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Economic Valuation of Ecosystem Services from Small-Scale Agricultural Management Interventions in Burkina Faso: A Discrete Choice Experiment Approach

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Received: 22 July 2017; Accepted: 18 September 2017; Published: 20 September 2017

Abstract: The main purpose of this paper is to estimate farmers' preferences and their willingness to pay (WTP) for ecosystem services derived from four agricultural water management (AWM) and resource recovery and reuse (RRR) intervention options in Burkina Faso, using a choice experiment (CE). These include; small water infrastructure, drip irrigation, recovery of organic matter from waste, and treated wastewater. The design decisions relating to attribute selection, the level of attributes, alternatives and choice tasks were guided by literature, field visits, focus group discussions, expert input and an iterative process of the STATA software to generate an orthogonal main-effects CE design. The data used was generated from a random sample of 300 farm households in the Dano and Ouagadougou municipalities in Burkina Faso. Results from conditional logit, latent class logit and mixt logit models show that farmers have positive and significant preferences for drip irrigation, treated wastewater, and organic matter. However, they are WTP on average more for drip irrigation and organic matter for agricultural sustainability. In line with economic theory, the cost of an intervention reduces demand for a given intervention. These findings can provide policy makers with evidence for agricultural policy design to build farmers' resilience in the Sahel.

Keywords: Burkina Faso; climate change; agriculture; AWM interventions; ecosystem services; economic valuation; choice experiment; willingness to pay

1. Introduction

Understanding the economic value of nature and the services it provides to mankind (e.g., food, fiber, medicines, improved air quality and clean water; protection from flooding, storms, and pests; and cultural and spiritual wellbeing, among others) has become increasingly important since the publication of the Millennium Ecosystem Assessment (MEA) report in 2005 [1]. Since its publication, there has been increased recognition that the benefits people gain from nature, including its services, are fundamental to the global economy and human well-being [2]. This explains why economic and ecological valuations of ecosystem services (ES) have received much attention in recent years. In fact, it is increasingly being recognized that quantifying and integrating ES and benefits into decision-making will be crucial for sustainable development [1].

This is particularly relevant for sub-Saharan Africa (SSA) in general, and West Africa in particular, where agriculture is the main source of livelihood for over 60% of the population, and known to represent humankind's largest engineered ecosystem through its provisioning services [3]. Indeed, the intensive use of chemical fertilizers and pesticides, including agricultural practices that enhance soil degradation among others, lead to ecosystem dis-services that reduce productivity or increase production costs [3]. This is coupled with the worsening threat from climate change (CC). According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), CC will amplify existing stress on agricultural systems and water resources in SSA [4]. In fact, the report stresses that it is projected that between 75 million and 250 million people in SSA will be exposed to increased water stress due to climate change. Consequently, it is projected that agricultural production, including access to food, in many SSA nations will be severely compromised by climate variability and change [5]. According to the Montpellier panel of 2013, without positive productivity changes, food production systems in West Africa, for example, will only be able to meet 13% of needs in 2050; and, under moderate CC without adaptation, total agricultural production in West Africa will even decline by at least 1.5% by 2050 [6].

The situation is abysmal in Burkina Faso, West Africa, where the frequency of annual droughts and extremely hot temperatures during the seasons have increased considerably [7]. This has had profound, adverse effects on the nation's major economic growth driver, agriculture [8]. The search for solutions has led to overwhelming agreement that the most effective strategies capable of addressing the devastating consequences of climate change on socio-ecological systems are embedded in simultaneously (i) tackling the issue of soil infertility and land degradation; (ii) scaling up recommended agricultural technologies or practices to increase agricultural productivity; (iii) improving the livelihoods of smallholders and enhancing food security; (iv) mainstreaming solutions to climate change and variability into local, regional and transnational development plans; and (v) developing the capacity of smallholders, stakeholders and policy makers [9–11].

It is in that context that an array of agricultural water management and resource recovery and reuse intervention solutions are currently being promoted in the country, to improve agricultural productivity in different ways. For instance, smallholder drip irrigation has been extensively promoted in Burkina Faso to improve agricultural productivity and generate livelihood benefits through water-saving [12,13]. Similarly, the reuse of wastewater to supplement periods of water scarcity during small-scale irrigation efforts, or recovering organic matter from fecal sludge for soil fertility improvement, are under experimentation in Burkina Faso [14,15]. In addition, the reuse of wastewater as an alternative source of water in water-scarce conditions is especially anticipated in urban and semi-urban agriculture in the country [15].

Despite the great potential of AWM/RRR interventions to improve productivity, food security, livelihoods and environmental health, these solutions have not received much publicity in many parts of the country [16]. As a result, many smallholder farmers still practise the traditional, less-water efficient, bucket-based irrigation, which constantly leads to water shortages, especially in the dry season. Dry-season farming is increasingly becoming important in many parts of the country. In fact, many smallholders are now engaged in market gardening of vegetables in the dry season as a way of generating an additional household income stream outside the rainy season [12]. However, access to sufficient water and soil infertility remain major challenges to sustainable production in the country.

The main purpose of this paper was, therefore, to find out the value placed by smallholder farmers on AWM/RRR interventions for sustainable agricultural productivity in the country. Specifically, the paper estimates farmers' preferences and their willingness to pay (WTP) for four AWM/RRR intervention solutions using the discrete choice experiment (CE) approach. These include small water infrastructure, drip irrigation, organic matter recovery from waste, and treated wastewater. Knowledge about farmers' preferences and their WTP for AWM/RRR interventions can help policy makers, NGOs, donor agencies as well as international research institutions working on agricultural policy to effectively address AWM and RRR policy design in order to help build farmers' resilience in the Sahel.

The rest of the article is structured as follows: a brief description of the choice experiment design, the econometric specification and the case study are presented in Section 2. Section 3 presents the results, followed by the discussion and conclusion in Section 4.

2. Materials and Methods

2.1. Study Area

The study was conducted in Burkina Faso in West Africa. The country covers an area of 274,400 km^2, and in relief is made up of plains and is dominated by the savannah shrub and steppe [17]. Rain-dependent subsistence agriculture to provide basic food for the population is extensive and almost exclusive. The experimental sites were located in the center and south-west of Burkina Faso: Ouagadougou and Dano (Figure 1).

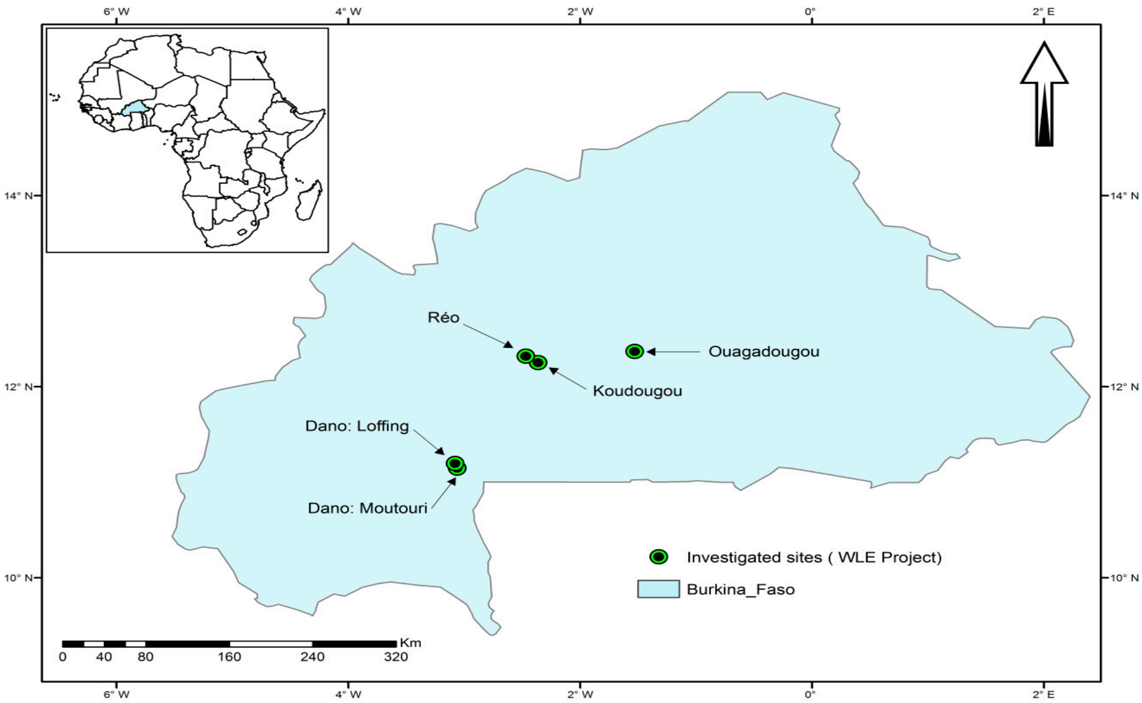

Figure 1. Study areas in Burkina Faso.

Ouagadougou is the capital of Burkina Faso. It is also the capital of the province of Kadiogo, located in the center of the country. The city has a land area of 2805 km^2 for a population of about 2,600,000 inhabitants in 2016 [18]. Situated in the Sudano-Sahelian agro-ecological zone, the area is characterized by a rainy season extending from May to October when rainfall is rarely above 700 mm [17]. Regarding urban agriculture carried out in the city, the main activity is the production of vegetables for market such as cabbages, cucumbers, salads, and onions.

Located in the south-western part of Burkina in Ioba province, Dano covers a total area of 195 km^2. This zone reflects Sudanian agro-ecology and is characterized by wooded, scrubby savannah and abundant annual grasses. The area is one of the most watered areas of the country. Agriculture is the main activity of the population. Vegetable production is extensively carried out in the dry season. In the rainy season, crops like sorghum (*Sorghum bicolor*), millet (*Pennisetum glaucum*), cotton (*Gossypium hirsutum*), maize (*Zea mays*), cowpeas (*Vigna unguiculata*), and groundnut (*Arachidis hypogaea*) are cultivated [17].

2.2. Sampling

The sampling framework used for the study was a 2-stage stratified simple random technique. In the first stage of the design, a comprehensive list of farmers in each study area was drawn up. In the second stage of the design, farmers were classified into three strata based on the total land size their farms covered in the dry season: low land size (less than 0.025 ha), average (between 0.025 and 0.05 ha), and high land size (0.05 ha and above). On the basis of this, 50 respondents were then randomly selected from each strata, which amounted to over 300 respondents in Dano and Ouagadougou (150 per area). The two municipalities were purposely selected from the two agro-ecological zones based on the importance of vegetable market-gardening production. All respondents agreed to be interviewed and answered all questions.

The survey was pre-tested in two rounds of interviews, with 5 and 10 interviews, in March 2016. After the first pre-test, minor modifications to the questionnaire were made, while the second pre-test did not result in further changes. The survey was conducted in April 2016 via face-to-face interviews. Interviews were conducted in the local languages (Dagara and Moore) on respondents' farms upon appointment.

To minimize likely biases that may affect the quality of collected information, the enumerators explained the concepts and purposes of the survey and presented an overview of the various functions to be valued, including a description of the attributes and the levels presented. Respondents were assured that the collected data would be kept anonymous, in order to minimize the social desirability bias.

2.3. Analytical Framework

2.3.1. Choice Experiment (CE) Approach

For analytical purposes, the discrete choice experiment (CE) approach was used. The method is deeply rooted in Lancaster's theory of consumer choice [19], which postulates that consumption decisions are determined by the utility that is derived from the attributes of a good, rather than from the good per se. The econometric basis of the CE hinges on the behavioural framework of random utility theory, which describes discrete choices in a utility-maximizing framework [20,21]. Thus, it can be assumed that farmers, when asked to value alternatives among AWM and RRR solutions for increasing agro-ecological resilience and sustainability, make their choices on the basis of the specific features of AWM and RRR practices. The utility obtained from a certain AWM and RRR solutions feature is then the sum of the utilities obtained from each choice in the attributes defined in the CE design.

According to the random utility theory, the utility from a good consists of deterministic and stochastic elements as follows [20]:

$$U_{in} = V_{in} + \varepsilon_{in} \tag{1}$$

where U is the true but unobservable utility of an individual n for alternative i,V is the deterministic and observable component of utility, depending on the alternatives' attributes and ε_i is a random variable that captures the unobservable influences on choice. The latter is a stochastic component of utility that is independent and identically distributed (iid) across individuals and alternative choices, and takes a known (Gumbel) distribution. The underlying assumption following [20] on random utility theory is that an individual n, would choose an alternative i from a specific choice set C, given the utility U, if i is greater than the utility of any other choice j in the choice set:

$$\text{Prob}(Y_n = i/C) = \text{Prob}(V_{in} + \varepsilon_{in} > V_{jn} + \varepsilon_{jn}), \forall j \in Cn,\ j \neq i \tag{2}$$

Y_n denotes the respondent's chosen alternative in choice set C, and the respondent's sequence of choice in the C choice occasion is $Y_n = Y_{n1}, Y_{n2}, \ldots\ldots.. Y_{nc}$.

However, accounting for preference heterogeneity provides a broader picture of the distributional consequences and other impacts of policy actions, thereby providing better insight into policy outcomes [22]. Thus, among recent innovations aimed at accounting for preference heterogeneity in choice models are the latent class logit model (LCL) and the mixed logit (ML) [23–25].

The LCL postulates a discrete distribution of tastes in which individuals are intrinsically sorted into numbered segments (or classes), with each class holding the same preferences (homogenous in preferences) and heterogeneous across segments [26]. This may be a constraint to the assumption of the independence of irrelevant alternatives (IIA). If we assume that $P_{n|s(i)}$ stands for the probability that an individual n belongs to segment S, Zn for the socio-demographic and farm characteristics, and β_s for a vector of class-specific coefficient, the segment specific choice probability becomes [27]:

$$P_{n|s(i)} = \frac{\exp(\tau_s Z_n)}{\sum_{s=1}^{s} \exp(\tau_s Z_n)} \tag{3}$$

Hence, the probability P_{ins} that individual n belonging to a segment S chooses the alternative i is given by:

$$P_{ins} = \sum_{S=1}^{S} P_{in} \cdot P_{n|s(i)} \tag{4}$$

The relationship between socio-demographic and farm characteristics and the segment membership was estimated using a multinomial logit specification.

One advantage of using the mixed logit (ML) model is that it relaxes the assumption of independence of irrelevant alternatives that results from the independent and identically distributed property underlying the conditional logit model. This, therefore, allows for the parameters to be randomly distributed across the population in order to capture preference heterogeneity [21,25]. However, since we do not observe β_i, but only its density $f(\beta_n|\theta)$ is assumed to be known, the unconditional probability of the respondents' sequence of choices is given as:

$$\text{Prob } (Y_n = i) = \int \frac{\exp(\beta_n X_{in})}{\sum_{jeC} \exp(\beta_n X_{jn})} f(\beta_n|\theta d)\beta_n. \tag{5}$$

Note that rather than considering all these models as competing approaches, in this paper they were used as complementary models to enhance our understanding of the preferences underlying the observed choices of AWM and RRR solutions for sustainable agricultural production.

2.3.2. Welfare Analysis

Following [28], we estimate farmers' WTP for a change in attribute levels by taking the ratio between the coefficients of individual attributes and the price attribute as follows:

$$WTP_i = \frac{dx_i}{dx_c} = \frac{-\beta_i}{\delta_c} \tag{6}$$

where, by definition, WTP_i is the willingness to pay for a given AWM and RRR attribute, β_i is the marginal utility of an attribute i, and δ_c is the estimated parameter of cost associated to the alternatives.

2.3.3. The Attributes and Attribute Levels of the Selected AWM and RRR Solutions

The AWM and RRR solutions considered in this study are small-scale water infrastructure (SWI), drip irrigation, treated wastewater from households, and organic manure from excreta. They are currently objects of experimentation in the Sahel to improve sustainable agricultural practices, including ES sustainability, in different ways.

In order to select the attributes of AWM and RRR solutions, focus group discussions (FGDs) were conducted with farmers to better define and validate the attribute levels [29]. The main interests in this consultation were: to give an overview of the level of information to be provided to respondents during the survey; to identify the different groups concerned by agricultural productivity issues; and to know their opinions of and interests in AWM and RRR solutions for sustainable agricultural production. For example, reference [30] recommended identifying large groups of users in advance, then grouping them into groups of 3 to 6 people with the same purpose, in order to avoid conflicts of interest during the focus. The latter was used during the fieldwork to generate discussions about the characteristics of the AWM and RRR solutions, their definition, and their potential variation in different levels. Consequently, this resulted in the follow attribute levels:

- Small-scale water infrastructure: reservoir, deep-well, drilling (borehole);
- Irrigation system: manual, drip irrigation;
- Wastewater use for irrigation: yes, no;
- Fertilizer use: chemical fertilizer, organic matter from human sludge.

For the definition of the monetary attribute, the average area sown for market gardening was first estimated through focus group, which is on average 1 ha. The cost associated with the current production practices is estimated, on average, at 312,000 F CFA (US$494.7) (1 USD = 630.7 F CFA, Live mid-market rate (28 December 2016 12:30 local time)) per ha per production. Based on this amount, farmers were asked to state their WTP to improve current agricultural practices with AWM and RRR interventions. Subsequently, it was estimated how much they are WTP above the 312,000 F CFA to opt for AWM and RRR solutions. This resulted in increases of 10%, 20% and 30% on the current cost (312,000 F CFA). Alternatively, when asked about how much they are WTP below the current cost of production, the results were a decrease of 10% and 20% of 312,000 F CFA. Hence, the monetary attribute levels were: 249,600 F CFA (US$395.8) and 280,800 F CFA (US$445.2) below the current cost of production; and 343,200 F CFA (US$544.2), 374,400 F CFA (US$593.6) and 405,600 F CFA (US$643.1) above the current cost. These, therefore, led to the definitions of the levels of the attributes (i.e., five) presented in Table 1.

Table 1. Attributes and attribute levels.

Attributes	Description	Levels
Small Water Infrastructures (SWI)	Affordable SWI is required for sustainable irrigation in the dry-season.	**Reservoir**
		Deep-well
		Drilling (borehole)
Irrigation System	Appropriate irrigation technology for saving water in the dry-season.	**Manual irrigation**
		Drip Irrigation
Wastewater Re-use	Value of the wastewater from household in agricultural production contributes to improving farmer welfare.	**No**
		Yes
Organic Waste Use	Relocating human faeces as organic amendment to increase crop production helps sustain agriculture.	**Chemical**
		Organic matter from human sludge
Monetary Attributes	Payment (FCFA) per hectare.	249,600; 280,800; 343,200; 374,400 and 405,600.

Notes: Levels in bold represent the current practice available in the study areas.

2.3.4. Experimental Design

The five attributes and their different levels resulted in (3 × 2 × 2 × 2 × 6) × (3 × 2 × 2 × 2 × 6) = 20,736 possible alternative options. The STATA Software package was used to generate an orthogonal main effects design. This resulted in 18 paired choice alternatives which were then randomly blocked into three sets of six choices using the D-create option in STATA (Note that after running dcreate, the blockdes command was used in STATA to randomly divide the design into blocks. The blockdes command assumes that no changes to the dataset have been made after running D-create. Any changes are likely to affect the quality of the blocking.) Hence, each farmer faced at most six choice tasks. Presenting the choices in this format is ideal for saving questionnaire completion time and preventing response fatigue [31]. Each paired choice set offered respondents a choice of two alternatives with a status quo option. Thus, during the choice experiment survey, respondents were interviewed on which of the two alternatives they preferred, but were allowed to state for 'status quo' which represents neither. Including the status quo alternative avoids a forced choice by giving respondents the possibility to choose neither alternative in the choice set, which serves to make the results obtained consistent with demand theory [32]. An example of a choice set presented to the farmers is shown in Table 2.

Table 2. Example of choice card.

Choice	Alternative 1	Alternative 2	Status Quo
SWI	Drilling (borehole)	Deep-well	
Irrigation System	Drip irrigation	Manual irrigation	
Waste Water Re-use	Yes	No	
Organic Waste Use	Organic waste from faeces	Chemical fertilizer	
Payment (F CFA) per hectare	405,600 F CFA	343,200 F CFA	
Which of the alternatives do you prefer?	◯	◯	◯

Note: Farmers must choose only one.

The questionnaire consisted of three main sections. The first section contained questions relating to socio-economic and farm operations (farm area, type of crop grown, type of irrigation system used and type of fertilizer used). The second part elicited information about farmers' perceptions of AWM and RRR for sustainable agriculture production. The last section contained the choice sets and a follow-up question to check for protest bidders.

3. Results

3.1. Sample Statistics

The descriptive statistics for the sample respondents are presented in Table 3. The results show that approximately 68.3% of the respondents were male farmers, while only about 31.7% were females. The mean age of the sample was 41 years with an average vegetable-farming experience of about 16 years. The mean income of the sample was estimated at 365,195.5 F CFA or about US$579.0 for an average farm holding of approximately 0.12 ha. The results reveal, furthermore, that over 67% of the sample acknowledged using at least one of the proposed alternatives of the AWM and RRR intervention solution as follows: drip irrigation (33.3%), organic matter (33.3%), wastewater (32.7%), deep-well (22.3%), and drilling (22.3%). Finally, the average cost per hectare for a given AWM and RRR intervention solution was calculated at 219,452.2 F CFA or about US$347.9.

Table 3. Sample statistics.

Variables	Units	Code	Mean	Std. Dev.
ASC	%	1 = Alternative of AWM and RRR, 0 otherwise	66.7	0.47
Deep-well	%	1 = If deep-well and 0 otherwise	22.3	0.41
Drilling	%	1 = If drilling and 0 otherwise	22.3	0.41
Drip irrigation	%	1 = If drip irrigation and 0 otherwise	33.3	0.47
Wastewater	%	1 = If wastewater and 0 otherwise	32.7	0.46
Organic matter	%	1 = If organic matter and 0 otherwise	33.3	0.47
Cost per hectare	F CFA	Continuous	219,452.2	160,825.62
Age	Year	Continuous	41.1	8.53
Sex	%	1 = Male, 0 = Female	68.3	0.46
Experience	Year	Continuous	16.0	7.82
Income	F CFA	Continuous	365,195.5	321,881.5
Land size	Hectare	Continuous	0.12	0.09

3.2. Model Estimation Results

3.2.1. Conditional Logit (CL) Estimates

Column 2 of Table 4 presents the results of the CL model. As indicated earlier in the section on methodology, the CL model imposes the assumption of IIA. However, if the IIA assumption does not hold, then the CL model would yield biased estimates [33]. The Hausman and McFadden test for the IIA property was applied under the null hypothesis of no violation in order to test the IIA assumption [34]. Violation of the IIA assumption is not evident from the test results. This, therefore, suggests that the CL modelling results are likely to yield unbiased estimates of the attributes. We equally used the likelihood ratio (LR) test under the null hypothesis that all the coefficients of the model are equal to zero in order to test for model robustness. Since the computed LR statistic of $x^2(7) = 3114.1$ is larger than the computed t-value of 18.5 at seven degrees of freedom, we reject the null hypothesis and conclude that the model has a robust explanatory ability.

As shown (column 2, Table 4), most of the coefficients of the attributes of the CL model are highly significant at 5% and below, except for the alternative specific constant (ASC). The significance of the attribute and the sign shows that, *ceteris paribus*, deep-well, drilling, drip irrigation, wastewater and organic matter from human sludge increase the likelihood of selecting a given AWM and RRR intervention option; while higher costs of a choice option decreases the probability that it would be preferred, keeping all other attributes constant. The positive and insignificant coefficient of the ASC suggests that farmers have preference for the proposed AWM and RRR intervention options. However, the expected utility impact is bidirectional. That is, it can occur from the attributes or from the status quo scenario. This is consistent with the results of the descriptive statistics (Table 3), which show that about 33.33% of farmers were willing to keep their status quo level.

Overall, the CL results therefore suggest that farmers would prefer an AWM and RRR intervention solution that will guarantee constant water supply and availability (deep-well), efficient water use and labour saving (drip irrigation), abundant crop nutrients (wastewater), and soil health improvement and fertility restoration (organic matter). We also found considerable consistency with economic theory. Specifically, that the cost of an AWM and RRR intervention option reduces demand for a given AWM and RRR intervention option. The empirical findings, therefore, suggest the existence of significant values and preferences for the stated AWM and RRR attributes.

However, despite the fact that the IIA assumption holds in the CL model, CL further assumes homogeneity across individual preferences. Since preferences are heterogeneous, we need to account for this heterogeneity in order to obtain unbiased estimates of individual preferences. In addition, for a prescription of policies that take into account equity concerns, accounting for preference heterogeneity is critical [22,35].

3.2.2. Latent Class Logit (LCL) Estimates

In order to explore if heterogeneity in farmers' preferences may reflect systematic variation and be ascribed to groupings among farmers, we therefore used the latent class logit (LCL) model. The LCL model postulates a discrete distribution of tastes in which individuals are intrinsically sorted into a number segments (or classes), with each class holding the same preferences (homogenous in preferences) and heterogeneous across segments.

Following [22,36], the age, sex of the farmer, experience in dry-season vegetable production, average income earned from vegetable production, frequency of production in the dry-season, and land size were used to differentiate farmers into groups. The Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used to select the preferred model in terms of the number of classes. According to [37], the preferred model is the one with the lowest AIC and BIC. As observed (Table 5), the criteria increase slightly as the number of class increases, but the improvements of the predictive quality are much smaller from models of class 2 to that of class 3. This suggests that a two-class solution may be appropriate. Hence, the model with two classes is the preferred specification.

Table 4. Farmers preferences for AWM & RRR solutions from CL, LCL and ML models.

Attributes [1]	CL (Model I) [2]		LCL (Model II) [3]				ML (Model III) [4]			
	Coefficients	Standard Errors	Class 1 Coefficients	Standard Errors	Class 2 Coefficients	Standard Errors	Mean of Parameters	Standard Errors	S.D of Parameters	Standard Errors
ASC	20.134	405.619	21.673	888.291	12.16	904.99	47.98	7730.47	-	
COST	−0.0003 ***	0.0002	−0.0003 ***	0.0004	0.0003 ***	0.0001	−0.0004 ***	0.0005	-	
Deep-well	0.296 *	0.165	0.417	0.277	−1.836 ***	0.524	0.385 **	0.193	−0.482	0.341
Drilling (borehole)	0.556 ***	0.182	0.716 **	0.293	0.243	0.311	0.677 ***	0.222	0.812 **	0.383
Drip irrigation	2.716 ***	0.143	3.775 ***	0.344	3.208 ***	0.452	3.505 ***	0.356	1.247 ***	0.263
Wastewater	0.552 ***	0.102	0.756 ***	0.154	0.102	0.244	0.794 ***	0.170	−0.164	0.335
Organic matter	1.720 ***	0.137	2.781 ***	0.346	0.055	0.228	2.17 ***	0.2235	−0.487 **	0.234
Log-Likelihood	3114.08		2818.49		469.99		-		16.93	
p-value	0.000		0.000		0.000		0.000		0.0046	
Hausman $x^2(5)$	0.76									
McFadden Prob > x^2	0.98									

Significance of parameters *** <0.01, ** <0.05, * <0.10.

Table 5. Criteria for selecting number of latent classes.

		Log Likelihood	AIC	BIC	Predictive Quality (%)
Latent Class	Class 2	−359.14	718.32	718.32	94.18
	Class 3	−359.21	718.40	718.40	95.58
	Class 4	−367.26	718.39	718.39	92.95

Table 6 shows the effects of farmers' characteristics on the probability of class membership. As shown (Table 7), the average probability of being in class 1 is estimated at 82.6% and in class 2 at 17.4%. Equally, while 84% of the sample holds class 1 membership, about 16% are in class 2. Furthermore, the class-membership model parameters reveal that the sex of farmers (male), age (older), higher income and larger land size holdings increase the probability of belonging to class 1. Similarly, in class 2, the class membership coefficients show that farmers having more experience in vegetable production and farmers that produce vegetables more frequently in the dry season are more likely to belong to this class.

Table 6. Class membership.

Variable	Class 1		Class 2
Average class probability (%)	82.63		17.37
Class share (%)	84.00		16.00
	Coefficients	**Standard Errors**	
Constant	0.25	0.27	Reference
Age	0.13 ***	0.008	
Sex (1 = Male, 0 = Female)	1.72 ***	0.15	
Experience	−0.11 ***	0.008	
Income	0.104 ***	0.05	
Frequency of production	−2.38 ***	0.09	
Land size	15.19 ***	0.85	
Log-Likelihood	1886.77		
p-value	0.000		

Significance of parameters *** <0.01.

Table 7. Change in welfare estimates for AWM and RRR intervention solutions.

Attributes	Willingness to Pay (F CFA Per Ha)			
	LC	LCL		ML
	N = 5391	Class 1 (*N* = 4530)	Class 2 (*N* = 861)	*N* = 5391
Deep-well	20,800	-	102,875	-
Drilling	39,100	37,170	-	35,160
Drip irrigation	190,700	195,745	179,700	181,800
Wastewater	39,440	39,730	-	-
Organic matter	120,780	144,200	-	112,550

The LCL results suggest that there is substantial heterogeneity in preferences for AWM and RRR attributes across classes, as indicated by the differences in the magnitude, significance and signs of the parameters (column 3, Table 5). As expected, the coefficients of the cost attribute are highly significant, at 1% in both models. However, while it is negative in the class 1 membership model, it is positive in the class 2 model. The latter is so perhaps because class 2 farmers produced more frequently in the dry-season and, as such, are more willing to incur higher costs for a given AWM and RRR intervention option to ensure dry-season production.

The results reveal, furthermore, that farmers belonging to class 1 exhibit a positive preference for drilling, drip irrigation, treated wastewater and treated organic matter from human sludge, as demonstrated by the positive sign of the coefficients of these attributes. Thus, it seems that when the farmer is an older male, has large land holdings, and earns more from dry-season vegetable production, he would prefer to invest in drilling, drip irrigation, wastewater and organic matter to produce more in the dry season. This is not surprising considering the fact that dry-season vegetable production is labour intensive, very strenuous, time- and water-consuming, as well as being highly dependent on soil nutrients and fertility. Thus, investing in drilling, drip irrigation technology, wastewater and organic matter would not only guarantee a constant water supply and availability, but would equally ensure that water is efficiently used, time and labour is saved, crops will receive abundant nutrients, and that there would be improved soil health and fertility.

Furthermore, the results show, by contrast, that class 2 farmers have a positive preference only for drip irrigation. This is expected, as drip irrigation is widely presented as the ideal option for the efficient use of water in agriculture in a water-scarce region like Burkina Faso. In fact, because class 2 farmers produced more frequently in the dry season, water efficiency is of paramount importance to them. Thus, it is therefore not surprising that they expressed a higher preference for drip irrigation than other AWM and RRR attributes. Similarly, their preference for deep-well is negative, which means that they express a greater dis-utility for this attribute as a SWI to ensure water availability in the dry season. Based on their experience, it seems that deep-wells cannot provide and ensure constant water availability for production, especially during the dry-season. Even if they do, experience has shown that farmers might need to put in extra effort to ensure water availability.

The results of the LCL model that assumes homogeneity among farmers and heterogeneity across farmers' group reveal significant preferences for the proposed AWM and RRR intervention solutions. However, the model does not show the sources of heterogeneity among farmers [26]. To address this issue in our analysis, we used the mixt logit model.

3.2.3. Mixt Logit Estimates

In order to estimate the mixt logit (ML) model, the cost attribute and the ASC variable were specified as fixed. Also, to ensure that the signs of the standard deviations can change throughout the full range of the estimated model, all other attributes of the AWM and RRR solutions were entered as random parameters assuming a normal distribution [38]. To test for model robustness, we again used the likelihood ratio test statistics. The LR test result reveals a computed value of $x^2(5) = 16.93$ as shown in column 4 of Table 4. However, since the computed LR value is greater than the *t*-value of $x^2(5) = 15.1$, we conclude that the model has a higher level of parametric fit with very robust explanatory ability. These results are shown in column 4 of Table 4.

Note that, as in the case of the CL and LCL models the coefficients of cost attribute and the ASC in the ML model remained unchanged in signs. According to [39,40], the estimated means and standard deviations of the normally distributed coefficients reported in column 4 of Table 4 provide information about the proportion of farmers anticipating a positive value on a particular attribute, as well as those that that place a negative value on that attribute (i.e., the probability distribution). Thus, an attribute is considered to have no impact on a farmer's choice decision when both the estimates of the mean and the standard deviation are not significantly different from zero [41].

Based on the derived standard deviations of parameter distributions, the results indicate the existence of heterogeneity in preference among the farmers for all attributes except deep-well and wastewater. This is based on the fact that, while the coefficients of the means for deep-well and wastewater are significantly positive, this does not hold for their respective standard deviations. In other words, although deep-well and wastewater are necessary interventions for farmers, the results suggest no diversity of preferences among farmers for these two attributes. This may be related to cost constraints. By contrast, the coefficients for means and standard deviations for drilling (borehole), drip irrigation, and organic matter attributes, were all significant and positive. This, therefore, shows that on average, vegetable farmers preferred AWM and RRR intervention policies that featured drip irrigation, drilling, and organic matter from human sludge. This is not surprising, as these attributes would guarantee a constant water supply and availability, efficiency in water use, time and labour saving, as well as improvements in soil health and fertility essential for dry-season vegetable farming.

Overall, the results indicate that there is a significant heterogeneity in preferences among farmers for drilling, drip irrigation and organic matter. However, not all the farmers felt that these three attributes were necessary. For instance, while an estimated 79.8% (The value of 79.75% (probability distribution of preference) is calculated as ϕ [−(mean parameter estimate/parameter standard deviation)] where [x] is the cumulative standard normal distribution) of the farmers prefer drilling as SWI to ensure water availability in the dry season, more than 99.8% indicated a positive preference for the drip irrigation technology to save and use water efficiently. In addition, the use of the treated organic matter from human sludge seems to influence the preferences of almost all of the farmers. Evidence from the estimates parameters indicates that about 99.9% of farmers prefer organic matter from human sludge to ensure crop nutrients.

Judging from the high positive probability distribution, we may conclude as in [42] that, collectively, the attributes used in the CE design captured the range of preferences of the farmers with respect to sustainable agricultural productivity through AWM and RRR intervention solutions.

3.3. Estimating Willingness to Pay for the AWM and RRR Interventions

In the Section 3, we report farmers' average WTP for the AWM and RRR intervention solutions. This is calculated based on the significant parameter estimates of the CL, LCL and ML models reported in Table 4. Positive values depict the increase in per hectare payments that farmers would be willing to trade-off in order to gain a more desirable attribute of a given AWM and RRR intervention option. Negative values indicate the increase in the payments that farmers would demand in return for accepting a less desirable attribute. Thus, a high WTP value for a given AWM and RRR solution indicates that the farmers expect to obtain better utility/welfare through it. The results are shown in Table 7.

On average, farmers are WTP more for drip irrigation and organic matter from faeces, as evident from the results of the CL model (Table 7). That is, they are WTP about 190,700 F CFA or about US$302.4 for drip irrigation, and 120,780 FCFA (US$191.5) for organic matter recovery from faeces. However, when heterogeneity in preferences is factored into the calculations, we obtained marginal differences in the WTP estimates. For instance, the results show that farmers belonging to class 1 are WTP on average 195,745 F CFA or about US$310.4 for drip irrigation and 144,200 F CFA (US$288.6) for organic matter recovery from faeces. The relatively high WTP for drip irrigation and organic matter adoption suggest that farmers derive more direct benefits from these interventions. Given that class 1 is characterized by high income shares, they are more willing to invest in the use of drip irrigation and organic matter from faeces to improve their welfare. In contrast, their WTP for drilling and wastewater is lower, at about 39,000 F CFA (US$61.8) per hectare per production for wastewater and 37,170 F CFA (US$58.9) for drilling. The same could be said about farmers belonging to class 2. They are WTP on average 179,700 F CFA (US$284.99) to adopt drip irrigation as small water infrastructure. By contrast, their WTP for deep-well is about 102,875 F CFA (US$163.1) against a WTP value of 20,800 F CFA (US$32.9) on average per hectare in general, as shown in Table 7 above.

4. Discussion and Policy Implications

Changes in farmers' behaviour toward the adoption of AWM and RRR interventions in Burkina Faso and the Sahel region in general are necessary for sustainable agricultural production. Unfortunately, little is known about farmers' preferences and their WTP for the adoption of these small-scale agricultural management technologies and practices to improve farm productivity. Using the choice experiment approach to estimate farmers' trade-offs between five selected AWM and RRR attributes, we found that farmers in general, have positive and significant preferences for the adoption of drip irrigation technology, treated wastewater, and organic matter. Moreover, they are

WTP, on average, more for drip irrigation technology and organic matter recovered from human fecal sludge.

This, therefore, underscores the high importance farmers attached to these interventions for increasing agro-ecological resilience and agricultural sustainability in the Sahel. This is not surprising, as it has been shown that drip irrigation, for example, if used correctly and supported effectively, has the potential to make a significant contribution to household incomes, to help reduce food insecurity, and to help communities adapt to the impacts of climate change, while at the same time not threatening the ecosystems and ecosystem services that these communities rely on [43]. This is corroborated by other findings that smallholder drip irrigation is widely held as a promising technology for water saving, poverty reduction and food security, especially in sub-Saharan Africa [44–46].

The same can be said about the use of treated wastewater. It is increasingly being considered as a perfect substitute for freshwater sources of irrigation in the Sahel. This is as a result of the growing scarcity of freshwater in the region, which has necessitated the development of more reliable and cost-effective technologies to treat urban wastewater [47,48]. In fact, [49–51] noted that farmers preferred wastewater because of its nutrient content besides encouraging less use of chemical fertilizers in agricultural production. These findings are in line with those of [52], who postulated that, in general, farmers are WTP for wastewater treatment but that this depends largely on their perception with respect to the effectiveness of the reuse, which is variable. In South Africa, for example, farmers on average perceive the reuse of wastewater in agriculture as being highly beneficial and are, therefore, WTP about US$0.17/$m^3$ [53].

Lastly, we found a high preference for the use of organic matter from human faeces in the study. The heterogeneity in preferences show that more than 99% of the farmers have a great interest in using organic matter and are WTP on average, about 120,000 F CFA (US$190.3) per ha for RRR solutions that feature this attribute. This is in line with many previous studies, which have shown that the recovery and reuse of wastes can contribute substantially to reducing poverty, improving food security and managing natural resources more sustainability to protect ecosystems and build climate-resilient communities [54,55].

The results, therefore, open up relevant areas in need of immediate policy interventions to help build farmers' resilience in Burkina Faso and the Sahel. Key policy interventions would include: (i) encouraging farmers' use of drip irrigation kits through farm subsidies or access to credit facilities to buy and maintain equipment. Currently, the market price for drip technology is very high in the Sahel and only a few farmers can afford this; (ii) improving linkages between producers, markets and consumers, by creating and strengthening value chains and facilitating the flow of produce from drip irrigation farming; (iii) expanding the use of drip irrigation technology nationally by initiating and promoting relevant extension activities, such as the creation of demonstration sites across the country, as well as fostering awareness and understanding of drip irrigation among children, by supporting the creation of drip irrigation-fed vegetable gardens in schools; (iv) facilitating access to land suitable for drip irrigation agriculture; and finally; (v) investing more on urban wastewater treatment and resource recovery and reuse solutions, such as organic matter from human waste for agriculture. However, this should be accompanied by massive public enlightenment campaigns among farmers about the benefits of such technology, especially given the poor nature of soils in Burkina and the Sahel in general.

In conclusion, we strongly recommend more research that can further improve and extend upon this study. For example, efforts can be made to deal with the hypothetical bias issue in CE. Indeed, as in our CE study, respondents were confronted with a hypothetical situation in which no real transaction is required. They may have overstated their likely behaviour. These are important issues that need to be dealt with when using CE in valuing non-market goods and services.

Acknowledgments: This work is part of a CGIAR Research Program project on Water, Land and Ecosystems (WLE) and supported by CGIAR Fund Donors [Grant Code: WBS 114-02-01-CGI] and part of the WLE's funded Volta-Niger Focal Region projects (January 2015–December 2016): http://www.cgiar.org/who-weare/cgiar-fund/

fund-donors-2. The authors are grateful for this financial support under the auspices of the International Water Management Institute (IWMI). They are also grateful for organizational and technical support from the partners at the West African Science Service Centre for Climate Change and Adapted Land Use (WASCAL) and the University of Ouagadougou. The authors gratefully acknowledge the helpful comments and suggestions of J.P. Lamers and two anonymous reviewers.

Author Contributions: Houessionon Prosper, Bedru Balana, William M. Fonta, Aymar Y. Bossa and Safiétou Sanfo conceived and designed the experiments; Houessionon Prosper performed the experiments; Houessionon Prosper analyzed the data; William M. Fonta and Bedru Balana contributed reagents/materials/analysis and tools; and Houessionon Prosper, William M. Fonta, Aymar Y. Bossa, Bedru Balana, Safiétou Sanfo, Noel Thiombiano, Thomas B. Yameogo and P. Zahonogo wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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