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# Irrigation adoption: A potential avenue for reducing food insecurity among rice farmers in Benin

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ABSTRACT

Since the 1960s, the government of Benin has invested in the development of canal irrigation schemes in order to intensify food crop production and reduce food insecurity. This paper employed an ordered probit model with sample selection to assess the potential of irrigation in reducing food insecurity in the municipality of Malanville, Benin. The results show that 60% of the irrigation farmers and 46% of the dry land farmers were food secure. Adoption of irrigation has a positive effect on food security. Other variables explaining food security are education, informal training, credit, extension services, use of improved seed, fertilizer and herbicide application, farm and off-farm income. The study recommends that efforts to rehabilitate current irrigation scheme and develop other schemes should be intensified.

## 1. Introduction

Originally defined as the availability of food, the concept of food security has gradually evolved to an emphasis on access to food [16] up to today's definition stating the four dimensions of food security: availability, accessibility, utilization, and stability. The latest concept was adopted at the World Food Summit organized in Rome in 1996, and food security has been defined as " a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Therefore food security implies the provision of safe, nutritious, quantitatively and qualitatively adequate food, as well as access to it by all people at any time. It can be analyzed either from the supply or demand side, or both sides. [48] highlighted that food problems are influenced not only by food production and agricultural activities, but also by the structure and processes governing entire economies and societies. Following that view, food insecurity is caused not only by scarcity but also by institutional failures that led to suboptimal food distribution. For instance, the world has the capacity to provide at least 2.15 kg per person a day for the whole population but the world has about 795 million food insecure and undernourished people [15]. On this premise, this study suggests that food supply is a necessary condition while food access is a sufficient condition for food security.

Improving access to adequate and nutritious food for its population is the major goals of any developing country. This was re-emphasized with the 2007/08 global food prices shock. Despite efforts made towards hunger eradication worldwide, about 780 million people in developing countries still experience and suffer hunger. In Benin, an integrated modular survey on household living conditions conducted by the ''Institut National de la Statistique et de l'Analyse Economique [28]" found that about 22.5% and 23% of households were food insecure and at risk of food insecurity respectively in 2011. Food insecurity is unevenly distributed within regions and between urban and rural area. The situation is worse in rural areas where 24.7% of households were observed to be food insecure and 25.7% were at risk of food insecurity in 2011 [28]. A report of the World Food Program (WFP) in 2014 points to the fact

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that, in Benin, households that rely on agriculture as main source of livelihood are more vulnerable to food insecurity. About 21% of farm household in Benin were food insecure and 48% were at risk of food insecurity in 2013 [55]. The synthesis statistics by municipality reveal that 26% of households in the municipality of Malanville (study area) were food secure, 20% were food insecure, and 54% were at risk of food insecurity.

While agriculture is a key sector for Benin economy it is handicapped by climate change and weather variability. Many farmers cannot produce during the dry season and the production decreases when there is flooding or drought. It follows that the country experiences good production year when rainfall and spatial-temporal distribution of rainfall is favorable. As water is a limiting factor for agricultural production, irrigated agriculture is considered as one of the practices for controlling the effects of weather variability (flood and drought) on crop yield and thus for increasing food production in the countries [18,53,7,13,30,14]. Consistent with this the Government of Benin has developed several irrigation scheme through the country since 1960 in a bid to support cereal production and to reduce food insecurity. Several irrigation systems (gravity, pump, manual watering, among others) are used in Benin according to the financial capacity of the producers. Surface irrigation is practiced on 46% of the total area, followed by sprinkler irrigation on 42% of the total area and drip irrigation covers 12% of the total area under irrigation [33]. Sprinkler irrigation and drip irrigation are mostly used for vegetable production. Canal irrigation is used in all irrigated rice schemes in Benin with water from a river. For instance, in the irrigation scheme of Malanville (study area) the water used is pumped from the Niger River and distributed into the farms through surface canals. Public expenditure for irrigation schemes construction and maintenances are important factors of irrigation development. Such investments have been realized in Benin by the government and its development partners since 1960. It is therefore important to reinforce the justification for such investments and provide support for continuing investments.

Previous empirical works (Abonesh et *al.,* 2006 [36,52,51,7,3,22, 39, 49,57,2]; dealing with the effect of irrigation on livelihood have concluded that irrigation contributes to food availability which leads to lower food price, and thus to food security. For example, the project to install solar-powered water pumps in Benin significantly augments both household income and nutritional intake, particularly during the dry season [7]. Indeed, the per capita daily consumption expenditure for the beneficiary household has increased from US$ 0.69 to US$ 0.85. [7] argue that the project not only increased consumption, but also initiated small institutional changes: more children attended school, and women received formalized land rights and access to financial institutions. These findings were confirmed by Ref. [2] who showed that solar-powered drip Irrigation has the potential to improve household nutritional status in Benin. [3] point out that irrigation scheme enhanced household food security and wellbeing during the dry season in Ghana. Using a propensity score matching approach [57], showed that adoption of irrigation in Ethiopia has a positive effect on irrigation facilities users' household total expenditure. This agrees with previous findings by Refs. [1] and [52]. A study conducted in Malawi by Ref. [39]; based on a propensity score matching method indicated that access to irrigation facilities increases the daily per capita caloric intake for participants by 103 kcal, and that represented an average increase of 10 percent more than non-participants to the irrigation scheme. Studies [17,8]; in Zimbabwe have shown that irrigation schemes have the potential to achieve food security through employment creation, income generation, and acquisition of assets.

The present study seeks to answer the following important question for irrigation policy: what are the impacts of adoption of irrigation on food security among rice farmers? The choice of rice is due to the importance that has been given to its production in Benin. It occupies 50% of the irrigated land in Benin [19,20,40]. Rice is among the main food crop on which the government is focused to reduce food insecurity and poverty. There is no one best measure of food security. It has been measured using a range of indicators following quantitative approaches based on prevalence of undernourishment, per capita food consumption expenditure, daily per capita caloric intake, food consumption score, anthropometry measure, or qualitative approaches using questionnaires for measuring food insecurity experiences scales. The quantitative approaches are criticized for being data intensive, costly to implement, and insensitive to shocks and seasonality [21,11,25]. Questionnaires measuring experiences of food insecurity attempt to fill these gaps and are relatively less expensive and easy to use [21,5,42,19,20].

The study contributes to the growing literature on the effects of irrigation adoption on food security. It shows evidence of the importance of irrigation in reducing food insecurity in Benin. This is useful for policy makers in the formulation and evaluation of the food insecurity reduction programs. It takes an approach that differs from quantitative approaches of food security measurement by using the approach of food insecurity experiences scales to examine food security status. Currently, the efficacy of the irrigation development policy in Benin has not been sufficiently addressed. Literature on the effects of adoption of irrigation on food security is scant for Benin. Few studies [7,2]; have analyzed the impact of irrigation on food security in Benin. Thus, a study showing empirical evidence that irrigation adoption affects food security among rice farmers in Benin is of great importance as it contributes to advance existing literature. Context specific analysis is needed to support smarter policies in Benin.

Various methods have been used in the literature to examine impact of technology adoption on food security [52,51,39,57]. The main problem is sample selection bias. Some authors minimized the problem of selection bias by using the Heckman two step model [52,49]. Others ([39,57,62]; employed the propensity score matching (PSM) approaches. Both methods rely on assumptions. The Heckman approach relies on the restrictive assumption of normally distributed errors [62]. The validity of the matching approach depends on the conditional independence assumption which postulates that potential outcomes are independent of the treatment status [46,62,64]. This implies that technology adoption decision is entirely based on observed characteristics; even after this, there may be significant differences between adopters and non-adopters outcomes [62,63] because of unobservable characteristics such as farmers' motivation, and ability. To control for this problem, the instrumental variables (IV) model is commonly used. Applying the IV model requires the availability of at least one instrumental variable assumed to be highly correlated with the treatment variable and uncorrelated with unobservable factors affecting the outcome. The main limitation of this approach is the difficulty in identifying valid instruments. Comparing these different methods of addressing selection bias, Jalan and Ravallion [60] noted that the assumption of selection on observables is no more restrictive than assuming away problems of weak instruments, when Heckman or the

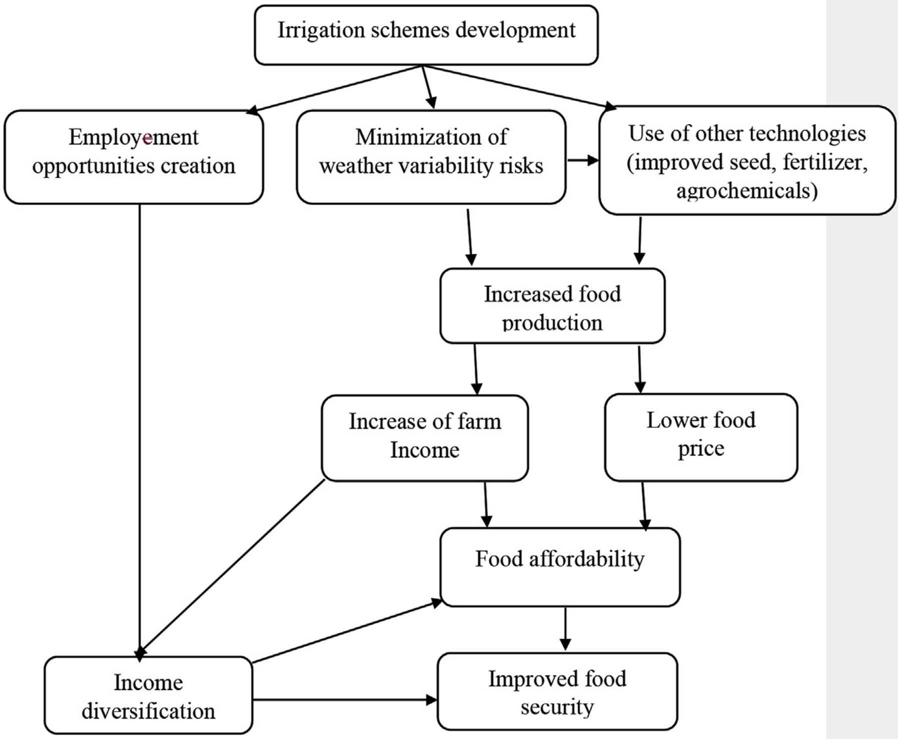


**Fig. 1.** Linkages between irrigation and food security.

IV approach is employed in cross-sectional data analysis. Majority of the studies have not considered the food security categories in examining the impact of irrigation adoption. To take advantage of this, the ordered probit model with sample selection was employed. This is a generalization of the [26] two step model to ordered outcomes [9].

The paper is arranged as follows. The introduction provides an overview and the objectives of the study. The next section describes the linkages between irrigation and food security. This is followed by the research design which includes the presentation of the study area, the sampling technique and data collection procedure, and then the methods of analysis. The results are presented and discussed in section 4, while the conclusion and policy implications of the study are given in section 5.

## 2. Conceptual framework: the link between irrigation and food security

Agricultural technology adoption is generally based on the expected utility derived from the adoption. This study therefore builds on a random utility framework, where farmers are assumed to maximize their utility from the adoption of irrigation. In this regard, farmers adopt irrigation when they perceive that this will provide them with greater utility in terms of reducing food insecurity. Irrigation water is an important resource for agricultural activities including livestock and fisheries. Without water people cannot water crops, provide food and productive environment for the fast growing population, animals, plants, and microbes worldwide [43]. This framework describes the way by which the adoption of irrigation contributes to achieve food security (Fig. 1).

[14] argues that the four dimensions of food security are likely to be improved due to increased availability of water. Investing in irrigation is a mean to hedge against weather variability such as drought and flood. Irrigation water allows for all year round food production. This allows food production in two or more cycles in a year. Studies by de Mey et al. [61] and Diagne et al. [58] have shown that the presence of severe production risks prevent farmers from intensifying their production system. As a risk-reducing technology, developing irrigation schemes is often a package of technologies, leading to crowding in of inputs and technologies such as improved seed, fertilizers, and agrochemicals, among others [59] which in turn may contribute to crop yield improvement and higher farm income. Non-farmers benefit from this through lower food price.

Increased returns from production can have important employment opportunities through increased demand for inputs and supply of outputs [27]. Another source of employment opportunity in the area is the additional demand for intensive use of labour during the construction of the schemes and the ongoing maintenance and rehabilitation works. These employment opportunities offer prospects for farmers to diversify their sources of livelihood resulting in an increase of their total income. As income increases, farmers can afford more nutritious foods for consumption and other goods or even increase farm investments. Therefore, adoption of

**Table 1**
Characteristics of the municipality of Malanville.
Source: [28,29].

| Malanville | |
|---|---|
| Population (2013) | 168, 641 |
| Religion (%) | Muslims: 80, Others: 20 |
| Child schooling rate (%) | 28.4 |
| Literacy rate (%) | 14.1 |
| Main economic activities | Agriculture, fishing, livestock, small business, trade and crafts |
| Major crops | Maize, rice, millet, sorghum, cotton, and vegetables |
| Food insecurity (%) | 35 |
| Poverty incidence (%) | 42.5 |

irrigation contributes not only to food availability through crop yield improvement but also by improving access to food through lower food price and higher farm income, enabling farmers to afford more food and food security boost. It should also be noted that irrigation water is also used for other activities including domestic use, livestock rearing, fish production [27,14,40]; which are part of the farmers' income diversification strategies, leading to food security.

## 3. Research design

### *3.1. Description of the study area and survey design*

The study[1] is carried out in Benin in the municipality of Malanville which is borded to the North by the Republic of Niger, to the South by the municipalities of Kandi and Ségbana, to the West by the municipality of Karimama, and to the East by the Federal Republic of Nigeria. The municipality is located in the Sudano-Sahelian zone of Benin with only one rainy season which lasts for 5–6 months from May to October with a rainfall range between 700 mm and 1000 mm. This low rainfall negatively affects agricultural production especially rice. Malanville is characterized by high level of food insecurity and poverty (Table 1). The majority of its inhabitants are involved in subsistence agriculture and other economic activities such as fishing, livestock rearing, small business, trade and crafts. The major crops grown are maize, rice, millet, sorghum, cotton, and vegetables.

The municipality of Malanville was chosen for this study for three main reasons. First it is the largest rice producing area in Benin, second it is crossed by the Niger River and its tributaries which offer an important opportunity for rice production, and third among other rice irrigation schemes developed by the State, the irrigation scheme at Malanville is the most important in terms of size and yield. The total irrigable land under the scheme is 516 ha of which 400 ha were cultivated in 2015. The average rice yield under the scheme is about 5.7 MT/ha. The irrigation scheme of Malanville was constructed in 1970 and the water used is pumped from the Niger River and distributed into the farms through surface canals. There are approximately 1054 rice farmers operating on the scheme in 2015.

Four districts out of five in the municipality were selected for the survey based on distance to the irrigation scheme, and on the size of rice production. Districts selected were Garou, Guene, Malanville and Tombouctou. In each of these districts, two villages, one high rice producing village and one low rice producing village were purposively selected with the help of the extension officers. In total, eight villages within the four districts were selected for the survey.

### *3.2. Sampling design and data collection*

There were two groups of respondents considered for this study. The irrigation farmers who produce rice under irrigation in the formal irrigation scheme of Malanville and the dry land farmers producing rice under rainfed condition in the same municipality. [34] reveals that about 9% of the rice farm population in Benin are irrigation farmers, and the rest are under rainfed condition. Based on the prevalence of irrigation and rainfed farmers, the optimal sample size required to produce accurate results was determined for each group of farmers using [10] sample size formula. We obtained an optimal sample size of 126 for irrigation farmers and 359 for dry land farmers. Oversampling was done and hence 150 irrigation farmers and 540 dry land farmers were finally chosen. A large sample size minimizes sampling error.

Practically, a list of irrigation farmers was obtained from the committee in charge of the management of the irrigation scheme of Malanville. Farmers from the scheme are in groups of 20–100 people with a total of 24 groups. To ensure a fair representation, a proportional sampling technique was used to select 150 irrigation farmers. Further, the dry land farmers were selected from the eight villages covered by the survey. For this group the approximate list of the rice farmers was provided by the Chief of the village. Ninety (90) farmers were randomly selected in each high rice producing village and 45 farmers were also randomly selected in each low rice producing village totaling to 540 dry land farmers. The total number of respondents interviewed for the survey was 690 rice producers comprising of 150 irrigation farmers and 540 dry land farmers. Farm level data was collected between April and June 2015.

[1] Details of the survey and sampling techniques can also be found in Ref. [40].

**Table 2**
Set of questions on food insecurity experienced.
Source: [4,19,20,42];

| During the last 12 months, was there a time when: |
|---|
| Q1. You were worried you would run out of food because of a lack of money or other resources? |
| Q2. You were unable to eat healthy and nutritious food because of a lack of money or other resources? |
| Q3. You ate only a few kinds of foods because of a lack of money or other resources? |
| Q4. You had to skip a meal because there was not enough money or other resources to get food? |
| Q5. You ate less than you thought you should because of a lack of money or other resources? |
| Q6. Your household ran out of food because of a lack of money or other resources? |
| Q7. You were hungry but did not eat because there was not enough money or other resources for food? |
| Q8. You went without eating for a whole day because of a lack of money or other resources? |

### 3.3. Method of analysis

#### 3.3.1. Framework for the measurement of food insecurity under the Rasch model

The food insecurity experience scale (FIES) is an experience-based measure of severity of food insecurity. It comprises a set of eight questions (Table 2) that the respondents were directly asked about their experiences associated with increasing difficulties in food access due to resource constraints. The questionnaire is very simple to apply at a fairly low cost and with less time. Responses were coded as ‘’yes = 1″ for an affirmative value, and ‘’ no = 0″ for a negative value.

The Rasch model [45] programmed in R package was used to analyze the data. It provides a theoretical framework for models that use questionnaire items measuring the same latent trait [21,44]. Compared to the other related item –response models, the Rash model is more appropriate for use in small samples and allow to assess the relative contribution of each item to the latent variable measured [32,50]. In Rasch modelling the likelihood that a subject with ability $b_h$ responds correctly to a test items characterized by difficulty level $a_i$ is a logistic function of the difference between $b_h$ and $a_i$:

$$Prob\ (x_{h,i} = 1\ /b_h,\ a_i) = F(b_h - a_i) = \frac{e^{b_h - a_i}}{1 + e^{b_h - a_i}} \tag{1}$$

The underlying assumptions of the Rasch model are that the items within the questionnaire are uni-dimensional, the probability that a respondent affirms an item is a logistic function of experienced food insecurity, all items within the questionnaire discriminate equally, meaning that they are equally and strongly associated with the latent trait, and the items are conditionally independent [21,42]. Before the validation of the results, the items were subjected to a test that indicates whether the responses fit the assumptions of the Rasch model. After testing the Rasch model assumptions for all rice farmers, separate test was done for irrigated and rainfed rice farmers to compare the psychometric characteristics of the two sub-groups within the sample. The idea is to ensure that all items are strong indicators of food insecurity for the two sub-groups before starting any comparison between them.

Two statistics commonly used as indices of fit of the items and of the individuals are “item infit” and “item outfit”. Both compare observed deviations of responses from the deviations expected under Rasch assumptions [24,31,42].

“Item infit” is calculated as follows:

$$INFIT_i = \sum_{1}^{N} [(X_{i,h} - P_{i,h})^2] / \sum_{1}^{N} [P_{i,h} - P_{i,h}^2] \tag{2}$$

“Item outfit” is defined as follows:

$$OUTFIT_i = \frac{1}{N} \sum_{1}^{N} [(X_{i,h} - P_{i,h})^2 / (P_{i,h} - P_{i,h}^2)] \tag{3}$$

Where: $X_{i,h}$ is the observed response of farmer h to item i; $P_{i,h}$ is the probability of an affirmative response by farmer h to item i; and N is the total number of farmers. When the responses fit the model perfectly, the value of “infit” and “outfit” are 1. Values above 1 indicate items that are weakly related to the food insecurity, and values below 1 show items that are more strongly related to food insecurity [44,42]. In practical analysis the recommended value for fit statistics ranges from 0.8 to 1.2, and a wider acceptable range of 0.7–1.3 [21,44,42].

The raw score is a sufficient statistic for food insecurity measurement when the conditions of the Rasch model are met [19,20,5,42]. Therefore the respondent's maximum food insecurity scale is 8 (for farmers who provide an affirmative response to all eight questions) and the minimum scale is 0 (for farmers who provide negative answers to all eight questions). The higher the score, the more food insecurity the farmer experiences. The score 0 corresponds to high food security, the score of 1–3 corresponds to marginal food security, the score 4–6 corresponds to moderate food insecurity, and the score 7–8 corresponds to severe food insecurity [5,19,20,42].

#### 3.3.2. Econometric analysis of the effect of irrigation adoption on food security

Based on their food security status (FS), farmers were classified as follows: 1 for severe food insecurity, 2 for moderate food insecurity, 3 for marginal food security, and 4 for high food security. Then the appropriate model to estimate is an ordered response model. This is employed to take advantage of the ordinal nature of the food security categories [37]. For instance, a farmer in moderate food insecurity category is worse off than a farmer in the marginal and high food security categories, but he is better off than a farmer in a severe food insecurity category. Therefore, grouping moderate and severe food insecurity into a single food insecure category can be misleading because it fails to distinguish between serious and less serious conditions of food insecurity. The ordered response model is an extension of the binary response model by adding multiple cutoff points.

Assuming that the latent variable FS* is determined by the regression relationship:

$$FS^* = \beta' x + \varepsilon \tag{4}$$

Where $x$ is a vector of independents variables with the corresponding parameter vector $\beta$. $\varepsilon$ refers to the error term which is assumed normally distributed. In practice, $FS^*$ is unobservable. The observed aspect of food security can be written as:

$$FS = \begin{cases} 1 \ if \ FS^* < \mu_1 \\ 2 \ if \ \mu_1 < FS* < \mu_2 \\ 3 \ if \ \mu_2 < FS* < \mu_3 \\ 4 \ if \ FS* > \mu_3 \end{cases} \tag{5}$$

Where $\mu_1$, $\mu_2$ and $\mu_3$ are the cutoff points. With the four categories of the food security model, three cutoff points are estimated. By assuming a normal distribution function form, an ordered probit model was estimated. Finally, to control for the selection bias that may arise since participation in an irrigation project is not random and purposive targeting and self-selection occurs, an ordered probit model with sample selection was estimated. This is a generalization of the classical [26] two steps selection model to ordered categorical outcomes [9]. Argue that the two step estimator is more robust and is a better choice for practical applications.

Variables included in the ordered probit model are socio-economic characteristics such as age, gender, education level, informal training and geographical location of the farmer, farm inputs such as crop variety, fertilizer, herbicide, adoption of irrigation, and institutional variables such as access to extension services and credit. Farm income and off-farm income were also included in the model as wealth status indicators. The main hypothesis is that adoption of irrigation contributes to reduce food insecurity in Benin. Previous studies [52,7,3]; Nkhata et al., 2014 [49]; have shown positive relationship between adoption of irrigation and food security. It is also hypothesized that use of the other agricultural inputs (fertilizer, herbicide, and improved seed) positively affects farmer's food security status [37]. Have shown that the use of fertilizer and improved seed leads to reducing food insecurity through increased production. Positive effects of the wealth proxy variables on the food security status of a farmer was expected. Study by Ref. [51] showed that the socio-economic variables such as age, education, and income are positively correlated with household welfare. It is also expected that due to the low level of literacy (Table 1 above) in the municipality of Malanville, farmers who do not have formal education, but have gone through an a form of informal training such as carpentry, engineering, mason, dress-making, hairdressing among others, will have high probability of being food secure.

## 4. Results and discussion

### 4.1. Descriptive statistics

Comparison of the socio-economic characteristics of irrigation and dry land farmers are reported in Table 3.

All the differences discussed are statistically significant. Irrigators were relatively younger compared to dry land farmers suggesting that young farmers are likely to adopt irrigation. Few female farmers (25%) were involved in rice production. Irrigators used more inputs (fertilizer, herbicide, and improved seed) than the dry land farmers. This implies that adoption of irrigation is likely to lead to intensive use of inputs and technologies. This result is in line with previous finding by Emerick et al. [59]. Irrigators have better institutional support than the dry land farmers. The majority (94%) of irrigators had access to extension services while only 49% of the dry land farmers had. About 87% of irrigators received credit, against 54% of dry land farmers. Higher proportion of

**Table 3**
Comparison of irrigators and dry land farmers.

| Variable definition | Measurement | Irrigators | Dry land farmers | $t$-test/$\chi 2$ value |
|---|---|---|---|---|
| Age of the farmer | Years | 40.09 | 42.05 | 02.15** |
| Farm income | CFA | 1,153,040 | 1,051,782 | −1.25 |
| Off farm income | CFA | 20,830 | 12,180 | −02.60*** |
| Fertilizer | Kg/ha | 305,33 | 226.20 | −10.38*** |
| Herbicide | Liter/ha | 02.81 | 01.75 | −06.76*** |
| Gender | 1 = Male; 0 = Female | 0.80 | 0.72 | 04.18** |
| Informal training | 1 = Yes; 0 = No | 0.10 | 0.05 | 06.45** |
| Extension services | 1 = Yes; 0 = No | 0.94 | 0.49 | 98.53*** |
| Access to credit | 1 = Yes; 0 = No | 0.87 | 0.4 | 53.67*** |
| Use of improved seed | 1 = Yes; 0 = No | 1 | 0.44 | 149.18*** |
| Education | 1 = None, 0 = otherwise | 0.66 | 0.64 | 0.39 |
| | 1 = Primary school, 0 = otherwise | 0.22 | 0.24 | |
| | 1 = Secondary school, 0 = otherwise | 0.11 | 0.12 | |

**Table 4**
Summary of response characteristics and item severity.

| Items | Affirmative responses (%) | | | Item severity | | |
|---|---|---|---|---|---|---|
| | All | Irrigation farmers | Dry land farmers | All | Irrigation farmers | Dry land farmers |
| Q1. Worried to run out of food | 68.99 | 67.33 | 69.44 | - 1.65 | - 2.25 | - 1.51 |
| Q2. Unable to eat healthy and nutritious food | 58.55 | 52.67 | 60.19 | - 0.86 | - 1.01 | - 0.83 |
| Q3. Ate only a few kinds of foods | 53.91 | 49.33 | 55.19 | - 0.53 | - 0.75 | - 0.48 |
| Q4. Skip a meal | 41.59 | 32 | 44.26 | 0.35 | 0.76 | 0.26 |
| Q5. Ate less than thought | 48.55 | 38.67 | 51.30 | - 0.15 | 0.12 | - 0.22 |
| Q6. Ran out of food | 43.77 | 36.67 | 45.74 | 0.19 | 0.30 | 0.16 |
| Q7. Hungry but did not eat | 37.68 | 34.67 | 38.52 | 0.65 | 0.49 | 0.68 |
| Q8. Went without eating for a whole day | 23.33 | 20.67 | 24.07 | 2.00 | 2.32 | 1.94 |

irrigators had an informal training compared to dry land farmers. Irrigators earn higher off-farm income than the dry land farmers. They earn about 71% more in off farm income than the dry land farmers.

### *4.2. Meeting the Rasch model assumptions and analysis of food security distribution*

Assessing the extent to which the data are consistent with the Rasch model assumptions is an important step in the validation of the food security data [42]. Table 4 presents the affirmative responses and items severity for both irrigated and rainfed rice farmers. In overall about 69% of the surveyed rice farmers reported that they were worried not having enough food to eat, 44% ran out of food and 23% went without eating for a whole day at some time during the last year because they lacked food or money for food. Comparisons of affirmative responses between irrigation and dry land farmers show that a relatively higher percentage of dry land farmers have affirmed each item than the irrigation farmers. The frequency of the affirmative response to the items is an inverse function of the items severity. This decreases as the severity of the items increases. Also in all cases, it is observed that less severe items had lower measure values of severity than the more severe items. For instance the item “ran out of food” has a lower measure value than items “hungry but did not eat” and “went without eating for a whole day”, but has a higher measure value than the item “worried to run out of food”.

Item infit values ranged from 0.73 to 1.29 for all rice farmers and also for irrigated and rainfed rice farmers (Table 5). This is outside the appropriate range of 0.8–1.2 but still within the acceptable range of 0.7–1.3. Overall, item outfit values were within the acceptable range of 0.7–1.3., except for the irrigated rice farmers where these values were elevated for the least severe item “Worried to run out of food”, indicating few highly unexpected responses [44,42,47]. Given the good infit statistics for all items, the elevated outfit statistics may not threat the suitability of the data and do not indicate any serious violation of the Rasch model assumptions [47].

The item fit statistics indicate that the 8 items considered are independent of one another, and they measure the same construct, then they are strong indicators for food insecurity measurement. This confirms the suitability of the data in fitting Rasch modelling to measure food insecurity. Therefore the raw score is a sufficient indicator of food insecurity experience scale among rice farmers in the municipality of Malanville.

Table 6 summarizes the distribution of the raw score and the food security status among irrigation and dry land farmers in the municipality of Malanville. In all 15% of the surveyed rice farmers were classified into the high food security category, 36%, 28%, and 21% of irrigation and dry land farmers were in the marginal food security, moderate food insecurity and severe food insecurity categories respectively. Regarding the farming system, 21% of the irrigation farmers and 13% of the dry land farmers were in the high food security category while about 20% of irrigators and 22% of dry land farmers were in the severe food insecurity category. The

**Table 5**
Rasch model item fit statistics.

| Items | Items fit statistics | | | | | |
|---|---|---|---|---|---|---|
| | Infit values | | | Outfit values | | |
| | All | Irrigation farmers | Dry land farmers | All | Irrigation farmers | Dry land farmers |
| Q1. Worried to run out of food | 1.24* | 1.29* | 1.18 | 1.13 | 2.39** | 0.92 |
| Q2. Unable to eat healthy and nutritious food | 1.03 | 0.92 | 1.05 | 1.15 | 0.86 | 1.20 |
| Q3. Ate only a few kinds of foods | 0.94 | 0.74 | 0.97 | 0.92 | 0.61** | 0.97 |
| Q4. Skip a meal | 0.93 | 0.93 | 0.94 | 0.86 | 0.74 | 0.89 |
| Q5. Ate less than thought | 0.92 | 0.93 | 0.92 | 0.91 | 0.78 | 0.94 |
| Q6. Ran out of food | 0.89 | 0.73 | 0.93 | 0.89 | 0.59** | 0.95 |
| Q7. Hungry but did not eat | 1.04 | 1.12 | 1.02 | 1.09 | 1.18 | 1.07 |
| Q8. Went without eating for a whole day | 1.02 | 1.18 | 1.00 | 0.71* | 0.88 | 0.70 |

**Note:** *out of the appropriate range of 0.8–1.2 but still within the acceptable range of 0.7–1.3.
** Out of acceptable range of 0.7–1.3.

**Table 6**
Distribution of raw score and food security status among rice farmers.

| Raw score | Food security status[2] | All | | Irrigation farmers | | Dry land farmers | |
|---|---|---|---|---|---|---|---|
| | | Number | % | Number | % | Number | % |
| 0 | High food security | 103 | 14.92 | 32 | 21.33 | 71 | 13.15 |
| 1 | Marginal food security | 64 | 09.27 | 19 | 12.67 | 45 | 08.33 |
| 2 | | 92 | 13.33 | 19 | 12.67 | 73 | 13.52 |
| 3 | | 80 | 11.59 | 20 | 13.33 | 60 | 11.11 |
| 4 | Moderate food insecurity | 67 | 09.71 | 10 | 06.66 | 57 | 10.55 |
| 5 | | 58 | 08.40 | 12 | 08.00 | 46 | 08.52 |
| 6 | | 80 | 11.59 | 08 | 05.33 | 72 | 13.33 |
| 7 | Severe food insecurity | 51 | 07.39 | 07 | 04.66 | 44 | 08.15 |
| 8 | | 95 | 13.76 | 23 | 15.33 | 72 | 13.33 |
| Total | – | 690 | 100 | 150 | 100 | 540 | 100 |

Significant differences were observed between food secured and non-food secured farmers (Table 7).

**Table 7**
Comparison of food secured and non-food secured farmers.

| Variable definition | Measurement | Food secure | Food insecure | *t*-test/$\chi 2$ value |
|---|---|---|---|---|
| Age of the farmer | Years | 42.25 | 41.02 | −1.63 |
| Farm income | CFA | 1,312,089 | 843,646 | −7.28*** |
| Off farm income | CFA | 19,777 | 8540 | −4.13*** |
| Fertilizer | Kg/ha | 269.17 | 218.51 | −7.81*** |
| Herbicide | Liter/ha | 2.17 | 1.80 | −2.75*** |
| Gender | 1 = Male; 0 = Female | 0.76 | 0.71 | 2.16 |
| Informal training | 1 = Yes; 0 = No | 0.09 | 0.03 | 11.73*** |
| Irrigation | 1 = Yes; 0 = No | 0.60 | 0.46 | 09.06*** |
| Extension services | 1 = Yes; 0 = No | 0.57 | 0.59 | 0.21 |
| Access to credit | 1 = Yes; 0 = No | 0.70 | 0.52 | 23.85*** |
| Use of improved seed | 1 = Yes; 0 = No | 0.65 | 0.47 | 24.69*** |
| Education | 1 = None, 0 = otherwise | 0.54 | 0.74 | 30.38*** |
| | 1 = Primary school, 0 = otherwise | 0.30 | 0.17 | |
| | 1 = Secondary school, 0 = otherwise | 0.15 | 0.08 | |

aggregate distribution shows that about 60% of the irrigation farmers against 46% of the dry land farmers were food secure. These results reveal that while food security is still a challenge among rice farmers, a large percentage of dry land farmers experience food insecurity than irrigated rice farmers. Irrigation farmers show a higher level of food security than dry land farmers. Holding other factors constant, one may deduce that irrigation adoption contributes to reduce food insecurity among rice farmers in the municipality of Malanville (See Table 7).

Food secured farmers have higher farm income and off-farm income than the non-food secured farmers. The food secured farmers used more intensive inputs (fertilizer, herbicide, and improved seed) than the non-food secured farmers. Intensive use of inputs leads to increased production which in turn is positively correlated with food security. About 70% of the food secured farmers had access to credit against 52% of the non-secured farmers. This implies that access to credit is positively associated to food security. Higher proportion of food secured farmers (45%) are educated compared to the non-food secured farmers (25%). This suggests positive correlation between education and food security. More educated farmers are likely to be food secure.

### 4.3. Effects of irrigation adoption on food security

The estimates of the ordered probit model with sample selection are reported in Table 8. Following [6] and [54]; the endogeneity of farm income[3] was controlled using the expected values as follows: (1) farm income was regressed on the exogenous explanatory variables, (2) expected values were obtained, and (3) the food security equation was estimated using the expected values of farm income as an instrument for observed values. This procedure is more efficient than the two stage least squares (2SLS) technique and the control function approach [56,6,54]. The results of the selection equation is not presented since this is not the primary objective of the study.[4] The chi square test is significant at 1% indicating the significance of the overall model. The estimated cut-off points satisfy the conditions that $\mu_1 < \mu_2 < \mu_3$. This implies that the four categories of the food security differ, and should be included in the model. The coefficient of the inverse mills ratio (Lambda) is significant, suggesting the presence of selection bias which is controlled

[2] This classification follows [5,19,20]; and [42].
[3] The endogeneity of farm income comes from the fact that it is linked to inputs (seed, credit, fertilizer, herbicide, among others) through a production function.
[4] Interested readers may read [41].

**Table 8**
Ordered probit coefficient estimates for food security. Dependent variable: Food security status: 1 for severe food insecurity; 2 for moderate food insecurity 3 for marginal food security and 4 for high food security.

| Variables | Coefficient | Prob. |
|---|---|---|
| Age | −0.030 | 0.282 |
| Gender (1 = Male, 0 = Female) | 0.156 | 0.139 |
| Education (reference: No formal education) | | |
| Primary school (1 = Yes, 0 = No) | 0.462*** | 0.000 |
| Secondary school (1 = Yes, 0 = No) | 0.589*** | 0.001 |
| Access to credit (1 = Yes, 0 = No) | 0.970*** | 0.012 |
| Use of improved seed (1 = Yes, 0 = No) | 1.783*** | 0.002 |
| Access to extension services (1 = Yes, 0 = No) | 1.469*** | 0.002 |
| Fertilizer (kg/ha) | 0.0026** | 0.045 |
| Herbicide (Liter/ha) | 0.319** | 0.0296 |
| Informal training (1 = Yes, 0 = No) | 0.524*** | 0.005 |
| Log of farm income (Income in CFA) | 0.105*** | 0.000 |
| Log of Off farm income (Income in CFA) | 0.053*** | 0.000 |
| Adoption of irrigation (1 = Yes, 0 = No) | 2.714*** | 0.001 |
| Districts location (reference: District of Malanville) | | |
| Garou | - 0.466 | 0.483 |
| Guene | - 2.476** | 0.000 |
| Tombouctou | - 0.855 | 0.141 |
| Extension visit × Location (reference: Malanville) | | |
| Garou | - 1.536*** | 0.000 |
| Guene | - 0.708* | 0.082 |
| Tombouctou | - 1.656*** | 0.000 |
| Use of improved seed × Location (reference: Malanville) | | |
| Garou | - 0.892*** | 0.007 |
| Guene | - 2.020*** | 0.000 |
| Tombouctou | - 1.850*** | 0.000 |
| Access to credit × Location (reference: Malanville) | | |
| Garou | 0.225 | 0.476 |
| Guene | 0.223 | 0.448 |
| Tombouctou | - 0.162 | 0.587 |
| Fertilizer × Location (reference: Malanville) | | |
| Garou | - 0.0013 | 0.532 |
| Guene | - 0.0020 | 0.326 |
| Tombouctou | 0.00076 | 0.701 |
| Herbicide × Location (reference: Malanville) | | |
| Garou | - 0.197* | 0.085 |
| Guene | - 0.412*** | 0.001 |
| Tombouctou | 0.025 | 0.835 |
| Adoption of irrigation × Access to extension services | 0.241 | 0.581 |
| Adoption of irrigation × Use of improved seed[a] | – | – |
| Adoption of irrigation × Fertilizer | 0.0071** | 0.008 |
| Adoption of irrigation × Access to credit | 0.6892* | 0.075 |
| Adoption of irrigation × Herbicide | - 0.084 | 0.535 |
| Access to extension services × Fertilizer | −0.00035 | 0.794 |
| Access to extension services × Use of improved seed | 0.405* | 0.099 |
| Access to extension services × Access to credit | - 0.069 | 0.745 |
| Access to extension services × Herbicide | 0.066 | 0.417 |
| Fertilizer × Access to credit | - 0.0034** | 0.014 |
| Fertilizer × Use of improved seed | 0.0014 | 0.389 |
| Fertilizer × Herbicide | 0.00018 | 0.645 |
| Use of improved seed × Access to credit | −0.156 | 0.479 |
| Use of improved seed × Herbicide | - 0.322*** | 0.000 |
| Herbicide × Access to credit[a] | – | – |
| Lambda | - 0.079** | 0.047 |
| $\mu_1$ | 0.810 | – |
| $\mu_2$ | 1.916 | – |
| @$\mu_3$ | 3.321 | – |
| Log likelihood | - 748.52 | |
| $\chi 2$ | 361.99*** | |
| Pseudo $R^2$ | 0.189 | |
| N | 690 | |

Note: *** significant at 1%, ** significant at 5%, and * significant at 10%; a: variables omitted because of collinearity.

**Table 9**
Marginal effects associated with the ordered probit model.

| Variables | Severe food insecurity | | Moderate food insecurity | | Marginal food security | | High food security | |
|---|---|---|---|---|---|---|---|---|
| | dy/dx | Prob | dy/dx | Prob | dy/dx | Prob | dy/dx | Prob |
| Age | 0.0065 | 0.281 | 0.00024 | 0.284 | −0.003 | 0.281 | −0.005 | 0.282 |
| Gender (1 = Male, 0 = Female) | - 0.033 | 0.141 | −0.012 | 0.142 | 0.019 | 0.144 | 0.026 | 0.139 |
| Education (dummy) | | | | | | | | |
| Primary school (1 = Yes, 0 = No) | - 0.096** | 0.000 | −0.042*** | 0.000 | 0.058*** | 0.000 | 0.080*** | 0.000 |
| Secondary school (1 = Yes, 0 = No) | - 0.117*** | 0.000 | −0.059*** | 0.009 | 0.068*** | 0.000 | 0.108*** | 0.003 |
| Access to credit (1 = Yes, 0 = No) | - 0.208** | 0.012 | −0.077** | 0.015 | 0.122** | 0.014 | 0.164** | 0.012 |
| Use of improved seed (1 = Yes, 0 = No) | - 0.383*** | 0.002 | −0.142*** | 0.004 | 0.224*** | 0.002 | 0.301*** | 0.002 |
| Access to extension services (1 = Yes, 0 = No) | - 0.316*** | 0.002 | −0.117*** | 0.003 | 0.185*** | 0.002 | 0.248*** | 0.002 |
| Fertilizer (kg/ha) | - 0.0005** | 0.045 | −0.0002* | 0.058 | 0.00033** | 0.048 | 0.00044** | 0.049 |
| Herbicide (Liter/ha) | - 0.068** | 0.028 | −0.025** | 0.036 | 0.040** | 0.030 | 0.053** | 0.031 |
| Informal training (1 = Yes, 0 = No) | - 0.112*** | 0.005 | −0.041*** | 0.006 | 0.066*** | 0.006 | 0.088*** | 0.005 |
| Log of farm income (Income in CFA) | - 0.022*** | 0.000 | −0.008*** | 0.000 | 0.013*** | 0.000 | 0.017*** | 0.000 |
| Log of Off farm income (Income in CFA) | - 0.115*** | 0.000 | −0.0042*** | 0.000 | 0.006*** | 0.000 | 0.009*** | 0.000 |
| Adoption of irrigation (1 = Yes, 0 = No) | - 0.583*** | 0.001 | −0.216*** | 0.002 | 0.342*** | 0.001 | 0.458*** | 0.001 |
| Districts location (reference: District of Malanville) | | | | | | | | |
| Garou | 0.100 | 0.483 | 0.037 | 0.485 | - 0.058 | 0.484 | 0.078 | 0.483 |
| Guene | 0.532*** | 0.000 | 0.197*** | 0.000 | - 0.312 | 0.000 | 0.418*** | 0.000 |
| Tombouctou | 0.184 | 0.140 | −0.068 | 0.151 | - 0.107 | 0.144 | 0.144 | 0.142 |
| Extension visit × Location (reference: Malanville) | | | | | | | | |
| Garou | 0.330*** | 0.000 | 0.122*** | 0.000 | −0.193*** | 0.000 | 0.259*** | 0.000 |
| Guene | 0.152* | 0.084 | 0.056* | 0.090 | −0.089 | 0.088 | 0.119* | 0.083 |
| Tombouctou | 0.356*** | 0.000 | 0.132*** | 0.000 | −0.208*** | 0.000 | 0.279*** | 0.000 |
| Use of improved seed × Location (reference: Malanville) | | | | | | | | |
| Garou | 0.191*** | 0.007 | 0.071** | 0.010 | −0.112*** | 0.008 | −0.150*** | 0.008 |
| Guene | 0.434*** | 0.000 | 0.161*** | 0.000 | −0.254*** | 0.000 | −0.341*** | 0.000 |
| Tombouctou | 0.398*** | 0.000 | 0.147*** | 0.000 | −0.233*** | 0.000 | −0.312*** | 0.000 |
| Access to credit × Location (reference: Malanville) | | | | | | | | |
| Garou | −0.048 | 0.476 | −0.018 | 0.476 | 0.028 | 0.477 | 0.038 | 0.476 |
| Guene | −0.049 | 0.447 | −0.018 | 0.450 | 0.029 | 0.449 | 0.038 | 0.447 |
| Tombouctou | 0.035 | 0.588 | 0.012 | 0.588 | −0.020 | 0.558 | −0.027 | 0.587 |
| Fertilizer × Location (reference: Malanville) | | | | | | | | |
| Garou | 0.00029 | 0.532 | 0.00011 | 0.534 | −0.00017 | 0.532 | −0.00023 | 0.533 |
| Guene | 0.00044 | 0.327 | 0.00016 | 0.331 | −0.00026 | 0.328 | −0.00035 | 0.328 |
| Tombouctou | −0.00016 | 0.701 | −0.00006 | 0.700 | 0.00096 | 0.700 | 0.00012 | 0.701 |
| Herbicide × Location (reference: Malanville) | | | | | | | | |
| Garou | 0.042* | 0.084 | 0.015* | 0.087 | −0.024* | 0.088 | −0.033* | 0.082 |
| Guene | 0.088*** | 0.001 | 0.032*** | 0.002 | −0.052*** | 0.001 | −0.069*** | 0.001 |
| Tombouctou | −0.0053 | 0.835 | −0.0019 | 0.834 | 0.0031 | 0.835 | 0.0042 | 0.835 |
| Adoption of irrigation × Access to extension services | −0.052 | 0.580 | −0.019 | 0.582 | 0.030 | 0.581 | 0.040 | 0.580 |
| Adoption of irrigation × Use of improved seed | – | – | – | – | – | – | – | – |
| Adoption of irrigation × Fertilizer | −0.0015** | 0.008 | −0.00056** | 0.010 | 0.00089*** | 0.009 | 0.0012*** | 0.008 |
| Adoption of irrigation × Access to credit | −0.148* | 0.076 | −0.055* | 0.083 | 0.086* | 0.079 | 0.116* | 0.076 |
| Adoption of irrigation × Herbicide | 0.018 | 0.534 | 0.0067 | 0.534 | −0.010 | 0.535 | −0.014 | 0.534 |
| Access to extension services × Fertilizer | 0.00007 | 0.794 | 0.000028 | 0.794 | −0.00004 | 0.794 | −0.00005 | 0.794 |
| Access to extension services × Use of improved seed | −0.087 | 0.098* | −0.032 | 0.103 | 0.051* | 0.095 | 0.068 | 0.102 |
| Access to extension services × Access to credit | 0.014 | 0.745 | 0.0055 | 0.745 | −0.0087 | 0.746 | −0.0116 | 0.744 |
| Access to extension services × Herbicide | −0.014 | 0.418 | −0.0052 | 0.417 | 0.0083 | 0.418 | 0.0111 | 0.418 |
| Fertilizer × Access to credit | 0.0007** | 0.015 | 0.00027** | 0.016 | −0.00042** | 0.015 | −0.00057** | 0.015 |
| Fertilizer × Use of improved seed | −0.0003 | 0.390 | −0.00011 | 0.388 | 0.00018 | 0.389 | 0.00024 | 0.390 |
| Fertilizer × Herbicide | −0.00004 | 0.645 | −0.00001 | 0.643 | 0.000023 | 0.645 | 0.000031 | 0.644 |
| Use of improved seed × Access to credit | 0.033 | 0.480 | 0.012 | 0.482 | −0.019 | 0.481 | −0.026 | 0.480 |
| Use of improved seed × Herbicide | 0.069*** | 0.000 | 0.025*** | 0.001 | −0.040*** | 0.000 | −0.054*** | 0.000 |
| Herbicide × Access to credit | – | – | – | – | – | – | – | – |
| Lambda | 0.017** | 0.046 | 0.0063** | 0.049 | −0.010** | 0.046 | −0.013** | 0.047 |

Note: *** significant at 1%, ** significant at 5%, and * significant at 10%; dy/dx indicates the marginal effects.

through the two step procedure. Interactive terms of key agricultural inputs were included in the model to assess how the combination of these inputs may affect food security status of the farmers. The district of Malanville was chosen as reference for comparison across districts of the effect of variables included in the model because the rice irrigation scheme is located in that district. The marginal effects are interpreted relative to the food security category and the sign (Table 9).

The results (Table 9) show that the prevalence of food insecurity differs among districts. Relative to the farmers in the districts of Garou, Guene and Tombouctou, living in the district of Malanville decreases the probability of being in severe and moderate food insecurity categories while increasing the probability of being in marginal and high food security categories. However, the effect is significant only for the district of Guene. Farmers in the districts of Guene are about 53% more likely to be in severe food insecurity category and 42% less likely to be in the high food security category than farmers in the district of Malanville (Table 9). With regard to this, one explanation to the difference in food security status among districts could be the presence of the irrigation scheme in the district of Malanville allowing irrigation farmers to produce even during the dry season, and also provision of more institutional support in terms of access to productive inputs and rice marketing.

Consistent with this, adoption of irrigation has a positive and significant effect on the food security status of the farmer (Table 8). This decreases the probability of a farmer being in severe food insecurity category by about 58% while increasing the probability of being in high food security category by about 46% (Table 9). The implication is that the adoption of irrigation contributes to reduce food insecurity among the rice farmers. This is in line with majority of studies [36,52,51,7,3,22,39,49] dealing with the effect of irrigation on food security. In addition to the use of water, irrigation farmers benefit from more support such as extension services, use of improved seed and access to fertilizer and credit. The results also reveal that the interaction terms between adoption of irrigation and access to fertilizer and credit are positive and significant, demonstrating that the adoption of irrigation accompanied by access to fertilizer and credit decrease the probability of a farmer being in severe and moderate food insecure categories while increasing the probability of being in marginal and high food secure categories. Positive sign was also observed for the interaction between extension services and use of improved seed. This means that the effect of adoption is larger for farmers that received extension services and used improved seed than farmers who did not. Negative sign was found for the interactions of the variables fertilizer and access to credit, and use of improved seed and herbicide. This implies that the effect of adoption is smaller for farmers who use fertilizer but lack credit, and also for farmers that used improved seed and lack herbicide. So in addition to the use of irrigation water, accessibility to extension services, fertilizer, credit and improved seed variety should be key policy focus for agricultural development in Benin.

Apart from adoption of irrigation, the other farm input variables have significant effect on food security status among rice farmers in the municipality of Malanville. Use of fertilizer, herbicide and improved seed variety are farm input variables that positively affect food security status of the farmer. For instance the use of improved seed decreases the probability of being in severe food insecurity category by about 38% and increases the probability of being in high food security category by about 30% (Table 9). The results also indicate that the return from the use of improved seed is less in the district of Garou, Guene, and Tombouctou than in the district of Malanville. There was no significant difference in the return from the use of herbicides between Malanville and the district of Tombouctou while in the districts of Garou and Guene, the return is less compared to the district of Malanville.

Regarding the institutional variables, access to credit decreases the probability of a farmer being in the severe food insecurity category by about 21% while increasing the probability of being in high food security category by about 16%. Similarly, access to extension services decreases the probability of a farmer being in the severe food insecurity category by about 32% while increasing the probability of being in high food security category by about 25%. It is observed that the return from access to extension services is higher in Malanville than in the districts of Garou, Guene and Tombouctou. No significant difference was found among the four districts in terms of return from access to credit.

The amount of farm and off-farm income have an effect of decreasing the probability of being in severe or moderate food insecurity categories and increasing the probability of being in marginal or high food security categories. As highlighted in the conceptual framework (Fig. 1), the development of irrigation schemes can also attract a vibrant services sector, which may provide off-farm income opportunities to farmers and contributes to increased total income. This supports the argument that irrigation cannot be introduced in a vacuum without encouraging surrounding service sectors [58]. Theoretically, these results imply that farmers with high farm and off farm income are likely to be food secure. One reason is that as income increases, the farmers may have more money for food, other goods and farm investments. Increased education level of farmers also decreases the probability of being in severe or moderate food insecurity categories and increases the probability of being in marginal or high food security categories.

Compared to uneducated farmers, those that have attained at least primary school have a higher probability of being food secure. This result implies that education is important for improving the food security status of farmers as the educated farmers are more likely to be food secure. The importance of informal training in reducing food insecurity was also stressed in this study. In the municipality of Malanville where only about 14% of the population are literate [28], informal training is an option for improving food security. Farmers who have attained informal training have higher probability of being in the food secure category. The major informal training reported by the surveyed farmers are carpentry, mason or construction works, engineering, and dress making.

The findings of this study suggest that the development of irrigation schemes have helped enhancing food security in Benin. Previous studies [27,14] have shown that irrigation adoption reduces risk of crop failure, leads to food security through higher productivity and income. [12] reported that the irrigation schemes did not only contribute to increased food security, but also profited surrounding communities who were not in the schemes. Irrigators benefit more from institutional support services in terms of access to extension services and credit, and use of farm inputs. The results support the idea that the development of irrigation schemes lead to crowding in of inputs and technologies [59]. The findings also suggest that irrigation schemes offer opportunities for employment through increased demand for inputs and supply of output. This therefore helps farmers in diversifying income sources. For greater impact of irrigation on food security, there is a need for complementary inputs services, policies and institutional support measures. Previous studies [23,38] argue that impacts of investments in irrigation schemes on crop productivity, food security and poverty reduction are greater where institutional support measures and complementary policies and infrastructure are available. While the findings of this study support our hypotheses and expectations, further research might test the robustness of our findings using different data set such as panel data. Furthermore, further research may also consider other outcomes of irrigation adoption such as income diversification, and explore the spillover effects related to changes in food prices.

## 5. Concluding remarks

The motivation of this study was to demonstrate the significance of the linkage between irrigation and food security using the irrigation scheme of Malanville, Benin as an empirical case study. Questionnaire on food insecurity experiences were administered to 690 rice farmers and Rasch modelling was used to assess the validity of the farmers' responses to items. After fitting Rasch model assumptions with the overall rice farmers, separate assessment was done for the irrigation and dry land rice farmers. This shows that both irrigators and dry land farmers' responses to food insecurity questionnaire fit the Rasch model assumptions. Descriptive statistics analysis of food security status of the farmers shows that about 60% of the irrigated rice farmers and 46% of the rainfed rice farmers were food secure, indicating that irrigators were more food secure than dry land farmers. The statistical results were confirmed by an estimation of ordered probit model with sample selection, which demonstrates a positive relationship between irrigation and food security. Other variables that influence food security include educational level, access to credit, use of improved seed, access to extension services, fertilizer and herbicide, farm income, off-farm income, and informal training. The study concludes that investment in irrigation is a potential avenue for reducing food insecurity in Benin. Efforts to rehabilitate current irrigation scheme and develop other schemes should be intensified. However, importance should be given to other factors that affect food insecurity. Thus, there is an urgent need to improve farmers' access to farm inputs, credit and extension services. With these complementary actions, food insecurity could be reduced among rice farmers in Benin.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.wre.2018.05.002.

## References

[1] T. Abonesh, B. Ayalneh, B. Dereje, N. Regassa, Impact of small-scale irrigation on households' food security: evidence from Godino and Filtino irrigation schemes in Ada Liven district, Ethiopia, Irrigat. Drain. Syst. 22 (2006) 145–158.
[2] H. Alaofè, J. Burney, R. Naylor, D. Taren, Solar-powered drip irrigation impacts on crops production diversity and dietary diversity in northern Benin, Food Nutr. Bull. 37 (2016) 164–175.
[3] E. Bagson, C.J.W. Kuuder, Assessment of a small scale irrigation scheme on household food security and leisure in kokoligu, Ghana, Res. Humanit. Soc. Sci. 3 (2013).
[4] T.J. Ballard, A.W. Kepple, C. Cafiero, The Food Insecurity Experience Scale: Developing a Global Standard for Monitoring Hunger Worldwide. Technical Paper. Rome, FAO, (2013) Available at: http://www.fao.org/./FIES_Technical_Paper_v1.1.pdf.
[5] T.J. Ballard, A.W. Kepple, C. Cafiero, J. Schmidhuber, Better measurement of food insecurity in the context of enhancing nutrition, Ernahrungs Umsch. 61 (2014) 38–41.
[6] S. Bezu, G.T. Kassie, B. Shiferaw, J. Ricker-Gilbert, Impact of improved maize adoption on welfare of farm households in Malawi: a panel data analysis, World Dev. 59 (2014) 120–131.
[7] J.A. Burney, R.L. Naylor, Smallholder irrigation as a poverty alleviation tool in sub-saharan Africa, World Dev. 40 (2012) 110–123.
[8] B. Chazovachii, The impact of small scale irrigation schemes on rural livelihoods: the case of Panganai irrigation scheme Bikita District Zimbabwe, J. Sustain. Dev. Afr. 14 (2012) 217–231.
[9] R. Chiburis, M. Lokshin, Maximum likelihood and two-step estimation of an ordered- probit selection model, STATA J. 7 (2007) 167–182.
[10] W.G. Cochran, Sampling Techniques, third ed., John Wiley & Sons, New York, 1977.
[11] H. de Haen, S. Klasen, M. Qaim, What do we really Know? Metrics for food insecurity and undernutrition, Food Pol. 36 (2011) 760–769.
[12] A. Dillon, Access to Irrigation and the Escape from Poverty: Evidence from Northern Mali, IFPRI Discussion Paper 00782, Development Strategy and Governance Division, 2008.
[13] L. Domenech, C. Ringler, The impact of irrigation on nutrition, health and gender, IFPRI Discussion Paper 01259 (2013).
[14] L. Domenech, Improving irrigation access to combat food insecurity and undernutrition: a review, Global Food Security 6 (2015) 24–33.
[15] FAO, IFAD, WFP, The State of Food Insecurity in the World. Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress. Rome, FAO, 2015, (2015).
[16] FAO, World Food Security: a Reappraisal of the Concepts and Approaches, Director Generals Report, Rome, 1983.
[17] FAO, Socio-economic Impact of Smallholder Irrigation Development in Zimbabwe: Case Studies of Ten Irrigation Schemes, FAO Sub-regional Office for East and Southern Africa, Harare, Zimbabwe, 2000.
[18] FAO, Preliminary Review of the Impact of Irrigation on Poverty with Special Emphasis on Asia, Land and Water Development Division, Rome, 2003.
[19] FAO, Measuring Food Insecurity through People's Experiences, One metric for the world, Rome, 2014 Available at: http://www.fao.org/3/a-as583e.pdf.
[20] FAO, Statistical Database (FAOSTAT), Food and Agriculture Organization, Rome, 2014.
[21] M. Hackett, H. Melgar-Quinonez, M.C.A. Uribe, Internal validity of a household food security scale is consistent among diverse populations participating in a food supplement program in Colombia, BMC Publ. Health 8 (2008) 175, http://dx.doi.org/10.1186/1471-2458-8-175.
[22] F. Hagos, K. Mamo, Financial viability of groundwater irrigation and its impact on livelihoods of smallholder farmers: the case of easternEthiopia, Water Resour. Econ. 7 (2014) 55–65.
[23] M.A. Hanjra, T. Ferede, D.G. Gutta, Reducing poverty in Ssub-sSaharan Africa through investments in water and other priorities, Agric. Water Manag. 96 (2009) 1062–1070.
[24] J.-B. Hardouin, Rasch analysis: estimation and tests with raschtest, STATA J. 7 (2007) 22–44.
[25] D. Headey, O. Ecker, Rethinking the measurement of food security: from first principles to best practice, Food Security 5 (2013) 327–343.
[26] J. Heckman, Sample selection bias as specific error, Econometrica 47 (1979) 152–161.
[27] I. Hussain, M.A. Hanjra, Irrigation and poverty alleviation: review of the empirical evidence, Irrigat. Drain. 53 (2004) 1–15.

[28] INSAE, Rapport final de l'Enquête Modulaire Intégrée sur les Conditions de Vie des ménages (EMICoV, 2011). Cotonou, (2011).
[29] INSAE, Tableau de Bord Social 2012, Institut Nationale de Statistique et de l'Analyse Economique, Cotonou, 2013.
[30] IWMI, Revitalizing Irrigation in Sub-Saharan Africa, Productive Water Use, International Water management Institute, 2013.
[31] J.M. Linacre, B.D. Wright, (Dichotomous mean-square) chi-square fit statistics, Rasch. Meas. Trans. 8 (1994) 360.
[32] J.M. Linacre, Comparing “partial credit models”(PCM) and “rating scalem models”(RSM), Rasch. Meas. Trans. 14 (2000) 768.
[33] MAEP, Projet de renforcement des capacités nationales de suivi des ressources en eau axe sur la gestion de l’eau agricole, Ministère de l'Agriculture, de la pêche et de l’élévage, Cotonou, 2009.
[34] MAEP, Réalisations de la campagne agricole 2014–2015, Bénin: Ministère de l'Agriculture, de la pêche et de l’élévage, Cotonou, 2015.
[36] J.H. Mangisoni, Impact of treadle pump irrigation technology on smallholder poverty and food security in Malawi: a case study of Blantyre and Mchinji districts, Int. J. Agric. Sustain. 6 (2008) 248–266.
[37] J.T. Nata, J.M. Mjelde, F.O. Boadu, Household adoption of soil-improving practices and food insecurity in Ghana, Agric. Food Secur. 3 (2014) 17.
[38] C.V. Nguyen, T.D. Phung, V.K. Ta, D.T. Tran, The impact of rural roads and irrigation on household welfare: evidence from Vietnam, Int. Rev. Appl. Econ. (2017) 1–20, http://dx.doi.org/10.1080/02692171.2017.1324408.
[39] R. Nkhata, C. Jumbe, M. Mwabumba, Does Irrigation Have an Impact on Food Security and Poverty? Evidence from Bwanje Valley Irrigation Scheme in Malawi, (2014) Working Paper 04, IFPRI.
[40] G.M.A. Nonvide, D.B. Sarpong, G.T.-M. Kwadzo, H. Anim-Somuah, F. Amoussouga Gero, Farmers' perceptions of irrigation and constraints on rice production in Benin: a stakeholder-consultation approach, Int. J. Water Resour. Dev. (2017), http://dx.doi.org/10.1080/07900627.2017.1317631.
[41] G.M.A. Nonvide, Effect of adoption of irrigation on rice yield in the municipality of Mallanville, Benin, Afr. Dev. Rev. 29 (2017) 109–120, http://dx.doi.org/10.1111/1467-8268.12266.
[42] M. Nord, Introduction to Item Response Theory Applied to Food Security Measurement: Basic Concepts, Parameters, and Statistics, Technical Paper FAO, Rome, 2014 Available at: http://www.fao.org/economic/ess/ess-fs/voices/en.
[43] D. Pimentel, B. Berger, D. Filiberto, M. Newton, B. Wolfe, E. Karabinakis, S. Clark, E. Poon, E. Abbett, S. Nandagopal, Water resources: agricultural and environmental issues, Bioscience 54 (2004) 909–918.
[44] M. Rafiei, M. Nord, A. Sadeghizadeh, M.H. Entezari, Assessing the internal validity of a household survey based food security measure adapted for use in Iran, Nutr. J. 8 (2009) 28.
[45] G. Rasch, Probabilistic Models for Some Intelligence and Attainment Tests, Danish Institute for Educational Research, Copenhagen, 1960.
[46] P.R. Rosenbaum, D.B. Rubin, The central role of the propensity score in observational studies for causal effects, Biometrika 70 (1983) 41–55.
[47] N.R. Sahyoun, M. Nord, A.J. Sassine, K. Seyfert, N. Hwalla, H. Ghattas, Development and validation of an arab family food security scale, J. Nutr. 144 (2014), http://dx.doi.org/10.3945/jn.113.187112 751–575.
[48] A. Sen, Poverty and Famine: an Essay on Entitlement and Deprivation, Oxford University Press, New York, 1981.
[49] S. Sinyolo, M. Mudhara, E. Wale, The impact of smallholder irrigation on household welfare: the case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa, Water SA, Pretoria 40 (2014) 145–156.
[50] L. Teh, C. Pirkle, C. Furgal, M. Fillion, M. Lucas, Psychometric validation of the household food insecurity access scale among lnuit pregnant women from Northern Quebec, PLoS One 12 (2017) e0178708 .
[51] S.S. Tekana, O.I. Oladele, Impact analysis of taung irrigation scheme on household welfare among farmers in north-west province, South Africa, J. Hum. Ecol. 36 (2011) 69–77.
[52] A. Tesfaye, A. Bogale, R.E. Namara, D. Bacha, The impact of small-scale irrigation on household food security: the case of Filtino and Godino irrigation schemes in Ethiopia, Irrigat. Drain. Syst. 22 (2008) 145–158.
[53] G.J. Veldwisch, A. Bolding, P. Wester, Sand in the engine: the travails of an irrigated rice scheme in bwanje valley, Malawi, J. Dev. Stud. 45 (2009) 197–226.
[54] S. Verkaart, B.G. Munyua, K. Mausch, J.D. Michler, Welfare impacts of improved chickpea adoption: a pathway for rural development in Ethiopia? Food Pol. 66 (2017) 50–61.
[55] WFP, Analyse Globale de la Vulnérabilité et de la Sécurité Alimentaire (AGVSA) Benin, (2014).
[56] J.M. Wooldridge, Further results on instrumental variables estimation of average treatment effects in the correlated random coefficient model, Econ. Lett. 79 (2003) 185–191.
[57] W. Zeweld, G.V. Huylenbroeck, A. Hidgot, M.G. Chandrakanth, S. Speelman, Adoption of small-scale irrigation and its livelihood impacts in Northern Ethiopia, Irrigat. Drain. 64 (2015) 655–668.
[58] M. Diagne, M. Demont, P.A. Seck, M.A. Diaw, Self-sufficiency policy and irrigated rice productivity in the Senegal River Valley, Food Secur. 5 (2013) 55–68.
[59] K. Emerick, A. de Janvry, E. Sadoulet, M.H. Dar, Technological innovations, downside risk, and the modernization of agriculture, Am. Econ. Rev. 106 (2016) 1537–1561.
[60] J. Jalan, M. Ravallion, Does piped water reduce diarrhea for children in rural India? J. Econom. 112 (2003) 153–173.
[61] Y. de Mey, M. Demont, M. Diagne, Estimating bird damage to rice in Africa: evidence from the Senegal River Valley, J. Agric. Econ. 63 (2012) 175–200.
[62] V. Owusu, A. Abdulai, S. Abdul-Rahman, Non-farm work and food security among farm households in Northern Ghana, Food Pol. 36 (2011) 108–118.
[63] J. Smith, P. Todd, Does matching overcome LaLonde’s critique of nonexperimental estimators? J. Econom. 125 (2005) 305–353.
[64] D. Zeng, J. Alwang, G.W. Norton, B. Shiferaw, M. Jaleta, C. Yirga, Ex post impacts of improved maize varieties on poverty in rural Ethiopia, Agric. Econ. 46 (2015) 515–526.