Farmer Perception, Environmental Awareness, and Overuse of Fertilizer in Kalpitiya: A Preliminary Investigation using Bayesian Econometrics

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ABSTRACT

Overuse of fertilizer has long been identified as a major issue in many parts of the world, including Sri Lanka. Sandy regosol soil and the shallow groundwater table in Kalpitiya, has aggravated the impacts of extensive fertigation, raising doubts on the long-term socio-economic and environmental sustainability of intensive agricultural systems of the region. In this background, this study attempts to determine the driving factors influencing the overuse of fertilizer within the farming community in Kalpitiya. Primary data collected from face-to-face interviews with 107 farmers from Kalpitya area using a pre-tested questionnaire was used to estimate a Bayesian probit model with sufficiently diffuse normally distributed priors. The model was estimated using a Random Walk Metropolis-Hastings sampling method, which iterated 125,000 times and 25,000 were discarded as burn-in. Results reveal that farmers who perceive that fertilizer has no effect on soil and groundwater tend to move away from fertilizer recommendations and are overusing. Farmers who are aware and believe that ground water is contaminated in the area tend to apply the recommended amount of fertilizer. In addition, larger farmers seem to apply recommended dosages than smaller farmers. Raising awareness through proper extension services and creating economic disutility by increased fertilizer costs coupled with the introduction of organic fertilizer could be recommended to circumvent the ill effects of overuse of fertilizer.

KEYWORDS: Awareness and perception, Bayesian econometrics, Fertilizer application, Kalpitiya

Introduction

Fertilizer plays a significant role in increasing crop yield and helps to ensure food security in any country. Nevertheless, the excessive use of fertilizer has led to several environmental impacts including pollution and groundwater contamination in different parts of the world (Datta, et al., 1997; Shamrukh, et al., 2001). Despite the fact that the country's cultivating activities solely depend upon organic fertilizer many years ago, the utilization of chemical fertilizer is now on the rise and has become a much-discussed topic. In the present scenario, most agricultural lands have been used for more than 100 or several years for agricultural purposes. Because of this continuous usage of lands and the application of chemical fertilizer, soil quality is being declined In the Sri Lankan context, farmers often resort to easily available chemical fertilizers and in most intensively cultivated vegetable fields; farmers rely on applying high quantities of chemical fertilizers (Vithanage, et al., 2014).

The use of inorganic fertilizer has increased because of increased cropping intensity with high yielding varieties. Widespread and intensive use of inorganic fertilizer is common in vegetable cultivation (Padmajani et al., 2014). The chemical fertilizer application rate has ranged from zero to 830% of the recommended level in different cropping systems in Sri Lanka (Kendaragama, 2006). Sri Lanka imports about 800 million kg of chemical fertilizers annually (Department of Census and Statistics, 2019). Many argue that farmers use excessive chemical fertilizer, well above the recommended levels, as they receive the products at considerably subsidized rates.

Farmer attitudes and perceptions towards fertilizer quality have led to an increase in the use of fertilizer in cropping fields. Most farmers who overuse chemicals believe that those chemicals in the market are of low quality (Fasina, 2013). Despite best management practices recommended by the research institutions, indiscriminate use of chemical fertilizers and low use efficiencies of fertilizers under tropical conditions, have increased environmental pollution, negatively affecting human and ecosystem health, and creating social and political unrest in the country (Jayasingha, et al., 2013). Agronomic practices adopted by farmers further degrade soil fertility threatening the food security in Sri Lanka.

Kalpitiya is a sandy peninsula situated in the Puttalam District in North-Western Province in Sri Lanka. Being one of the highly productive agricultural areas of the country, Kalpitiya contributes to a high percentage of vegetable and fruit production of the country, while generating a high number of job opportunities (Jayasekera et al., 2011). Agro-products have become one of the major income sources of the people in the peninsula. However, the presence of a shallow groundwater table along with highly permeable soil and unsaturated zone and intensive application of agrochemicals have raised doubts regarding the socio-economic and environmental sustainability of intensive agricultural systems in Kalpitiya (Kumarasinghe et al., 2016).

Groundwater usage of the Kalpitiya peninsula is about 100% as there are no surface water resources available. Intensive agricultural practices and human settlements have already imposed a high demand for groundwater within the Kalpitiya peninsula (Jayasekera et al., 2011).

Farmers often tend to apply excessive amounts of nitrogen fertilizers, while further increments are applied during the rainy season to compensate for losses due to leaching (Jayasingha et al., 2013). The retention of Nitrogen (N), which is essential for plant growth, is influenced by a variety of factors including soil constituents, irrigation practices and the fertilizer application in terms of type and the quantity (Rinaudo et al., 2005). Retention of N in the sandy soil of Kalpitiya is restricted due to poor contents of organic matter, clay, and silt fractions. Such continuous and rigorous application of agrochemicals and over-extraction of groundwater has led to significant levels of nitrate and other agro-chemical contamination of groundwater, similar to many other countries such as China, Australia and Europe (Jalali, 2005). Studies conducted in the Kalpitiya Peninsula show that the leaching of chemical fertilizers from intensively cultivated land tend to increase the nitrate concentration in groundwater (Kuruppuarachchi, 1995). Indiscriminate fertilizer usage, over-extraction of groundwater and frequent application of heavy doses of irrigation have been recognized as the major reasons for groundwater contamination (Sharma, 2009).

Due to these reasons, it is important to carry out multiple socio-economic analyses to perceive how this fertilizer application is practiced. Farmers' attitudes, perception, and awareness upon the environment and groundwater pollution play a major role in fertilizer usage. It is a fact that farmers apply chemical fertilizer without considering the proper fertilizer recommendations given by the Department of Agriculture. Simultaneously, it needs to be clarified, whether farmers are aware of the negative impacts of the excessive fertilizer application.

Numerous studies have been conducted previously to identify technologies to mitigate the extensive use of fertilizer in cropping fields (Giller et al., 2004; Millar et al., 2010). However, only a limited number of studies have attempted to study the farmer's fertilizer application behavior, attitudes, and awareness. Existing studies present that fertilizer application depends on several factors including, knowledge and training (Huang et al., 2015), off-farm employment, characteristics of the supply chain (Hasler et al., 2016), and characteristics of the farmers (Wu et al., 2018). Therefore, it is a fact that fertilizer application decisions or over-use are jointly affected by several factors. Among them, apart from the observable characteristics, psychological characteristics are less understood. This study attempts to fill this gap by presenting the linkages between farmer perception, environmental awareness, and fertilizer overuse in the Kalpitiya area.

Methodology

This research uses data from 107 sample farmers from the Kalpitiya area. The data collected are a part of a larger study on "An Integrated Approach to Improve the Socio-Economic & Environmental Sustainability of Intensive Agricultural Systems with Special Reference to Kalpitiya Peninsula" conducted by the Wayamba University of Sri Lanka. Farmer locations were purposely selected to match the objectives of the study. A two stage sampling method was used in selecting farmers for the study. In the first stage, six Grama Niladhari (GN) divisions were selected purposively to reflect the pollution levels in the area. Farmers were randomly selected from these GN divisions in the second stage. Farmers' current production levels, extents cultivated, socio-economic variables and more importantly, perceptions and attitudes of farmers were collected through a pre-tested questionnaire. In this study, we aimed to relate farmer perception to behavior, especially, behavior related to the application of recommended dosage of fertilizer. In this sense, we use a dependent variable, which is dichotomous in nature requiring us to make use of a probit regression. The probit, model fall in the general class of 'random utility models', because it assume in its development, an underlying latent distribution of differences in utility, y_i, which follow a normal linear regression model with observed characteristics contained in a covariate matrix, $\mathbf{x}_i$ and a normally distributed error, ε_i (Koop, 2003). In general, the random utility model is specified as:

$$y_i = x_i'\beta + \varepsilon_i \quad [1]$$

In the probit model, only two outcomes are observed. In this research, the outcome variable is whether farmers apply the recommended dosage of fertilizer or not.

Bayesian Analysis

We implement this model in a Bayesian framework, by forming prior pdf over parameters, and likelihood, $f(\mathbf{y}\,|\,\boldsymbol{\theta})$ and by studying the resultant posterior distribution $f(\boldsymbol{\theta}\,|\,\mathbf{y})$ for the parameters using the customary relationship in Bayesian analysis as,

$$\pi(\boldsymbol{\theta}\,|\,\mathbf{y}) \propto f(\mathbf{y}\,|\,\boldsymbol{\theta})\,\pi(\boldsymbol{\theta}) \quad [2]$$

In the probit, data generating density is normal $f^{N}(\mathbf{y}\,|\,\boldsymbol{\theta})$. The likelihood for the probit is $f^{N}(\mathbf{y}|\boldsymbol{\theta})=\prod_{i=1}^{N}(\Phi(-x_i'\beta))^{1-y_j}(\Phi(x_i'\beta))^{y_j}$;. The notation, Φ (.) denotes the cumulative distribution function of the normal distribution. The parameters of interest in the probit model are $\theta \equiv (\beta)$. The method used to estimate regression coefficients is a Random Walk Metropolis-Hastings (MH) sampling algorithm. Metropolis-Hastings algorithm (MH) is a general form of Markov Chain Monte Carlo (MCMC) methods. MCMC is essentially a Monte Carlo integration using Markov chains.

MCMC methods are becoming increasingly popular in recent times to simulate complex nonstandard multivariate distributions. In implementing MH algorithm, a candidate generating density, $q(\theta,\theta')$ is chosen. At each time t, the next state θ^{t+1} is chosen by first sampling a candidate point, θ' from this proposal distribution. If $q(\theta,\theta')$ satisfy the reversibility condition (i.e. $\pi(\theta)\,q(\theta,\theta') = \pi(\theta')\,q(\theta',\theta)$) draws will move equally between θ and θ'. However, if $q(\theta,\theta')$ is not symmetric, (i.e. $\pi(\theta)\,q(\theta,\theta') > \pi(\theta')\,q(\theta',\theta)$) the process will move too often from θ to θ' than θ' to θ. In such situations, a probability of move ($\alpha(\theta,\theta') < 1$) is introduced to correct this. If a move is not made, the algorithm keeps θ as a value from the target distribution (Chib and Greenberg, 1995). The probability of move can be stated as,

$$\alpha(\theta,\theta') = \min\left[\frac{\pi(\theta')q(\theta',\theta)}{\pi(\theta)q(\theta,\theta')},1\right] \quad \text{if } \pi(\theta)q(\theta,\theta')>0 \quad [3]$$
$$= 1 \qquad \text{otherwise}$$

Bayesian analysis is centered on its ability to use of prior information. In the present context, sufficiently diffuse normally distributed priors $f^{N}(0,10000)$ are used because of the vagueness of the prior beliefs about regression. Because the latent distribution in the probit model is assumed to follow a normal linear regression model, normally distributed priors are conjugate and hence applied in this case. Although various other distributions are possible, this study uses conjugate priors because they reduce Bayesian updating to modifying the parameters of the prior distribution, which greatly simplifies analysis.

Variables in the Regression

Table 1 lists the variables used in the probit model. The question related to the dependent variable is reported as recommended fertilizer application by farmer. As there was no possibility of arriving at the correct amount of fertilizer that farmers apply, we had to rely upon what farmers report. We have included an important variable to capture farmer attitude towards impact from fertilizer on water pollution [Fertilizer Impact].

Table 1: Description of Variables in the Model

Variable	Description
Apply Recommendation [AR]	Do you apply recommended amount of fertilizer to your crops? Yes=1 No=0 [Dependent]
Fertilizer Impact [FI]	Dummy Variable: Agreement to a statement that fertilizer have no effect on soil [Agree=1; Disagree=0]
Water Pollution [WP]	Dummy Variable: Agreement to a statement that ground water in Kalpitiya Peninsula is polluted [Agree=1; Disagree=0]
Age	Age in years
Edu2	If educated from 5-10 =1; otherwise 0
Edu3	If passed GCE O/L =1; otherwise 0
Edu4	If passed GCE A/L =1; otherwise 0
Extent	Total extent cultivated in Acres

Farmers' agreement to the statement, "Fertilizer and chemicals used in agriculture does not have any impact on water pollution, and they just go into soil" reported data on a binary scale: agree or disagree. Farmers who answered, "Do not know" were excluded from the analysis. Farmers who agree to this statement have a perception that excessive applications of fertilizer cause no harm. Thus, the expectation is a negative coefficient for the variable.

The next important variable captures farmer "awareness" about the present pollution situation in the Kalpitiya area. Farmers were asked to agree or disagree to the statement

"Ground water in Kalpitiya Peninsula is highly polluted". Those who agree to the statement are assumed aware of the pollution issue in the Kalpitiya area and therefore, as responsible citizens, they may not be applying fertilizer in higher amounts than the recommendation. Because of this reason, a positive sign is expected for this variable. Similar to the previous statement, those who answered 'do not know' were excluded from the analysis. Age of the farmer was included to represent farming experience. Education was included in the model using dummy variables. Education is expected to make farmers more 'responsible' and therefore, make environmentally friendly choices.

Results and Discussion

Description of the Sample

Age of the average farmer in the sample is 43 years (Table 2). The age distributed from a minimum of 19 to a maximum of 78 years. However, average farmer in the area is middle-aged. They cultivate on 3.23 Acres of land on the average. However, the sample included few large farmers [Maximum= 22 Ac], and those who with very small plots [Minimum=.25 Ac] of land.

Table 2: Descriptive Statistics of the Variables in the Model

Variable		Mean	Std. Dev.	Percent
Age		43.35	13.30	-
Extent		3.23	3.10	-
Fertilizer Recommendation [FR]	No	-	-	69.16
	Yes	-	-	30.84
Fertilizer Impact [FI]	Disagree	-	-	45.78
	Agree	-	-	54.22
Water Pollution [WP]	Disagree	-	-	14.89
	Agree	-	-	85.11
Less than grade5		-	-	12.15
Grade 5-10		-	-	49.53
O/L		-	-	24.3
A/L				8.41

There were only 30.8% of farmers that apply the correct recommended amounts of fertilizer. Thus, close to 70% is disregarding the recommendation and overusing fertilizer in their cultivations.

About 54% of the farmers agreed to the statement, "Fertilizer and chemicals used in agriculture does not have any impact on water pollution, and they just go into soil". Thus, majority's perception on the impact of fertilizer is incorrect. However, interestingly, majoriy [85.1%] agreed to the statement, "Ground water in Kalpitiya Peninsula is highly polluted" suggesting that a high majority in the area accepts that there is ground water pollution in Kalpitya. This seems precarious. Farmers seem to believe that ground water pollution is not because of xcessive use of fertilizer and chemicals.

Results of the Bayesian Probit Model

In estimating the Bayesian probit model, the Random Walk Metropolis-Hastings algorithm drew 125,000 samples. Out of that, 25,000 were discarded as the burn-in sample, limiting the analysis sample to 100,000. The convergence of Markov Chain Monte Carlo [MCMC] chains were verified through observing visual diagnostic tools such as trace plots, histograms and autocorrelation diagrams. Histograms in Figure 1 indicate a satisfactory mixing from sample space and therefore, MCMC chains have converged. The posterior summaries of variable estimates in the model are given in Table 3. The first column reports the posterior mean, while the second column reports the posterior standard deviation. The MCSE in the third column reports the standard error of the MCMC iterations. MCSE is about the accuracy of our simulation results and MCSE values close to zero is regarded as the best. However, to achieve zero, an infinite number of iterations are required (StataCorp, 2017).

Table 3: Posterior Estimates of the Probit Model

Variable	Mean	Std. Dev.	MCSE	Median	Equal-tailed [95% Cred. Interval]	
Fertilizer Impact [FI]	-0.6656	0.3205	0.0059	-0.6595	-1.3745	-0.0605
Water Pollution [WP]	0.7388	0.5132	0.0090	0.7239	-0.2648	1.7359
Age [A]	-0.0004	0.0133	0.0003	-0.0003	-0.0269	0.0252
edu2 [E2]	0.5001	0.4548	0.0149	0.4914	-0.3602	1.4275
edu3 [E3]	0.4494	0.5354	0.0155	0.4487	-0.5978	1.4983
edu4 [E4]	-0.1982	0.7347	0.0164	-0.1784	-1.6314	1.2285
Extent [Ext]	-0.0280	0.0571	0.0010	-0.0265	-0.1419	0.0823
Constant	-1.0206	0.9222	0.0209	-1.0189	-2.8486	0.7408

Note: MCSE= standard error of the MCMC iterations

Posterior medians are in the fifth column. The equal-tailed 95% credible interval reports an interval, within which an unobserved parameter value falls with a 95% probability (Edwards et al., 1963).

If the credible interval does not include zero, such variables are regarded as "significant" in Bayesian methods. Because Bayesian estimates simulate the population distribution of coefficients, Bayesian method enables the researcher to obtain various other measures of probability statements about the coefficients of variables. As indicated earlier, main interest in this research lies around the two variables, "Fertilizer Impact [FI]" and the "Water Pollution [WP]". As expected, the variable FI returned a negative coefficient implying that farmers, who perceive that there is no environmental influence of excessive applications of fertilizers, tend to apply fertilizers in higher dosages than the recommended ones. Examination of the probability distribution of the coefficient of FI reveals that majority of the mass is to the negative side of zero (Figure 1a). Several recent studies emphasize that perception shapes behavior. For instance, Zegeye et al. (2010), where a sample of Ethiopian farmers show that perception about the modern variety has a highly significant effect on adoption. Njankoua et al. (2012) report that perception play a key role in adoption of New Aquaculture Technologies in the Western Highlands of Cameroon. In the present study, wrong perception about fertilizer application leads to harmful behavior to the environment causing ground water pollution in Kalpitiya.

In our study, we also attempted to determine the impact of knowledge or awareness regarding ground water pollution in Kalpitya area on the overuse of fertilizer. If a farmer were aware of the current situation, then he would not probably want to worsen the situation. Thus, awareness should lead to careful application of fertilizer. The WP variable, which captures this, returned a positive sign. Its credible interval includes a zero and seems not significant.

However, Bayesian output provides us with the 100,000 values of the parameter estimate for WP enabling us to simulate the population distribution of the parameter. Figure 1b show that although the credible interval includes zero, considerable amount of mass is to the right of zero (see reference line in Figure 1). Availability of the parameter distribution enables us to test the probability of the value of the parameter being more than zero (in other words area under the graph to the right of zero). As shown in Table 4, although, the credible interval for the coefficient of WP includes zero, there is 0.93 probability that this would be greater than zero [positive]. Thus, there is a high probability that awareness of the current situation of water pollution in the area to would induce farmers to apply recommend amount of fertilizer. Similar results are reported by Veihe (2010) in a recent study on sustainable farming practices in Ghana. They report that when farmers have a clear perception of the problem, they tend to adopt a correct behavior and a wide range of conservation measures in farming. Further, Farani et al., (2019) report that environmental awareness and environmental concern has a positive and significant influence on farmers' behavior in sustainable agriculture.

Age of the farmer usually represent experience (Tauer, 1995). The coefficient for the [age] has a negative sign, which is uncertain a priori. On one hand, farmers can learn from experience on the shortcomings of excessive application of fertilizer. If that is the case, the sign of the coefficient should be positive. On the other hand, farmers may experience that other farmers apply excessive fertilizer in any case and because of that, there may be no effect of them applying the correct amount. Then the sign would be negative. Observing Figure 1c and Table 4, we find that the probability of the coefficient value becoming more than zero [positive] is 0.49. Thus, probability of coefficient being less than zero [negative] is 0.51. Because of this, the sign of the coefficient is negative. However, if prior information is available on the direction of the effect, this could have been evaluated by using suitable informative priors.

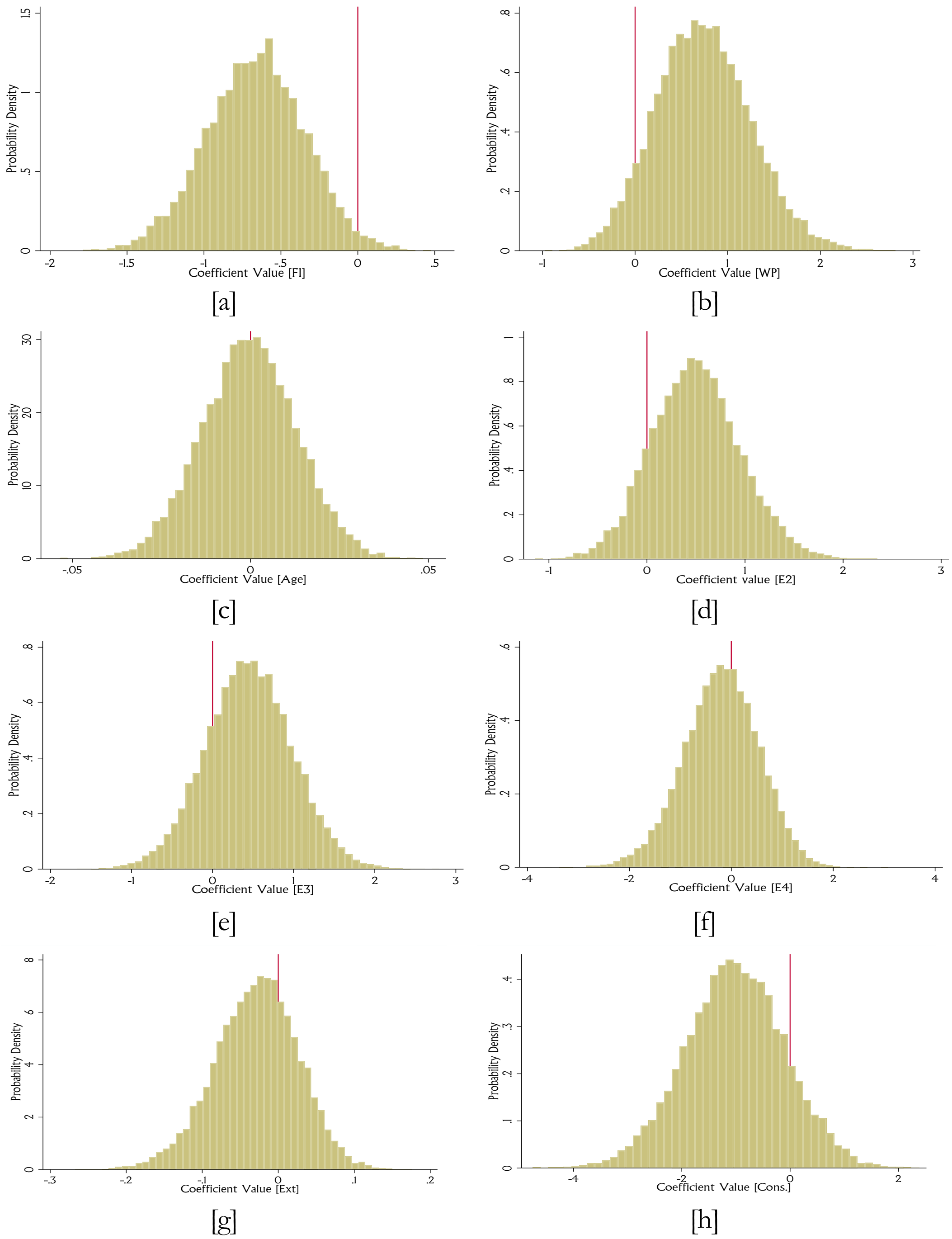

Figure 1: Histograms of Coefficients from MCMC Iterations [a] FI, [b] WP, [c] Age, [d] E2, [e] E3, [f] E4, [g] Extent, and [h] Constant

Note: Vertical line indicate zero on the x-axis

As expected, dummy variables representing education show positive signs, except those who have Advanced Level [A/L] qualifications. The regression omitted farmers with formal education of less than 5 years thus, making it the reference group. Although, E2 [grade 5-10] and E3 [O/L] are not significant, they show the expected sign with respect to the reference category of least level of education. Inspecting Figures 1d and 1e and the values in Table 4, suggests that considerable amount of mass is to the right of the distribution [positive]. Thus, there is a high probability of applying the recommended dosage by the educated farmers or in other words overuse of fertilizer decreases with higher education level. The unexpected result of E4 may be due to the low number of farmers in this category [8.4%]. Importance of education on best management practices in farming is highlighted in a recent study by Brown (2019).

The last variable included in the model is the extent of farming. Larger extents corresponds to higher cost of fertilizer application. Therefore, farmers may be discouraged to apply more than the recommendations. As expected mass to the right of distribution from zero is low [Figure 2g] with 0.31 probability [Table 4]. In other words, there is less chance to observe a positive coefficient with respect to extent.

Table 4: Interval Estimations of the Coefficients

	Mean	Std. Dev.	MCSE
Probability of coefficient of FI<0	0.982	0.132	0.002
Probability of coefficient of WP>0	0.931	0.254	0.003
Probability of coefficient of age>0	0.490	0.499	0.009
Probability of coefficient of E2>0	0.852	0.355	0.007
Probability of coefficient of E3>0	0.802	0.398	0.009
Probability of coefficient of E4>0	0.402	0.490	0.009
Probability of coefficient of Ext>0	0.315	0.465	0.007

Note: MCSE= Standard error of the MCMC iterations

Conclusion and Policy Implications

This research attempts to evaluate the role of perception and environmental awareness of farmers on shaping the behavior related to overuse of fertilizer, as overuse of fertilizer is a growing concern in Kalpitiya area. In the current study, we consider few critical aspects that can be used to curb such fertilizer over use. We find evidence that inaccurate perception on fertilizer's effect on the environment play a key role in over use. Secondly, environmental awareness, or knowledge that the immediate environment has degraded also has a critical role to play in the decision to overuse. This leads to an important conclusion, that awareness can play a significant role in reducing over use of fertilizer. Extension services can greatly assist in this endeavor. Mobilizing the existing extension force for not only their day-to-day work, but also specifically thrusting on the knowledge sharing and environmental awareness is necessary. Further, special programs directed at farmers in the area through regional media may help. Education also show an important relationship with probability of overusing fertilizers. Higher levels of education show less propensity to overuse fertilizer in comparison to the lowest level of education in the sample. Thus, education make farmers more "responsible" and therefore, encourage them to make environmentally friendly choices. This finding further strengthens conclusion made above. There must be more awareness on the demerits of excessive use of fertilizer.

Results further show that creating financial dis-utility may also assist reducing the fertilizer overuse. We find that increases in cultivated extents reduce the probability of fertilizer overuse, highlighting that overusing in large areas is unprofitable. As farmers are profit motivated, increasing cost of fertilizer may restrict the application, at least to the recommended levels.

This economic incentive will work when coupled with other attempts described above aiming at behavioral changes. To avoid farmer protests and to improve soil conditions, such price increases should be coupled with propaganda to promote organic fertilizer in Kalpitiya area.

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