Joint Adoption of Safer Irrigation Technologies under Uncertainty: Evidence from Ghana

Victor Owusu and Awudu Abdulai

Department of Agricultural Economics, Kwame Nkrumah University of Science and Technology, Ghana, University of Kiel, Kiel, Germany

1. May 2009

Joint Adoption of Safer Irrigation Technologies under Uncertainty: Evidence from Ghana

Victor Owusu
Kwame Nkrumah University of Science and Technology, Ghana

Awudu Abdulai
University of Kiel, Kiel, Germany

August 2009

Abstract
This paper examines joint adoption of safer irrigation technologies under uncertainty. The new irrigation technologies introduced in sub-Saharan Africa aim at ensuring safer vegetable production when untreated wastewater is used as irrigation water. The main hypothesis tested is that profit and health-related uncertainties influence adoption of safer irrigation technologies. The study employed a cross-sectional data on urban and peri-urban vegetable farmers in Kumasi of Ghana and examines theoretically and empirically, these possible technology adoption uncertainties, and other relevant factors which influence farmers' adoption decisions. The empirical results indicate that apart from household and farm characteristics, profit and health-related uncertainties influence adoption of irrigation technologies for safer vegetable production.

The authors wish to thank the Kiel Institute for World Economy for financial support for the data collection.

1. Introduction

In most cities of sub-Saharan Africa today wastewater vegetable production is becoming an important channel for income generation and a vehicle for alleviating urban food insecurity problems. Poverty, lack of access to alternative water sources, and poor water quality with inadequate sanitation infrastructure are factors contributing to the productive use of wastewater for agriculture by poor urban communities in less developed countries (Raschid-Sally, 2004). The World Health Organization (WHO) recognizing the resource value and the growing need for wastewater and its nutrient contents for agricultural production has acknowledged untreated wastewater as one of the resources for eliminating poverty and hunger in Africa. The increased use of untreated wastewater for vegetable production in the urban areas of Africa despite its potential health implications may stem from increasing water scarcity and stress, and degradation of fresh water resources resulting from improper disposal of human and industrial wastes, increasing population growth and its resultant demand for food (WHO, 2006).

In the face of the growing demand for raw and fresh vegetables for the consuming public in most cities of Africa, it has become imperative that urban vegetable producers who rely mostly on untreated wastewater as irrigation water adopt safer irrigation practices that ensure risk-free consumption of their agricultural products. Although WHO recommends the use of treated wastewater for irrigation of vegetables, treatment costs have been found to be too high for the predominant smallholder vegetable farmers in developing countries (WHO, 2006).The ongoing crusade by Food and Agriculture Organization (FAO), the World Health Organization(WHO) and the International Development Research Centre (IDRC) to meet the target of reducing the health-related risks of untreated wastewater use for urban agriculture include the introduction of safer options which comprise of a package of irrigation systems and practices that involve the application of hygienic handling procedures in irrigation vegetable production (WHO, 2007). Improving farmers' capacity to monitor irrigation water quality especially on safer and efficient irrigation practices as noted by Kinane et al. (2008), cannot be overemphasized. Apart from being cost effective, the new irrigation technologies ensure that health-related risks of using wastewater for irrigation are reduced to the barest minimum. As it is with any new technology, farmers are usually faced with uncertainties about the benefits from adopting the technology (Koundouri et al., 2006; Abdulai et al., 2008). In particular, vegetable farmers are uncertain about their profit margins when the new technology is adopted and are also not certain about the ability of the new technology to reduce health-related risks. The hypothesis tested in this paper is that uncertainties associated with new irrigation technologies are key determinants of farmer's technology adoption.

Despite the growing number of studies which have addressed the health and environmental concerns of untreated wastewater use for urban vegetable farming in Africa (Sonou 2001; Keraita et al., 2002; Keraita et al., 2003; Amoah et al., 2006; Amoah et al., 2006; Amoah, 2008), fewer empirical studies exist on adoption of safer irrigation technologies by farmers (Moreno and Sunding, 2005; Kinane et al., 2008) and especially studies that consider uncertainties associated with adoption of irrigation technologies are very few (Carey and Zilberman, 2002 ; Koundouri et al., 2006). The main contribution of the paper is that apart from providing theoretical and empirical insights on adoption of

safer irrigation technologies by smallholder farmers, the issue of uncertainty of technology adoption is theoretically and empirically addressed in the paper. Place et al. (2002) rightly points out that more adoption studies on irrigation technology development is anticipated since agriculture in Africa remains largely rainfed and even so as water scarcity issues are receiving much more prominence. The inadequate information on the social opportunity cost of water as noted by Brennan (2007) is likely to influence water-use decisions and incentives to adopt more water-efficient technologies in the near future. Understanding the adoption potential of safer irrigation technologies and farmers' strategies in using untreated wastewater for irrigation is critical for improving current irrigation practices especially in the framework of WHO's guidelines for safer vegetable production and also recommending policies for urban poverty alleviation and food security.

The next section provides a brief overview on irrigation technologies and wastewater vegetable production in Ghana. Section 3 presents the theoretical model. Section 4 discusses the empirical model. Section 5 provides the data description. Section 6 discusses the empirical results. The last section provides some concluding remarks.

2. Irrigation technologies and wastewater vegetable production in Ghana

Farmers in urban and peri-urban Ghana employ various irrigation technologies in vegetable production. In Kumasi for instance, Keraita et al. (2002) and Obuobie et al. (2006) report the use of watering can, bucket, motorized pump and hosepipe, surface and sprinkler systems for irrigation of vegetables with the watering can being the most commonly used method for farmers who cultivate in the valley bottom of urban Kumasi. The watering can is used to fetch water from streams, rivers, ponds and dug-out wells and transported manually onto the field for seedlings and fragile leafy vegetable irrigation (Obuobie et al., 2006). In addition to the watering can, women vegetable farmers in particular use buckets to fetch and transport irrigation water manually to the fields. Keraita et al. (2003) however note that these methods do not promote safer vegetable production as they encourage farmers to step into the water source during fetching and also lead to increasing possibility of crop contamination when the watering can is used to apply untreated wastewater directly to the crops. As Amoah (2009) rightly points out, farmers been aware now of the risks involved in the use of wastewater, are taking the necessary precautions by reducing contact with wastewater during fetching by not stepping into the water but standing on the periphery of the water source, and to further decrease contamination from the soil, watering cans are lowered during irrigation to reduce contamination from splash. The use of motorized pump for vegetable irrigation is also found in peri urban areas of Ghana (Keraita et al., 2003) but is on limited scale due the initial capital costs involved (Obuobie et al., 2006). With this method, a small motorized pump is temporarily placed near a water source and water is pumped and transported via plastic pipes or semi-flexible pipes which are connected to flexible pipehose at the end. The water is then applied to the crops either overhead or near the roots on the surface (Obuobie et al., 2006). The sprinkler irrigation system just like the motorized pump has also been adopted by a small fraction of vegetable farmers in Kumasi due to its operational costs. The sprinkler is usually connected to pipe-borne water source or a treadle pump which supplies the water for irrigation.

The need for vegetable farmers to adopt safer and improved irrigation technologies as already indicated has become an issue of topical concern for most researchers and policy makers in developing countries because of the continual use of untreated wastewater for urban vegetable production. As noted by WHO (2006) and Keraita et al. (2007), the health-related risks of untreated wastewater use for vegetable production could be rightly reduced through the use of sophisticated tertiary treatment and disinfection system but Carr and Strauss (2001) point out that such systems are less feasible for famers in developing countries because of the costs involved. Efficient and low-cost irrigation technologies for safer vegetable production have also been advocated and being tried in Ghana. For example safe water fetching techniques like standing on the periphery of irrigation water source and sieving of irrigation water, water transportation with watering can with shower outlet and close watering application techniques where watering can with cap outlet is raised from a height < 0.5m, and localized low-cost drip kit irrigation have all been introduced to vegetable farmers (WHO, 2006; Keraita et al. 2007).

Through field trials in Ghana, Keraita et al. (2007) further note that on-farm sedimentation of ponds through sand and fabric filters have shown great potential in removing heavier microorganisms like worm eggs, a safer irrigation water fetching technology which could be enhanced by training farmers on how to reduce suspension of sediments. Close watering techniques with watering can with shower outlet from a height of 0.5m is able to reduce the speed of water, lessen the splash of contaminated soil on crop leaves and is also found to reduce thermotolerant coliforms by 2.5 log units and Helminths by 2.3 eggs per 100g of lettuce compared to watering can without shower outlet from a height of > 1m. The effectiveness of cessation of irrigation before harvesting was found out by Vargas et al. (1996) and Keraita et al. (2007) to be effective in reducing crop contamination by providing time for pathogen die-off but the method appears to be unsuitable during the rainy seasons due to the creation of a suitable condition for pathogens to survive.

As WHO (2006) points out, localized irrigation technologies like the bubbler, drip, and trickle could offer vegetable farmers who use untreated wastewater for irrigation much healthier protection but the high cost of drip irrigation hinders its adoption in Ghana compared to Cape Verde and India where the similar irrigation systems have recently been adopted by farmers (Kay, 2001; Postel, 2001; FAO, 2002). The localized irrigation system is expected to offer pathogen reduction of 2-4 log units depending on whether the harvested part of the crop is in contact with the soil or not (WHO, 2006). The low-cost irrigation kits, Keraita et al. (2007) note are effective in offering the lowest level of pathogen contamination with an average of 4 log units per 100g when vegetables are irrigated with untreated water, and this is fewer thermotolerant coliforms than that irrigated with watering can. Safer irrigation practices include provision of safer irrigation water like shallow groundwater, protection of water sources from getting polluted, treating irrigation water, use of protective clothing by farmers, better methods for collecting water from irrigation sources and better water application techniques (Keraita et al., 2007).

3. Theoretical model

The farmer is assumed to cultivate an urban vegetable farm where he or she uses untreated wastewater for irrigation. As already indicated, the use of treated water for

irrigation would have been the safest form of vegetable production in terms of reducing health-risks to both producers and consumers but lack of treatment plants and cost constraints alone makes this option less feasible among smallholder urban vegetable producers. We also assume that producers were using the existing irrigation technologies for untreated wastewater vegetable production until the FAO/WHO/IDRC recommended and introduced the non-treatment risk reduction options for safer vegetable production.[1] These new technologies consist of a package of safer options for fetching, transporting and applying irrigation water on vegetable farms. With the new irrigation technologies, one source of uncertainty on the part of famers is whether they would be able to generate the necessary profit compared to the existing irrigation technologies. Another source of uncertainty is the ability of the new technologies to reduce the health risks to producers and consumers when untreated wastewater is used for irrigation.

Following Abdulai et al. (2008), we assume that farmer's adoption decisions about technologies that do not operate independently need to be jointly estimated or determined. The decisions to adopt any of the safer fetching, transporting and application technologies are therefore taken jointly by the vegetable farmer. Let us represent the benefit of an existing irrigation technology by $F(m)$, where m is the quantity of vegetables produced with the existing technology. The benefit from the new and more safer irrigation technologies is assumed to be $G(k,z,\omega)+H(k,z,\omega)\varepsilon$, where z, k and ω are assumed to be the quantities of vegetables produced from the safer irrigation technologies; $G(k,z,\omega)$ is the average benefit of the new irrigation technologies, H is a term related to benefit variability, and ε is a random variable with mean zero and variance σ_ε^2. Since the farmer does not have perfect information about the average benefit $G(k,z,\omega)$, of the new irrigation technologies, he or she is assumed to face two sources of uncertainties. The first has got to do with physical uncertainty, which concerns the output or costs and therefore benefit $(H(k,z,\omega)\varepsilon)$ related to the fact that the new irrigation technology could produce more (or less) vegetables or be characterized by more (less) costs than the average $G(k,z,\omega)$, depending on the specific characteristics of the vegetables produced and the irrigation technologies adopted. The second source of uncertainty can be characterized as health-related uncertainty, which bothers on the fact that farmers are not fully certain about the average benefit they could derive from the new irrigation technologies in terms of their ability to produce safer vegetables with untreated wastewater. This second technology is modeled as:

$$G(k,z,\omega)=K(k,z,\omega)+A(k)\nu+D(z)\phi+R(\omega)\gamma \tag{1}$$

where $K(k,z,\omega)$ is the farmers' belief about the average benefit from the new irrigation technologies. The real average benefit is the sum of the farmer's assumed average benefit and the errors that the farmer makes in his belief, $A(k)\nu$, $D(z)\phi$, and $R(\omega)\gamma$ with ν, ϕ and γ as stochastic error terms. For simplicity, it is assumed that the farmer has unbiased beliefs $(E(\nu)=0,\ E(\phi)=0,$ and $E(\gamma)=0)$. The farmer's error of prediction is assumed to decrease if vegetable production with the new irrigation technologies is safe (i.e. $\partial A/\partial k<0,\ \partial D/\partial z<0,$ and $\partial R/\partial\gamma<0$).

Given these specifications, farmers are assumed to maximize expected benefit (τ) through the optimal choice of $m,k,z,$ and $\omega,$ given the household constraint:

$$\max_{m,k,z,\omega} \; EU(\tau) \equiv EU[\tau(m,k,z,\omega)] \tag{2}$$

subject to $m + p_k k + p_z z + p_\omega \omega = B$

where E is the expectation operator, $U(\cdot)$ is the von Neuman-Morgenstern utility function, B is the total resources available for safer vegetable production; p_k p_z, and p_ω denote the unit costs of the three different safer irrigation technologies. The price of vegetable produced with the existing irrigation technology is used here as the *numeraire*. The total benefit can be specified as:

$$\tau = F(m) + G(k,z,\omega) + H(k,z,\omega)\varepsilon \tag{3}$$

Substituting Equations (1) into (3) yields the following benefit expression that contains the farmers' beliefs about expected benefit:

$$\tau = F(m) + K(k,z,\omega) + A(k)\nu + D(z)\phi + R(\omega)\gamma + H(z,k,\omega)\varepsilon \tag{4}$$

The first-order conditions of the farmers' maximization problem can be derived directly from Equation (2). Specifically, expressing m as a function of B, $k, z,$ and ω using the budget constraint, and maximizing the objective function in (2) with respect to k, z and ω yields the following relations:

$$E\left[U'(\tau)\frac{\partial \tau}{\partial k}\right] = E[U'(\tau)(G_k - p_k F_m + A_k \nu + H_k \varepsilon] = 0 \tag{5}$$

$$E\left[U'(\tau)\frac{\partial \tau}{\partial z}\right] = E[U'(\tau)(G_z - p_z F_m + D_z \phi + H_z \varepsilon] = 0 \tag{6}$$

$$E\left[U'(\tau)\frac{\partial \tau}{\partial \omega}\right] = E[U'(\tau)(G_\omega - p_\omega F_m + R_\omega \gamma + H_\omega \varepsilon] = 0 \tag{7}$$

Using the relation $E[xy] = E[x]E[y] + \text{cov}[x, y]$, Equations (5), (6) and (7), can be reformulated to obtain specifications for risk-averse farmers

$$E(G_k - p_k F_m) + A_k \frac{\text{cov}[U'(\tau),\nu]}{E[U'(\tau)]} + H_k \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} = 0 \tag{8}$$

$$E(G_z - p_z F_m) + D_z \frac{\text{cov}[U'(\tau),\phi]}{E[U'(\tau)]} + H_z \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} = 0 \tag{9}$$

$$E(G_\omega - p_\omega F_m) + R_\omega \frac{\text{cov}[U'(\tau),\gamma]}{E[U'(\tau)]} + H_\omega \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} = 0 \tag{10}$$

Given that the real derivative of the benefit function G is unknown to the farmer, this is replaced with its beliefs, specified as:

$$K_k - p_k F_m + A_k \frac{\text{cov}[U'(\tau),\nu]}{E[U'(\tau)]} + H_k \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} = 0 \tag{11}$$

$$K_z - p_z F_m + D_z \frac{\text{cov}[U'(\tau),\phi]}{E[U'(\tau)]} + H_z \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} = 0 \tag{12}$$

$$K_\omega - p_\omega F_m + R_\omega \frac{\text{cov}[U'(\tau),\gamma]}{E[U'(\tau)]} + H_\omega \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} = 0 \tag{13}$$

The term with the covariance in equations (11), (12) and (13) are the risk premia associated with the farmers' decision problem. While the risk premium terms with H_z, H_k and H_ω are associated with the physical uncertainties, the terms with A_k, D_z and R_ω are associated with the health-related uncertainties. Thus, for a risk-neutral farmer,

the third and the fourth terms on the right-hand side are zero. However, when the farmer is risk averse, these terms are different from zero.

The farmer's decisions to adopt the new technology can now be incorporated into the general model developed above. These decisions can be modeled as binary choices, where the farmer can choose to adopt the new technology option 1 for fetching irrigation water $(Y_{i1}=1)$ or not $(Y_{i1}=0)$, adopt the new technology option 2 for transporting irrigation water $(Y_{i2}=1)$ or not $(Y_{i2}=0)$, and adopt the new technology option 3 for applying irrigation water $(Y_{i3}=1)$ or not $(Y_{i3}=0)$. The farmer will adopt any of the new technology options for fetching, transporting and applying irrigation water if the expected utility of adoption is greater than the expected utility without adoption. That is

$$EU(\tau^1(m,z,k,\omega)) > EU(\tau^0(m,z,k,\omega)) \tag{14}$$

Given that the expected utility in the maximization problem is on benefit, the adoption decisions of the new irrigation technologies can be derived from the first-order conditions presented in Equations (11), (12) and (13) thus, for the risk-averse producer, the first-order condition for the fetching technology is given by:

$$K_k > p_k F_m - A_k \frac{\text{cov}[U'(\tau),\nu]}{E[U'(\tau)]} - H_k \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} \tag{15}$$

It is worth noting that the producer might try to adopt even if the expected marginal benefit is lower than the marginal cost, but the benefit of reducing the physical uncertainty is large enough to offset the loss.

As in the case of the fetching technology, the first-order conditions for the adoption of the transporting and application technologies for the risk-averse producer are given by:

$$K_z > p_z F_m - D_z \frac{\text{cov}[U'(\tau),\phi]}{E[U'(\tau)]} - H_z \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} \tag{16}$$

$$K_\omega > p_\omega F_m - R_\omega \frac{\text{cov}[U'(\tau),\gamma]}{E[U'(\tau)]} - H_\omega \frac{\text{cov}[U'(\tau),\varepsilon]}{E[U'(\tau)]} \tag{17}$$

4. Empirical considerations

From expressions (14), (15), (16) and (17), a farmer would adopt a new irrigation technology if his or her expected utility of benefits from using the new technology to produce safer vegetables, $EU(\tau^1)_i$ is positive or exceeds the expected utility of benefits, from using the already existing technology to produce vegetables, $EU(\tau^0)_i$. The parameters of this decision however are usually unobservable but could be represented by a latent variable:

$$EU(\tau^1)_i = 1 \text{ if } EU(\tau^1)_i > EU(\tau^0)_i \quad \text{and}$$

$$EU(\tau^1)_i = 0 \text{ if } EU(\tau^1)_i < EU(\tau^0)_i \tag{18}$$

The utility from adopting the new irrigation technology can then be related to a set of explanatory variables, X' such that:

$$U(\tau) = \alpha' X_i' + \xi_i \tag{19}$$

where

X' is a vector of household, farm and socioeconomic and characteristics, α' denotes a vector of parameters and ξ_i is the error term with zero mean and constant variance. The probability that the farmer adopts the safer irrigation technology is formally expressed as:

$$\Pr(U(\tau)=1) = \Pr(EU(\tau^1)_i) > \Pr(EU(\tau^0)_i)$$
$$= \Pr(\xi_i > -\alpha' X_i') = 1 - \Gamma(-\alpha' X_i') \quad (20)$$

where Γ is a cumulative distribution function for ξ.

As already indicated, vegetable producers undertake joint adoption of different safer irrigation technologies for fetching, transporting and applying irrigation water. This joint adoption decision can be estimated efficiently with the multivariate probit model which employs the simulated maximum likelihood (Geweke et al., 1997; Cappellari and Jenkins, 2006).[2] To explore this possibility, we specify N multivariate probit model:

$$Y_{in}^* = \beta_n' X_{in} + \mu_{in},\ n = 1, ..., N \quad (21)$$

$Y_{in} = 1$ if $Y_{in}^* > 0$ and 0 otherwise.

where Y_{in} denotes a binary dependent variable for n options of fetching or transporting or applying irrigation water, X_{in} are set of explanatory variables which influence the adoption of a particular option, μ_{in} are error terms distributed as multivariate normal, each with mean of zero, and variance-covariance matrix L, with values of 1 on the leading diagonal and correlations $\rho_{jk} = \rho_{kj}$ as off diagonals.

One of the relevant considerations in irrigation vegetable production is how to select or choose crops that promote safer vegetable production (Westcot, 1997; Kurukulasuriya and Mendelsohn, 2006). The choice of crops for wastewater use areas depends upon a number of factors and as rightly pointed out by Westcot (1997), the type of crop grown must be suitable to the agronomic conditions in the area such as soils, available water, and pest control, marketing, farmer skills and labor availability (Raschid-Sally et al., 2004). To address this concern in the empirical model, we employ the 2- stage estimation procedure. In the first stage, we control for farmer's crop choice by estimating a multinomial logit model due to the fact that the decision to cultivate the various vegetables with wastewater may not be independent (Seo and Mendelsohn, 2008). The residuals of the selected vegetables from the first stage regression are then included in the multivariate probit model in the second stage to examine the factors which influence the adoption of safer irrigation technologies. As Seo and Mendelsohn (2008) has proposed, a farmer i assumed to have a profit, $\pi_{ij} = S_j' + \delta_j$ from choosing crop $j(j = 1, 2, ..., J)$, has a crop choice problem stated as

$$\arg\max_j (\Pi_1^*(V_1), \Pi_2^*(V_2), ..., \Pi_j^*(V_i)) \quad (22)$$

where S' denotes a vector of exogenous farm, personal and household characteristics of the farmer. The probability P_{ji} of choosing the jth crop is given as

$$P_{ji} = \Pr\left\{\delta_k(V_i) - \delta_j(V_i) < S_j - S_k\right\}\ \forall\ k \neq j;\ S_j = S_j(V_i) \quad (23)$$

Also noted by Train (2003) is the fact that if we assume δ to be independently distributed and $S_k = V_{ki}\varphi_k + u_k$, then the probability that farmer i chooses vegetable j among J vegetable types is evaluated as:

$$P_{ji} = e^{V_{ji}\varphi_j} \Big/ \sum_{k=1}^{J} e^{V_{ki}\varphi_k} \tag{24}$$

Substituting the residuals in the first stage regression into the multivariate probit model in expression (21) yields

$$Y_{in}^{*} = \eta_n' Z_{in}' + q_n' Q_n' + \lambda_{in},\ n = 1, ..., N \tag{25}$$

where Z' represents a vector of personal, household and irrigation technology specific characteristics, Q' represents residuals from the first stage regression and λ is the error term capturing unobserved effects which influence adoption of safer irrigation technologies.

5. Data description

The study employs a cross-sectional data collected in urban and peri-urban Kumasi (a location of about 25km from the city centre) in 2008 on 202 vegetable farmers who use untreated wastewater for irrigation. Kumasi is the second largest city in Ghana and has a population of 1.0 million with an annual growth rate of 5.9% (Ghana Statistical Service, 2002). It attracts daytime population of 1.5 to 2 million people and has a total land area of 225km^2 of which about 40% is an open land. It is located in the middle belt of Ghana, a predominantly tropical forest zone with semi-humid tropical climate of an annual average rainfall of 1420mm.The rainfall pattern is bimodal with the major season falling between March and July and a minor rainy season around September and October. The mean monthly temperature of Kumasi ranges from 24^0 C to 27^0 C and the predominant soil type is the forest Ochrosol, which supports the cultivation of foodstuffs and vegetables. Important streams and rivers in Kumasi include the Owabi, Subin and Wawa (Obuobie et al., 2006). Most of these water bodies which run through inland valleys of the city's vegetable production sites are mostly polluted due to improper disposal of solid and liquid wastes.

The study's population included all vegetable farmers in the urban and peri-urban Kumasi. There were about 301 irrigation vegetable producers and a sample of 202 farmers constituting 74 project demonstration farmers in 6 different farm sites and 128 non-project farmers in 13 different farm sites were selected for the study. Stratified random sampling technique was employed to capture the differences in farming sites such as water availability, type of irrigation water source and farm size. The sampled farmers were mostly men (98%) between the ages of 25-34 years (table 1). Less female involvement in peri-urban vegetable production may be attributed to the high manual labor involved such as watering, weeding and manure application.[3] On the average, about 70% of the farmers had 7 years of formal education indicating lower involvement by the highly educated in urban vegetable production. Vegetables cultivated included cabbage, lettuce, spring onions, green pepper, cucumber, cauliflower, and carrot. Lettuce which was predominantly grown by the farmers covered a total land area of 17 ha while cauliflower was the lesser grown vegetable. The total land size under vegetable cultivation was 46.9 ha, with a mean farm size of 0.23 ha however almost 83.1% of the farmers cultivated less than half of a hectare. The main irrigation water sources for vegetable production were streams (22%), shallow wells (66%) and rivers (8%). The

most adopted safer irrigation technology was the watering can with shower outlet and the least adopted technology was the sieving method of fetching irrigation water.

The descriptive statistics of the variables used in the regression analyses are provided in Table 2. As already indicated, crop choice is a crucial determinant of safer irrigation vegetable production and to examine this we estimate a multinomial logit model (Westcot, 1997; Seo and Mendelsohn, 2008). A dependent variable for crop choice is measured as a binary variable indicating 1 in each case if the farmer cultivates lettuce or cabbage or spring onion, and 0 otherwise. For the adoption of safer irrigation technology, a dependent variable is measured as a dummy variable indicating 1 if the farmer adopts and 0 otherwise. Two different multivariate probit regressions which consider in each case, safer technologies for fetching, transporting and applying irrigation water were jointly estimated. The first regression concerns with joint adoption of the periphery, watering can with shower outlet, and close watering irrigation water application technologies. The second regression concerns with joint adoption of the sieving, watering can with shower outlet and the close watering irrigation technologies. The independent variables in the crop choice model were mainly agronomic variables such as soils and availability of water, as well as farmer's personal and household characteristics. Age and education of farmers are human capital variables and are expected to have positive relationships with crop choice and adoption of safer irrigation technologies. As noted by Karami (2006), more educated farmers are expected to have a higher capacity to accept change and modern irrigation methods. We included a gender variable representing males, and the probability for males to stand on the periphery and sieve irrigation water while fetching is expected to be higher. Their adoption of the watering can with shower outlet is also expected to be higher than females.

Other relevant factors which may affect vegetable choice and adoption of safer irrigation technologies are farm sizes (ha) and distance (km) from the farm to the irrigation water source. The farther away the farm is from the water source, the lower the probability to adopt the watering can. Farmers with smaller farm sizes are also hypothesized to adopt the watering can with shower outlet for transporting and applying irrigation water. Plot fertility which is relevant for vegetable production was captured in the crop choice regression with the inclusion of a loamy soil dummy. Safer vegetable production as noted by Westcot (1997) and Keraita et al. (2007) requires provision of safe irrigation water source. To control for the irrigation water quality, we included dummy variables capturing shallow well, streams and rivers in the crop choice model. In addition, irrigation water availability for vegetable production was considered in the crop choice model with the inclusion of dummies indicating regular supply of irrigation water and the presence of water reservoir on the farm. Information acquisition through extension contacts and training are key determinants of new technology adoption by farmers (Koundouri et al., 2006; Abdulai et al., 2008). Other socioeconomic variables explored in the models include credit access, membership of farmer's organization and cultivation of other crops apart from vegetables. It is important to note that farmers' perceptions influence their attitude and adoption behavior (Adesina and Baidu-Forson, 1995; Karami, 2006). The perception indicator we used to proxy for uncertainties on the adoption of a safer irrigation technology captures the expected profit and the health-related safety of the technology. This uncertainty measure was viewed as benefit perceptions from adopting the irrigation technology, *ceteris paribus*, expected to exert a

positive effect on adoption of new technologies.[4] As indicated already, potential endogeneity problem arises when specific vegetables cultivated by farmers are included in the model explaining adoption of safer irrigation technologies. To address this problem, some instrumental variables were used as exclusion restrictions in the irrigation technology adoption regressions. The variables included in the first stage regressions of crop choice but excluded from the second stage regression of irrigation technology adoption were availability of family labor, indicator of plot fertility (loamy soil), cultivation of other crops apart from vegetables, availability of water reservoir, regular supply of irrigation water, and irrigation water sources.

6. Empirical results

The multivariate probit estimates on the adoption of safer irrigation technologies for wastewater vegetable production have been presented in Tables 3 and 4, and the first stage multinomial logit regression estimates on vegetable choice and the correlation coefficients of the explanatory variables have been provided as appendices. It is however important to note before we discuss the adoption estimates that variables like age and education of the farmer, the use of hired farm labor, access to credit, farm size, distance of vegetable farm from irrigation water source, plot fertility, extension contact and regular supply of irrigation water, all significantly influenced the choice of vegetables that farmers cultivated. Also worth mentioning is the insignificant effect of the shallow well variable which was used to capture the quality of irrigation water source and the positive significant effect of the variable representing river. Statistically what these empirical findings reveal is that rarely do urban vegetable farmers pay much attention to the quality of irrigation water source available, which also emphasizes the need for them to adopt safer irrigation technologies. The correlation coefficients of the error terms in the multivariate probit regressions ranging from 0.211 to 0.489 are highly significant. This is also consistent with the hypothesis of interdependence of the safer irrigation technologies and thus statistically justify why adoption of different irrigation options for fetching, transporting and applying irrigation water needs to be determined jointly. The estimated coefficients also differ substantially across equations, indicating that differentiating between the safer irrigation types was statistically appropriate. The estimates in Table 3 were obtained from joint estimation of the propensities of vegetable farmers to adopt the *periphery* option for fetching irrigation water, adopt the *watering can with shower outlet* for transporting irrigation water and adopt the *close-watering* techniques for applying irrigation water. As already noted these irrigation options have health-related benefits because standing on the periphery of the water source instead of stepping into the stream or river to fetch irrigation water reduces direct contact with the untreated wastewater and thus minimizes possible health risks to vegetable producers. Employing the watering can with shower outlet for transporting and applying irrigation water with close watering techniques also reduce the speed of water and lessen the splash of contaminated soil on crop leaves.

The empirical results indicate that older vegetable farmers fetch irrigation water by standing on the periphery of the water source. The gender variable representing males had a positive statistically significant relationship with the probability of farmers to stand on the periphery to fetch irrigation water. The implication here is that males have higher probabilities to stand on the periphery than females who rarely engage in such manual

activity of fetching irrigation water. The survey data has already indicated that urban vegetable farming is mostly a men-dominated activity with women more involved in marketing rather than production. The empirical results on age and gender are consistent with literature. As Amoah (2009) rightly points out, experienced urban vegetable farmers in Ghana are becoming aware of the health implications of stepping into low quality streams and rivers which are mostly polluted with domestic and industrial wastes, as they take the necessary precautions in reducing direct contact with the untreated wastewater during fetching by not stepping into the water source. Vegetable farmers with higher education also tend stand on the periphery when fetching irrigation water, an empirical finding which concurs with the hypothesis that education as a human capital variable assist farmers to adopt new innovations and technologies (Koundouri et al., 2006; Abdulai et al., 2008). The education variable although insignificant is positively related to the adoption of the watering can with shower outlet and the close-watering techniques. As rightly pointed out by Amoah (2008), watering cans are usually lowered during irrigation to reduce contamination from splash from the soil and this requires skill acquisition and knowledge. The empirical results also show that married farmers tend to adopt the close-watering techniques for applying irrigation water probably due to the support they obtain from their spouses to manually transport the irrigation water in cans to the farms. The propensity to adopt the watering can with shower outlet is also higher for farmers with larger household sizes probably due to the manual labor involved in transporting the irrigation water from the source to the vegetable farms. Statistically, being a member of farmer's organization increases the probability to adopt the periphery method and watering can with shower outlet. Also having an individual farm enterprise was significant and positively related to the adoption of the watering can method for transporting irrigation water. The credit variable although statistically insignificant had the correct hypothesized sign in the model explaining the probability to adopt the watering can with shower outlet since acquisition of the cans requires some financial investments.

Distances from vegetable farms to irrigation water sources and farm sizes play crucial roles in the adoption of irrigation technologies. Our empirical results agree with the hypothesis that farmers with close distance farms to irrigation water sources tend to use watering cans and close watering techniques for water application. As Obuobe et al. (2003) rightly point out, the most efficient means of transporting irrigation water when there is a water source (a stream or a drain) nearby the vegetable farm is to use the watering can. The adoption probability of the periphery method of fetching irrigation water also increases even when the distance from irrigation water source is farther away from the vegetable plot. Having smaller farm size encourages the use of the watering can probably due to the less volume of irrigation water demand by the vegetables. The farm size variable however was insignificant in the periphery and close watering adoption specifications, which lend credence to the preposition in the empirical literature that small farm size is often an obstacle to adoption of new irrigation technologies (Karami, 2006). As already indicated, receiving training through extension contacts increase farmers' level of skill and knowledge acquisition on safe water management techniques. The extension variable exhibited the expected positive signs for all the irrigation technologies and in particular, showed a significant relationship with the adoption of the periphery method. As Raschid-Sally et al. (2004) rightly point out, empowering vegetable

farmers through education and training workshops could have beneficial impacts on the sustainable use of wastewater. The type of vegetables farmers cultivated with the safer irrigation technologies also provided interesting empirical results. Our findings show that farmers who grow spring onions have significant lower probability to adopt the watering can with shower outlet and the close watering techniques. However, the probability of lettuce growers to adopt the periphery and close watering techniques tends to be higher. Also worth noting are the effects of the first stage regression residuals of these crops on the adoption of the safer irrigation technologies. As expected, we find statistically significant and positive relationships in the multivariate probit models. The irrigation technology uncertainty index centered on the ability of the new technologies to increase profit, and reduce the health-related risks to consumers and producers. Interestingly enough, the empirical findings show a positive significant relationship with the adoption of the watering can with shower outlet method for transporting and applying irrigation water.

We now turn our attention to the empirical estimates in Table 4 which were obtained from joint estimation of adoption of the *sieving* technology for fetching, adoption of *watering can with shower outlet* for transporting and adoption of *close watering techniques* for applying irrigation water. As we pointed out in our earlier discussion, sieving or filtering irrigation water with on-farm sedimentation through sand and fabric filters during fetching reduces potential health risks by removing micro-organisms concentration like worm eggs (Keraita et al., 2007). Similar to the periphery technology, older farmers have significantly higher propensities to adopt the sieving technology, again emphasizing the role of experience in safer vegetable production. The education variable is also significant and positive for the sieving technology. These empirical results lend credence to the hypotheses by Joshi and Pandey (2005) and Gomez-Barbero et al. (2008) that education and experience play significant roles in the adoption of improved technologies and innovations by farmers. Using experimental field data from suburban areas of Varanasi in India, Sharma et al. (2007) and Sharma et al. (2008) observed that sieving irrigation water before fetching reduces heavy metal contamination of the soil and the plant which has a potential health implication for consumers.[5]

It also important to emphasize here that if the sieving technology instead of the periphery approach irrigation water fetching, the statistical results we obtained in Table 3 on the variables representing marital status, individual farms, membership of farmers' organization, farm size and distance from farm to the irrigation water source do not change in terms of signs and statistical significance of the coefficients, thus indicating the robustness of our joint estimation results. Also worthy of mentioning is the statistically negative and significant hired farm labor variable for sieving irrigation water. This suggests that vegetable farmers rather rely more on family labor for fetching irrigation water than hired farm labor. When the sieving technology is combined with the watering can and close watering techniques in irrigation of vegetables, we obtain statistically positive significant coefficient for the lettuce variable and statistically negative coefficient for the spring onion variable. The most interesting results here concern the positive and statistical significance of the uncertainty perception index in both the sieving technology and watering can with shower outlet regression specifications. Statistically, our empirical results are consistent with the findings by Sharma et al. (2007) on the

relevance of sieving untreated wastewater before irrigation in order to reduce the potential contamination and danger it might pose to both producers and consumers.

7. Conclusion

We have analyzed the adoption of safer irrigation technologies for producing vegetables with untreated wastewater. The study employed a cross-sectional data collected in 2008 on 202 vegetable farmers in urban and peri-urban Kumasi in Ghana. The main hypothesis tested is that uncertainties associated with new irrigation technologies are key determinants of farmer's adoption decisions. Understanding the adoption potential of new irrigation technologies and farmers' strategies in using untreated wastewater for irrigation and income generation under uncertainty are critical for improving current irrigation practices and also recommending policies for food security and poverty alleviation in developing countries.

The main irrigation water sources for vegetable production were found to be shallow wells, streams and rivers but most often these water bodies are polluted due to contamination of effluents from industrial and domestic waste within the city. In the absence of treated water for irrigation, vegetable farmers rely on untreated wastewater for vegetable irrigation. Safer irrigation technology adoption which was introduced in Ghana and other parts of sub-Saharan Africa by the FAO/WHO/IDRC aims at providing efficient and low cost technologies to urban vegetable farmers who use untreated wastewater for irrigation so that the health risks to producers and consumers are reduced. The new technologies include options for fetching, transporting and applying irrigation water. Related to the adoption of the technologies are uncertainties farmers face on the expected profits and the ability of the technologies to offer minimum health-related risks. These uncertainties and other relevant factors influencing farmers' adoption decisions were examined theoretically and empirically in the paper. In particular, the adoption probabilities of technologies for fetching, transporting and applying irrigation water were jointly determined with the multivariate probit model. Undertaking this joint estimation provided robust and statistically sound empirical estimates because of the interdependency of the irrigation technologies. Our findings indicate that farmers' propensities to adopt safer irrigation technologies are influenced by age, gender, education, farm size, distance of vegetable farms to irrigation water sources and extension contact. In particular, adoption of safer irrigation options increased when the uncertainty perception index on the ability of the technologies to increase profit and reduce health-risks to producers and consumers also increases.

Recognizing the increasing demand for raw and leafy vegetables by the ever-growing urban population in most less-developed countries and that urban vegetable production is key in reducing urban poverty, sound and innovative policy initiatives are needed to ensure that wastewater vegetable production is safe to both producers and consumers. One of the relevant short-term policy options for sub-Saharan Africa is to accelerate the pace of human capital development and in particular, institute affordable educational and training programs for the poor. Direct policy instruments for minimizing the risks to producers and consumers of wastewater agricultural production include raising awareness and promoting the use of various health-protection measures during production and marketing. In the longer term, local stakeholder agencies and governments are expected to enact, strengthen and regulate existing environmental laws.

References

Abdulai, A., Monnin, P., and J. Gerber (2008). Joint estimation of information acquisition and adoption of new technology under uncertainty. *Journal of International Development* 20:437-451.

Adesina, A. A. and J. Baidu-Forson (1995). Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics* 13(1):1-9.

Amoah, P. (2009). An analysis of the quality of wastewater used to irrigate vegetables in Accra, Kumasi and Tamale, Ghana. In: agriculture in urban planning, generating livelihoods and food security, Redwood, M. (eds). Earthscan and the International Development Research Centre (IDRC), 2009.

Amoah, P, Drechsel, P., Abaidoo, R. C. and W. J. Ntow (2006). Pesticide and pathogen contamination of vegetables in Ghana's urban markets. *Archives of Environmental Contamination and Toxicology* 50, 1–6.

Amoah, P., Drechsel, P., Abaidoo, R. C. and M. Henseler (2007). Irrigated urban vegetable production in Ghana: microbiological contamination in farms and markets and consumer risk group'. *Journal of Water and Health* 5 (3):455–466

Amoah, P. (2008). An analysis of the quality of wastewater used to irrigate vegetables in Accra, Kumasi and Tamale, Ghana. IDRC/CRDI. The Science for Humanity. The International Development Centre.

Bradford, A., Brook, R. and C. Hunshal (2003). Wastewater irrigation: Hubli-Dharwad, India. Paper presented in International Symposium on Water, Poverty and Productive uses of Water at the Household Level, 21-23 January 2003, Muldersdrift, South Africa.

Brennan, D**.** (2007). Policy interventions to promote the adoption of water saving sprinkler systems: the case of lettuce on the Gnangara Mound. *Australian Journal of Agricultural and Resource Economics* 51: 323-341.

Cappellari, L. and S. P. Jenkins (2006). Calculation of multivariate normal probabilities by simulated likelihood estimation. *The Stata Journal* 6(2):156-189.

Carey, J. M. and D. Zilberman (2002). A model of investment under uncertainty: modern irrigation technology and emerging markets in water. *American Journal of Agricultural Economics* 84 (1):171-183.

Carr, R. and M. Strauss (2001). Excreta-related infections and the role of sanitation in the control of transmission (Chapter 5). In: Fewtrell, L. and Bartram, J. (eds.) Water quality: guidelines, standards and health; assessment of risk and risk management for water-related infectious disease. International Water Association (IWA) on behalf on the World Health Organization, London, UK, pp. 89-113.

FAO (2002). International workshop on irrigation advisory services and participatory extension in irrigation management, FAO, ICID. http://www.aiaee.org/2001/ap01.pdf

Geweke, J., Keane, M. and Runkle, D. (1997). Statistical inference in the multinomial

multiperiod probit model. *Journal of Econometrics* 80: 125– 165.
Ghana Statistical Services (2002). 2000 Population and housing census: Summary report of final results, Accra, Ghana.
Gomez-Barbero, M., Berbel, J. and E. Rodriguez-Cerzo (2008). Adoption and performance of the first GM crop introduced in EU agriculture: Bt maize in Spain. JRC, European Commission Scientific and Technical Reports.
Greene, W.H. (2008). *Econometric analysis*. 6th Edition. Upper Saddle River, NJ: Prentice Hall.
Joshi, G. and S. Pandey (2005). Effects of farmers' perception on the adoption of modern rice varieties in Nepal. Paper presented at the Conference on International Agricultural Research for Development (Deutscher Tropentag 2005). Stuttgart-Hohenheim, October 11-13, 2005.
Karami, E. (2006). Appropriateness of farmers' adoption of irrigation methods: the application of the AHP model. *Agricultural Systems* 87:101–119.
Kay, M. 2001. Smallholder irrigation technology: prospects for sub-Saharan Africa. International Programme for Technology and Research in Irrigation and Drainage, Knowledge Synthesis Report No.3. Rome, IPTRID/FAO.
Keraita, B., Drechsel, P., Huibers, F. and L. Raschid-Sally (2002). Wastewater use in informal irrigation in urban and peri-urban areas of Kumasi, Ghana. *Urban Agriculture Magazine* 8, pp11.
Keraita, B., Drechsel, P. and P. Amoah (2003). Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana. *Environment and Urbanization* 15(2):171-178.
Keraita, B., Drechsel, P. and F. Konradsen (2007). Safer options for irrigated urban farming. *LEISA Magazine* 23(3):26-28. September 2007
Kinane, M.L., Tougma, A.T., Ouedraogo, D. and M. Sonou (2008). Socioeconomic considerations in promoting safer irrigation practices in urban vegetable farming in Burkina Faso. Proceedings of the Second IASTED Africa Conference. Water Resource Management (Africa WRM 2008). September 8-10, 2008 Gaborone, Botswana
Koundouri, P., Nauges, C. and V. Tzouvelekas (2006). Technology adoption under production uncertainty: theory and application to irrigation technology. *American Journal of Agricultural Economics* 88(3): 657-670.
Kurukulasuriya, P. and R. Mendelsohn (2006). "Modeling endogenous irrigation: the impact of climate change on farmers in Africa". World Bank Research Policy Working Paper (forthcoming)
Moreno, G. and D. L. Sunding (2005). Joint estimation of technology adoption and land allocation with implications for the design of conservation policy. *American Journal of Agricultural Economics* 87(4):1009-1019.
Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O., Raschid-Sally, L. and P. Drechsel (2006). Irrigated urban vegetable production in Ghana: characteristics, benefits and risks. IWMI-RUAF-CPWF, IWMI, Accra, Ghana.
Obuobie, E., Danso, G. and P. Drechsel (2003). Access to land and water for urban vegetable farming in Accra. *Urban Agriculture Magazine* 11:15-17.
Place, F., Swallow, B. M., Wangila, J. and C.B. Barrett (2002). Lessons for natural resources management technology adoption and research. In Barrett C. B., F. Place

and A. A. Aboud (eds). Natural resources management in Africa. Understanding and improving current practices. ICRAF-CABI Publishing. pp 275-287.

Postel, S. (2001). Growing more food with less water. *Scientific American*, February 2001, pp 34-37.

Raschid-Sally, L., Bradford, A. M., and D. Endamana (2004). Productive use of wastewater by poor urban and peri-urban farmers: Asian and African case studies in the context of the Hyderabad declaration on wastewater use. In P. Moriarty, J. Butterworth and B. van Koppen (Eds.), Beyond domestic: case studies on poverty and productive uses of water at the household level (pp. 95-116). Delft, the Netherlands: IRC International Water and Sanitation Centre and IWMI.

Seo, S.N. and R. Mendelsohn (2008). An analysis of crop choice: adapting to climate change in South American farms. *Ecological Economics*, 2008.

Sonou, M. (2001). Peri-urban irrigated agriculture and health risks in Ghana. *Urban Agriculture Magazine* 3: 33–34.

Sharma, R. K., Agrawal, M., and F.M. Marshall (2007). Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. *Ecotoxicology and Environmental Safety* 66:258–266.

Sharma, R. K., Agrawal, M., and F.M. Marshall (2008). Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: a case study in Varanasi. *Environmental Pollution* 154:254-263.

Train, K. (2003). *Discrete Choice Methods with Simulation*, Cambridge, U.K.: Cambridge University Press.

Vaz da Cosata Vargas, S.M., Bastos, R. K. X. and D. D. Mara (1996). Bacteriological aspects of wastewater irrigation, Research Monograph in Tropical Public Health Engineering, Monograph No. 8, University of Leeds.

Westcot, D.W. (1997). Health risks associated with wastewater use. In: quality control of wastewater for irrigated crop production. Food and Agriculture Organization of the United Nations, Rome, 1997, ISSN 1020-1203.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Volume 2:Wastewater use in agriculture. World Health Organization, Geneva, Switzerland.

WHO (2007). Non-treatment options for safe wastewater use in poor urban communities. *Briefing note on on-going FAO/WHO/IDRC research in West-Africa and Jordan*. Third edition of the guidelines for the safe use of wastewater, excreta and greywater in agriculture and aquaculture.

Table 1. Personal characteristics of vegetable farmers

Variable	Category	%
Age	15-24	19
	25-34	34
	35-44	27
	45-54	17
	> 55	4
Gender	Male	98
	Female	2
Education	None	30
	Primary	10
	JSH/Middle	48
	Secondary	7
	Vocational	2
	Tertiary	4
Irrigation water source	Stream	22
	Shallow well	66
	River	8
	Borehole	3
Vegetables	Cabbage	20
	Lettuce	38
	Spring onion	36
	Carrot	1
	Green pepper	3
	Cucumber	2
	Cauliflower	1
Safer irrigation technologies	Standing on the periphery	17(34)
	Sieving	12(39)
	Watering can with shower outlet	40(9)
	Close-watering techniques	31(18)

[a.] Proportion of non-adopters in parenthesis
Source: Survey data

Table 2. Descriptive statistics of variables used in the regression models

Variable	Variable definition	Mean	S.d
1.Dependant variables			
Safer irrigation technologies			
ADOPPERI	1 if farmer adopts the periphery technique in fetching irrigation water, 0 otherwise	0.34	0.48
ADOPSEIV	1 if farmer adopts the sieving technology in fetching irrigation water, 0 otherwise	0.24	0.43
ADOPWCS	1 if farmer adopts the watering can with shower outlet for transporting and applying irrigation water, 0 otherwise	0.82	0.38
ADOPCWT	1 if farmer adopts the close watering techniques when applying irrigation water, 0 otherwise	0.64	0.48
Vegetables			
CABBAGE	1 if farmer cultivates cabbage, 0 otherwise	0.37	0.48
LETTUCE	1 if farmer cultivates lettuce, 0 otherwise	0.71	0.45
SPONION	1 if farmer cultivates spring onion, 0 otherwise	0.66	0.47
2. Independent variables			
Household characteristics			
AGE	Age of the farmer (years)	35.00	10.60
EDUC	Years of formal education (years)	6.59	4.71
HOHSZE	Household size	0.24	0.72
GENDER	1 if farmer is a male, 0 otherwise	0.96	0.22
MARSTUS	1 if farmer is married, 0 otherwise	0.77	0.42
CREDIT	1 if farmer access credit, 0 otherwise	0.12	0.32
FARMOG	1 if farmer is a member of farmer's organization	0.20	0.40
HLABOUR	1 if farmer employs hired labor on the farm, 0 otherwise	0.95	0.23
FLABOUR	1 if farmer uses only family labor on the farm, 0 otherwise	0.15	0.36
Farm characteristics			
FARMSZE	Average vegetable farm size (hectares)	0.23	0.23
DISIRWT	Distance of irrigation water source (km)	8.22	7.31
LOAM	1 if soil on vegetable plot is a loamy , 0 otherwise	0.09	0.29
CULTCRP	1 if farmer cultivates other crops, 0 otherwise	0.17	0.38
EXTCONT	1 if farmer receives extension visit, 0 otherwise	0.28	0.45
Irrigation water source			
REGSPIRW	1 if farmer has regular supply of water, 0 otherwise	1.00	0.10
AVAILRES	1 if farmer has a water reservoir on the farm, 0 otherwise	0.36	0.48
SHALOWEL	1 if source of irrigation water is shallow well, 0 otherwise	0.66	0.47
STREAM	1 if source of irrigation water is a stream, 0 otherwise	0.22	0.41
RIVER	1 if source of irrigation water is a river, 0 otherwise	0.08	0.28
Perception indicator			
ITPINDEX	Benefit uncertainty perception index	0.42	0.45

Source: Survey data

Table 3. Multivariate probit regressions on adoption of safer irrigation technologies

	ADOPPERI		ADOPWCS		ADOPCWT	
Variable	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
AGE	0.0333**	2.03	-0.2930	-1.34	0.0053	0.36
GENDER	1.4673***	2.58	0.8576	1.07	0.0469	0.09
EDUC	0.0653**	2.13	0.0260	0.73	0.0226	0.86
MARSTUS	-0.1182	-0.34	0.3406	0.85	0.5971**	1.95
HOHSZE	0.0076	0.11	0.1653*	1.64	-0.0402	-0.59
FARMOG	1.8619***	4.51	2.3832***	2.59	-0.1372	-0.44
HLABOR	-0.4302	-1.42	0.3089	0.88	0.1732	0.67
CREDIT			0.2949	0.62		
INDFARM	-0.0049	-0.01	1.6218**	2.39	0.2625	0.58
FARMSZE	-0.7644	-0.91	-1.8161**	-2.46	0.0258	0.04
DISIRWT	0.0779***	3.41	-0.0512***	-2.58	-0.0523***	-3.22
EXTCONT	1.4781***	4.27	0.5917	1.29	0.1785	0.55
LETTUCE	-0.0528	-0.17	2.0040***	5.07	0.8889***	3.51
SPONION	0.0052	0.02	-1.1458**	-2.16	-0.5662**	-2.00
LETTRES	3.6792*	1.86	0.6225	0.45	2.3987**	2.40
SPONRES	5.7454***	3.03	2.7006***	2.57	1.6889**	1.98
ITPINDEX	0.2453	0.89	0.7699**	2.31	0.1636	0.68
CONSTANT	-9.9623***	-4.28	0.9078	0.64	-1.8077	-1.55
ρ_{21}	0.4870(3.21)***					
ρ_{31}	0.2113(1.53)					
ρ_{32}	0.4425(3.04)***					
Log-likelihood	-213.47					
Wald $\chi^2(49)$	140.82					
Observation	202					

Likelihood ratio test: $\rho_{21} = \rho_{31} = \rho_{32} = 0$: $\chi^2(3) = 15.4754$; Prob > $\chi^2 = 0.0015$

*** denotes significant at 1%

** denotes significant at 5%

* denotes significant at 10%

Source: Author's computation

Table 4. Multivariate probit regressions on adoption of safer irrigation technologies

	ADOPSEIV		ADOPWCS		ADOPCWT	
Variable	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
AGE	0.0568*	1.84	-0.0275	-1.26	0.0056	0.38
GENDER	0.0525	0.08	0.7176	0.88	0.0968	0.18
EDUC	0.0975**	1.93	0.0199	0.54	0.0238	0.92
MARSTUS	-0.4146	-0.80	0.3164	0.77	0.5502*	1.79
HOHSZE	-0.1933	-1.37	0.1371	1.33	-0.0358	-0.52
FARMOG	2.4584***	4.61	2.1852**	2.36	-0.1252	-0.41
HLABOR	-0.7868*	-1.91	0.4001	1.12	0.1902	0.74
CREDIT			0.2344	0.51		
INDFARM	-0.4949	-0.69	1.5676**	2.29	0.2744	0.60
FARMSZE	-1.1903	-1.17	-1.7535**	2.34	0.0515	0.08
DISIRWT	0.0205	0.79	-0.0509***	-2.67	-0.0536***	-3.32
EXTCONT	6.1494	0.04	0.7051	1.58	0.2203	0.69
LETTUCE	1.2736**	2.14	1.8782***	4.68	0.8827***	3.49
SPONION	-0.7902*	-1.77	-1.1783**	-2.13	-0.5364*	-1.91
LETTRES	0.1991	0.12	0.6257	0.45	2.4192**	2.44
SPONRES	1.7409	1.21	2.5077***	2.46	1.6144*	1.91
ITPINDEX	1.2251***	2.77	0.7212**	2.22	1.3401	0.57
CONSTANT	-9.9479	-0.06	1.1651	0.83	-1.8297	-1.57
ρ_{21}	0.4677(2.17)***					
ρ_{31}	0.2863(1.95)*					
ρ_{32}	0.4893(3.47)***					
Log-likelihood	-178.26					
Wald $\chi^2(55)$	112.43					
Observation	202					

Likelihood ratio test: $\rho_{21} = \rho_{31} = \rho_{32} = 0$: $\chi^2(3) = 12.6629$; Prob > $\chi^2 = 0.0054$

*** denotes significant at 1%

** denotes significant at 5%

* denotes significant at 10%

Source: Author's computation

Appendix 1. Multinomial logit regressions on crop choice

Variable	Cabbage		Lettuce		Spring onion	
	Marginal effect	z-value	Marginal effect	z-value	Marginal effect	z-value
AGE	0.0013*	1.80	0.0092***	2.44	0.0104***	2.67
EDUC	0.0012	0.93	0.0135*	1.69	0.0145*	1.73
MARSTUS	0.0059	0.37	0.0446	0.52	0.0505	0.57
HOHSZE	-0.0002*	-0.24	-0.0316*	-1.61	-0.0318	-1.58
FLABOR	-0.0187*	-1.63	-0.1573***	-2.99	-0.1761***	-3.65
HLABOR	-0.0169	-1.30	-0.0976	-1.45	0.1146*	1.65
CREDIT	0.1201***	2.71	0.0797	0.67	0.1998	1.49
INDFARM	0.0204	1.42	-0.0987	-0.62	0.0783	0.46
FARMSZE	0.0171	0.27	-0.3746*	-1.72	-0.3575*	-1.62
DISIRWT	0.0014*	1.72	0.0085*	1.89	0.0099**	2.35
LOAM	0.0056	0.23	0.4457***	3. 07	0.4401***	3.03
CULTCRP	-0.0088	-0.66	-0.1845***	-3.10	-0.1933***	-3.09
EXTCONT	0.0029	0.02	0.1526**	2.19	0.1497**	2.06
AVAILRES	0.0243	1.50	0.1165	1.38	0.1409	1.59
REGSPIRW	0.0337***	5.64	0.0434	0.24	0.0097	0.05
RIVER	0.2282*	1.75	0.0074	0.04	0.2356	0.69
SHLOWEL	-0.0203	-0.58	-0.0154	-0.10	-0.0357	-0.21
STREAM	-0.0192	-0.90	-0.0173	-0.11	-0.0365	-0.24
Log-likelihood	-110.8062					
Pseudo R^2	0.3409					
Observation	202					

*** denotes significant at 1%
** denotes significant at 5%
* denotes significant at 10%
Source: Author's computation

Appendix 2: Correlation of explanatory variables

	age	gender	educ	marstus	hohsze	hlabor	flabor	credit	farmog	indfarm	cultcrp	fmsze	disirwt	extcont	loam	availres	regspirw	river	shalowel	stream
age	1.0000																			
gender	-0.0170	1.0000																		
educ	0.1492	-0.0735	1.0000																	
marstus	0.4523	0.0074	0.0814	1.0000																
hohsze	0.6298	-0.1387	0.2077	0.5387	1.0000															
hlabor	0.2321	-0.1247	0.1700	0.1632	0.2520	1.0000														
flabor	0.0301	0.0755	0.0335	0.0652	0.1403	-0.1270	1.0000													
credit	-0.0045	-0.0733	0.0158	0.0936	0.1234	0.1205	-0.0243	1.0000												
farmorg	0.1337	-0.2505	0.1940	0.0678	0.2180	0.1541	0.1418	0.0479	1.0000											
indfarm	-0.0226	0.0562	0.0208	0.1260	0.0350	-0.2187	0.1002	0.0207	-0.1545	1.0000										
cultcrp	-0.0522	0.0828	-0.1185	0.0664	-0.1860	-0.1912	0.0295	-0.0468	-0.1290	0.0522	1.0000									
fmsize	0.1760	-0.0309	0.2891	0.1208	0.2625	0.3750	-0.0843	0.0683	0.1437	-0.1170	-0.1328	1.0000								
disirwt	0.0001	0.0457	0.0277	0.0919	0.0059	-0.0331	0.0314	-0.0298	-0.1681	-0.0496	0.0903	0.1022	1.0000							
extcont	0.1302	-0.1858	0.3948	0.0376	0.2430	0.1782	0.1192	0.1872	0.3819	-0.0941	-0.2979	0.2334	0.1943	1.0000						
loam	0.0030	0.0600	0.0219	-0.0136	-0.0226	0.1747	0.0480	-0.1217	0.0848	0.0796	-0.1080	0.1221	-0.1394	0.1175	1.0000					
availres	0.0679	-0.0051	0.3177	-0.0735	0.1107	0.1026	0.2074	-0.0533	0.1951	-0.2282	-0.1266	0.2581	0.1964	0.4714	-0.0079	1.0000				
regspirw	-0.0153	0.2130	0.1619	-0.0403	-0.0457	-0.1087	0.0030	-0.1814	-0.0417	0.0738	-0.0563	0.0128	-0.1390	-0.1456	-0.0278	0.1425	1.0000			
river	0.0437	-0.1081	0.2616	-0.0019	0.0144	0.1076	-0.1266	-0.0562	-0.0611	-0.1630	-0.1388	0.4091	0.3502	0.2330	-0.0408	0.2916	-0.0401	1.0000		
shalowel	-0.1384	0.0625	-0.2204	-0.0452	-0.2088	0.0652	-0.0560	0.0349	-0.0666	-0.0325	0.2708	-0.1736	0.0213	-0.2439	0.0608	-0.1619	-0.0777	-0.4255	1.0000	
stream	0.1313	0.0955	0.0334	0.0919	0.1948	-0.1692	0.0831	0.0286	0.0989	0.1266	-0.1782	-0.0923	-0.1703	0.0580	-0.0143	0.0025	0.1000	-0.1168	-0.7408	1.0000

Source: Author's computation

[1] The term "safer vegetable" is used here to mean vegetables which are produced with an irrigation technology that is capable of reducing the health-related risks associated with untreated wastewater based on WHO's guidelines recommended for safer vegetable production (WHO,2006;WHO,2007).

[2] The use of multivariate probit provides more optimal estimates than the ordinary probit since the decision to adopt any of the safer technologies for fetching , transporting and applying irrigation water may not be independent and to achieve independence of the error terms, the multivariate probit is appropriate (Green, 2008).

[3] Obuobe et al. (2006) note that women involvement in urban vegetable production in Ghana is comparatively less, however retail and marketing of vegetables are dominated by women.

[4] The irrigation technology perception index was derived by averaging the scores of two perception prepositions on whether the farmer strongly disagrees (-1.0), disagrees (-0.5), is neutral (0), agrees (0.5), or strongly agrees (1.0) with the perception that first, the irrigation option profitable and second, whether the irrigation technology is efficient in reducing health-related risks to consumers and producers.

[5] In particular, concentrations of Cd, Cu, and Ni in potions of vegetables produced from untreated waste water could cause potential long term risks to consumers. Sieving or filtering the untreated wastewater is also necessary to prevent debris from entering irrigation pump thereby reducing wear and tear and also preventing the fouling of soils with any debris and solid wastes present in the wastewater (Bradford et al., 2003).