begin{cases} D_1 \; if \; Z = 1 = IAR4D \\ D_0 \; if \; Z = 0 \end{cases} \qquad (1)$$

So we observe the triple Z, $D = D(Z)$ and $Y = Y(D(Z))$.

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Any intervention or treatment partitions the population into four groups defined by the potential treatment indicators D_1 and D_O [26]. Compliers are those who have $D_1 > D_0$ (or equivalently, $D_0 = 0$ and $D_1 = 1$). Likewise, always takers are defined by $D_1 = D_0 = 1$ and never takers by $D_1 = D_0 = 0$. Finally, defiers are defined by $D_1 < D_0 (or\ D_0 = 1\ and\ D_1 = 0)$. Note that since only one of the potential indicators (D_0, D_1) is observed, it is difficult to identify which one of these four groups any particular individual belongs to. Using an instrumental variable to measure impact of an instrument on outcome is based on three important assumptions.

Assumption 1: Randomly assigned instrument
It is assumed that there is independence between the potential outcomes {Y (D_{1i}, 1), Y (D_{0i}, 0), D_{0i}, D_{1i}} and the instrument Z. This assumption requires that the instrument is as good as randomly assigned and does not directly affect the outcome.

Assumption 2: Non zero average effect of Z on D
E[D(1) – D(0)] ≠ 0 This assumption requires the instrument to have an effect on the treatment status.

Assumption 3: Individual level monotonicity of Z on D. D_i (1) > D_i (0) for all i. This rules out the existence of defiers. This assumption ensures that the treatment affects the participation or selection decision in a monotonic way.

The exclusion restriction assumption requires that the potential outcomes Yi (D Z) are only a function of D and they are affected by the instrument Z_i through the treatment variable D_i. This implies that Y_i (D, 0) = Y_i (D, 1) for all i.

If the exclusion restriction holds, along with assumptions 1, 2 and 3, it is possible to point and identify the average causal effect of D on Y for compliers using the local average treatment effect (LATE). Under these assumptions, the parameter being estimated is interpretable as measuring the average effect of participating in production and marketing of root crops and tubers on income for smallholders that grow and sold the crops because they were in an IAR4D village. In other words, LATE is given by the effect of Z on Y (average effect of treatment assignment on outcome) divided by the effect of Z on D (the average effect of treatment assignment on treatment received). That is the average effect for smallholders whose treatment status was changed by the instrument – the compliers.

Mathematically, LATE can be defined as

$$\text{LATE} = \text{E}[Y_{1i} - Y_{0i}]\ D_{1i} - D_{0i} > 0 (2)$$

The LATE estimator can be written as follows:

$$E(y_1 - y_0 | d_1 = 1) = \frac{E(y|z = 1) - E(y|z = 0)}{E(d|z = 1) - E(d|z = 0)} \qquad (3)$$

The LATE estimator is the average treatment effect for those who would be induced to participate by changing Z from zero to one. The right hand side of equation (3) can be estimated by its sample analogue:

$$\left(\frac{\sum_{i=1}^{n} y_i z_i}{\sum_{i=1}^{n} z_i} - \frac{\sum_{i=1}^{n} y_i (1-z_i)}{\sum_{i=1}^{n} (1-z_i)}\right) \times \left(\frac{\sum_{i=1}^{n} d_i z_i}{\sum_{i=1}^{n} z_i} - \frac{\sum_{i=1}^{n} d_i (1-z_i)}{\sum_{i=1}^{n} (1-z_i)}\right)^{-1} \qquad (4)$$

which is the *Wald* estimator.

The assumption that Z is random in the population is unfeasible as it is the case that participation in IAR4D can be influenced by a number of socio-economic (observed and unobserved) and institutional variables [27].The study uses Abadie's [28] LATE estimator, which only requires the conditional independence assumption. That is, the instrument *Z* is independent of the potential outcomes D_1, $Y_1$and Y_0 conditional on a vector of covariates ***x*** that determine the observed outcome *Y*. With these assumptions, the following results can be shown to hold for the conditional mean outcome response function for potential beneficiaries $f(x, d) \equiv E\ (y|x, d;\ d_1=1)$ and any function *g* of (*y* ,*x*, *d*).

$$f(x,1) - f(x,0) = E(y_1 - y_0|x, d_1 = 1) \qquad (5)$$

$$E(g(y,d,x)|d_1 = 1) = \frac{1}{p(d_1 = 1)} E(\kappa . g(y,d,x)) \qquad (6)$$

Where $\kappa = 1 - \frac{z}{p(z=1|x)}(1-d)$is a weight function that takes the value 1 for a potential beneficiary and a negative value otherwise. The function *f*(*x*, *d*) is known as the *local average response function* (LARF) by Abadie [28]. Estimation proceeds by a parameterization of the LARF $f(\theta, x, d) = E(y|x, d;\ d_1 = 1)$ using multiple regression methods.

DATA ANALYSIS

The actual estimation of LARF was done in STATA 11.2 using the STATA add-on impact command developed by Diagne *et al.* [29]. In this study, the decision to estimate LARF is based on the assumption that impact is not homogenous across the population.

RESULTS

Results are presented in Tables 1, 2, 3 and 4. Table 1 compares demographic characteristics of root and tuber crop growers and marketers. The table displays the descriptive results for sampled households. The average per capita income is $0.474 and the mean age of the farmers is 45 years. About 85% of the households are male headed with over 17 years of farming experience. Average household size is 6 with a dependence ratio of 1.35. About 38% of the households participate in IAR4D research activities.

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The results of the impact of IAR4D on household income, computed as Local Average Treatment Effect (LATE) are presented in Table 2. The Local Average Treatment Effect captures the effects of participation in production and marketing of root and tuber crops due to a change as a result of participating in IAR4D organised action induced by the exogenous change in the instrument, IAR4D. It is only identified for the sub-population of compliers, in other words those farmers whose participation in production and marketing would have been induced by IAR4D.

Table 2 shows that participation in production and marketing of root and tuber crops had a significant impact on smallholder farmers' income. It is clear from the findings that those smallholder farmers who participated in IAR4D activities such as action research, production and marketing of root and tuber crops had higher incomes. In order to promote the production and marketing of root and tuber crops, it is also important to determine the factors affecting the adoption of the crop. Table 2 provides estimation of the determinants of the instrument.

Table 3 shows the determinants of the instrumental variable, which in this case is growing roots and tubers. Explanatory variables such as household head's age, sex, membership in a marketing group, and dependency ratio are not important in explaining whether a farmer participates in production and marketing of root crops and tubers or not. The only statistically significant variable in determining whether a smallholder farmer participates in marketing of root and tuber crops is participation in action research and being in an IAR4D village. Participation in IAR4D organized participatory action research significantly determined whether a farmer would grow root and tuber crops.

Determinants of end line income besides being a member of the Innovation Platform and participation in research as given by local average response function are presented in Table 4.As shown in the table, participating in production and marketing of root and tuber crops contributed significantly to the smallholder farmers' income. Demographic variables that also significantly explain household income include age, education level, sex of household head and participation in action research of the household head. There was a positive and significant relationship between smallholder farmers' participation in root and tuber crops marketing and household income. This could be because root and tuber crops growers are guaranteed of a harvest even in the face of cereal crops failure as a result of climate change and variability.

DISCUSSION

Participation in action research was positively and significantly correlated to household income. As Eicher and Haggblade [30] observe, experimental learning enables farmers to understand the crop's agronomic requirements and production and marketing dynamics. The older the household head, the higher the household income. Bogale and Shimelis [31] and Rena [32] argue that the older the household head, the more experienced he/she becomes, for example in forecasting weather variation. Male-headed households tend to have a significantly higher income than female headed ones. These results agree with the findings of Munaku and Chigora [33] who observed that male-headed households were better positioned to hire farm labor than female-headed households. As such, they are more likely to get higher income. Education level of household head was also an important determinant of household income. It allows the smallholder farmer to access information and effectively use it. The more educated the household head is, the more money the household is likely to make. This suggests that households who are more educated are more likely to have higher incomes than their counterparts with low levels of education.

Results from this study clearly show that within the IAR4D framework, the existence of an IP helps smallholder farmers not only to grow root and tuber crops but also to realize higher income. This can be attributable to the fact that IPs offered a forum where institutional and infrastructural constraints that inhibit the production and marketing of root and tuber crops are effectively dealt with and also provide unlimited space to the use of technical opportunities that come with commercializing these crops. Within the IP, there was easy access to production and marketing information, different farming technologies and proven agronomic practices designed to increase productivity. According to Coase [34], if actors have information necessary to evaluate correctly the alternatives they will consequently make a choice that achieves desired ends. IAR4D overcomes a major impediment towards that attainment of mutually desirable outcomes [35].

Despite the importance of root and tuber crops in dealing with the effects of climate change on rural livelihoods, there are many challenges that work against the successful production and marketing of these crops. As noted by Onubuogu and Onyeneke, [36], root and tuber crops are very popular in rural areas where most households cannot afford other more preferred food stuffs. Consumption of root and tuber crops in urban areas is very low as the crop is associated with low income people. It is also important to note that while root and tuber crops grown in most parts of southern Africa are an excellent source of carbohydrates, their nutritional value is very low [37]. These factors combine to reduce the bargaining power of roots and tubers producers.

CONCLUSION

As the climate changes and climatic variability intensifies, smallholder farmers need to change from traditional farming practices to crops that perform better under the harsher climatic conditions. Participation in research presents an opportunity for farmers to learn and appreciate new crop varieties. However, there are economic and institutional environments affecting the incentives for production and marketing of these new crops. The study shows evidence that smallholder farmers exposed to IARD were able to adapt to climate change through production and marketing of root and tuber crops.

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Table 1: Descriptive statistics

Variable	Mean/proportions
Per capita income (USD/year)	0.474
Age of household head	45.405
Sex of household head (prop. Male headed)	0.847
Farming experience (years)	17.094
Household size	5.925
Dependency ratio	1.350
Marital status (% married)	0.783
Research participation (%)	0.383

Table 2: LATE parametric (Exponential Non-Linear Least Squares) estimation of population parameters

income parameter	Std. Err.	Z	P>z	[95% Conf.	Interval]	
LARF						
LATE	221.838	116.426	1.910	0.057*	-6.353	450.029

Legend: * statistical significance at 10%; ** statistical significance at 5% and *** statistical significance at 1%

Table 3: Estimation of determinants of growing roots and tubers

Root crop	Coef.	Std. Err.	Z	P>z	[95% Conf. Interval]	
Household head age	-0.007	0.005	-1.250	0.211	-0.017	0.004
Household in IP village	0.221	0.123	0.332	0.001**	0.012	0.321
Member of marketing group	-0.206	0.173	-1.190	0.235	-0.545	0.134
Participation in research	0.361	0.162	2.220	0.026**	0.043	0.678
Dependency ratio	0.000	0.001	0.330	0.743	-0.001	0.002
Sex of household head	0.305	0.239	1.280	0.202	-0.163	0.773
Education of household head	0.025	0.034	0.740	0.458	-0.041	0.091
_cons	-1.475	0.385	-3.830	0.000	-2.230	-0.721

Pseudo R^2 = 0.313

Legend: * Statistical significance at 10%; ** statistical significant at 5% and *** statistical significant at 1%

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Table 4: LARF Exponential Non-Linear Least Squares regression

End-line income	Coef.	Std. Err.	T	P>t	[95% Conf. Interval]	
Marketing root crop	0.576	0.155	3.720	0.000***	0.272	0.881
Household head age	0.009	0.004	2.020	0.044**	0.000	0.018
Sex of household head	4.070	0.398	10.230	0.000***	3.289	4.851
Education of household head	0.208	0.035	6.010	0.000***	0.140	0.276
Household size	0.018	0.028	0.630	0.532	-0.038	0.073
Member of marketing group	0.137	0.143	0.960	0.339	-0.144	0.418
Participation in research	0.592	0.172	3.450	0.001***	0.255	0.929
Dependency ratio	0.000	0.001	-0.600	0.547	-0.002	0.001

R^2- = 0.2860

Legend: * statistical significance at 10%; ** statistical significance at 5% and *** statistical significance at 1%

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