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ENVIRONMENTAL EFFICIENCY IN VEGETABLE PRODUCTION IN PAKISTAN'S PUNJAB: IMPLICATIONS FOR SUSTAINABLE AGRICULTURE

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For many decades, pesticide (insecticide, fungicide and weedicide) and fertilizers have played an imperative role in improving agricultural productivity, but their adverse affects on the sustainability of natural resources (environment and ground water etc) has been largely ignored. The present study attempts to estimate the environmental efficiency indices of environmentally detrimental variables by employing a translog stochastic production frontier approach in vegetable production. Pesticide cost and active nutrients of fertilizer (NPK) are treated as environmentally detrimental variables. The input-output data from 140 freshwater and 135 wastewater farmers are collected from two major vegetable producing districts (Gujranwala and Faisalabad) of Pakistan's Punjab province in 2010. The mean technical efficiency indices in wastewater and freshwater area are 74 and 91 percent, respectively. The environmental efficiency indices of active nutrients of fertilizer (NPK) in wastewater and freshwater areas are 14 and 69 percent while the environmental efficiency indices of pesticide cost are 47 and 43 percent, respectively. This implies that substantial reduction (86 percent) in active nutrients of fertilizer in wastewater is possible while more than 50 percent reduction in pesticide cost can be made both in wastewater and freshwater areas by maintaining the revenue at maximum achievable level. The reduction in pesticide cost and active nutrients of fertilizer NPK is Rs.568 and Rs.1850 per acre in wastewater area while in freshwater area it is Rs.451.5 and Rs.1525.2 per acre, respectively. However, total saving at the province level from the reduction in pesticide cost both in wastewater and freshwater areas is Rs.314.5 million but from active nutrients of fertilizer is Rs.1060.9 million. The saving from the reduction in fertilizer use is more than three times the saving from the reduction in pesticide use. Our empirical findings demonstrate that safe vegetable for consumption (with fewer chemicals) together with reduction in environmental pollution and higher level of profitability through reduction in cash input use is achievable.

I. Introduction

The intensive use of agriculture inputs has worked as a catalyst to shift the production frontier but the most critical factor of sustainability of natural resources (environment and ground water etc) has been mostly ignored. Chemicals play an important role to intensify agriculture in the developing countries and offer the most attractive low cost method of increasing output and give the farmer a high economic

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return for their labor and investment. The drastic increase of pesticides and fertilizers use leads to both direct and indirect costs to farmers and the society. Empirical evidences exist that intensive use of pesticide is causing a wide range of acute poisoning incidences among farmers [Jeyaratnam, (1990); Maumbe and Swinton, (2003); Recena et al., (2006); Travisi and Nijkamp, (2008); and Travisi et al., (2006)]. It is estimated that at least three million cases of pesticide poisoning occur worldwide each year, with 220,000 deaths. These numbers, even more alarmingly, show a rising trend [WHO, (1990); Dasgupta et al., (2001); Rosenstock, et al., (1991); Pimental, et al. (1992); Kishi, et al., (1995); and [WRI, (1998)].

During the last two decades (1990-91 to 2007-08), vegetable area and its production has increased by 21 and 13 percent, respectively in Pakistan while this increase in the province of Punjab is 23 and 18 percent, respectively (excluding Potato). For the same period, amount of pesticide (insecticide and fungicide) use on vegetables has increased from 20213 metric tone to 94265 metric tone in Pakistan which accounts for 366 percent increase over last two decades. However, the expenditure on pesticide only become double which increased from Rs.5536 to Rs.10534 millions in last two decades. Similarly, the use of chemical fertilizer in Pakistan has also increased from 1884 thousand tons to 3581 thousand tons of nitrogen with an increase of 91 percent during the same periods (GOP, 2008b). The above figures clearly depicts that pesticide use has increased many folds compared to the area and production of vegetables, indicating an alarming intensification of pesticide use in vegetable production. Increased use of agro-chemicals endangers life on soil, water and air because of environmental health hazards associated with these chemicals. Dung et al., (2003) has summarized this situation as, use of pesticide has considerably increased in the developing countries where its advantages seem to have not been fully exploited.

A large amount of literature exists dealing with technical, allocative and economic efficiency in different crops and regions (Good et al., 1993; Ahmed and Bravo-Ureta 1996; Wilson et al., 1998; Larson and Plessman 2002; Villano 2005; and Abedullah et al., 2006) but very little work has been done to estimate the environmental efficiency of chemical inputs (pesticide and chemical fertilizer) in agricultural production system (Reinherd et al., 1999; Zhang and Xue 2005, Abedullah et al., 2010). Particularly, in Pakistan the environmental efficiency index of hazardous input use has not been explored in the vegetable sector of Pakistan. The development of environmental efficiency indexes of environmental detrimental variables is expected to play an important role to guide the policy maker in the reduction of chemical inputs in vegetable production. Such reduction in chemical use not only helps to grow safer vegetables for consumers but it also helps to improve the diversity and shrink the deterioration of natural resources (environment, soil and water). Moreover, any such reduction in chemical use will further assist to improve the farmer's health. Vegetable are being grown with freshwater and untreated wastewater in Peri-urban areas of Punjab, Pakistan. Untreated wastewater includes useful and hazardous chemicals, implying that vegetable production with wastewater and freshwater need to be dealt separately. The contribution of present study is to estimate the environmental efficiency indices of pesticides and chemical fertilizers in two groups of vegetables (grown with wastewater and freshwater) and to compare these indices. This will serve as a guide, how much reduction in pesticide and fertilizer use is achievable by maintaining the output at a maximum achieve able level. Fewer chemical uses imply less pollution of natural resources and little probability of acute poisoning.

The scheme of the paper is as follows. The following section delineates the theoretical and empirical framework to explain the estimation procedure of technical and environmental efficiency indices. It also explains the sampling design and data collection procedure. Empirical results are presented and implications are derived in the subsequent section. The summary and conclusion is presented in the last section.

II. Methodology and Data Collection Procedure

The methodology is elaborated in two subsections, conceptual framework and empirical model. The conceptual framework discuss general procedure adopted to estimate the technical and environmental efficiency while empirical model explains the details of endogenous and exogenous variables with production function specification and mathematical manipulation employed to estimate the environmental efficiency indices. The last part of this section explains the data collection procedure used for empirical analysis.

1. Conceptual Framework

In the relevant literature dealing with agricultural economics, output is treated frequently as a stochastic variable because of weather conditions, diseases and other exogenous random shocks. However, we assume that the decision variable (output but revenue in our case) is fixed in the short run and it is common and reasonable assumption when estimating production relationships in agriculture on cross sectional data (Coelli, 1995). The present study is employing stochastic frontier production function approach introduced by Aigner et al., (1977); Meeusen and Broeck, (1977); and Battese and Coelli (1988, 1992). The general form of stochastic production frontier is specified as follow;

$$Y_i = f(X_{ij}, Z_{ij}, \beta) * exp(V_i - U_i) \quad (1)$$

Where respondents and inputs (variables) are represented by subscripts i and j, respectively;

Y_i = is a per acre revenue of the *i-th* farmer;
X_{ij} = is a vector of normal inputs (X_{i1} is the seed in kg, X_{i2} the irrigation hours by wastewater or by Canal and Tube well water, X_{i3} is a total labor hours and X_{i4} is the total Tractors hours);
Z_{ij} = a vector of environmentally detrimental inputs (Z_{i1} is active nutrients of fertilizer application, Z_{i2} is pesticide cost (insecticide and fungicide cost)
β = is a vector of parameters that has to be estimated;
V_i = is a random error term which is independently and identically distributed as $N(0, \sigma_v^2)$, capture the influence of exogenous events beyond the farmers control, and

U_i = is nonnegative random error term i.e. $U_i \geq 0$, and $0 \leq exp(-U_i) \leq 1$ that captures the technical inefficiency of the *i-th* farmer. This one sided error term can follow different distributions such as, truncated-normal, half-normal, exponential, and gamma [Stevenson, (1980); Aigner et al., (1977); Green, (2000, 1990); Meeusen and Von den Broeck, (1977)]. In our case, U_i follows a half normal distribution $N(0, \sigma_v^2)$ as typically done in the applied stochastic frontier literature.[1]

The stochastic version of the output-oriented technical efficiency is empirically measured as below;

$$TE = exp(-U_i) = \left[\frac{Y_i}{f(X_{ij}, Z_{ij}, \beta)}\right] exp(v_i) \qquad (2)$$

Technical efficiency index in equation (2) is the ratio of observed to maximum feasible output and it is estimated by employing the traditional stochastic production frontier approach. However, the environmental efficiency index is the ratio of minimum feasible to observed use of an environmentally detrimental input, given the technology, observed levels of output and conventional inputs [Reinhard et al. (2000, 2002)].

Pittman (1983) is the first who considered environmental effects as undesirable outputs. Fare et al. (1989) and Fare et al. (1993) also followed the same and modeled environmental effects as unwanted outputs. These studies include environmental effects in the output vector to obtain inclusive measures of technical efficiency but Reinhard et al. (1999) considers one or more environmental effects as by-products of the production process. However, Pittman (1981) is the first who modeled pollution as an input in the production function and later his approach is refined and modified by Haynes et al. (1993), Haynes et al. (1994), Hetemäki (1996), Boggs (1997) and Reinhard et al. (1999). These are the pioneers who considered environmental effects as a conventional input rather than as an undesirable output which distinguished their study from the earlier literature. Recently this approach is adopted by Reinhard et al. (2002), Zhang and Xue (2005), and Wu (2007). Following later group of studies we also consider environmental effects of pesticide and fertilizer as a conventional input in the production process. Different studies used different environmentally detrimental variables according to their objectives and availability of data. We consider pesticide cost and fertilizer as environmentally detrimental variables in vegetable production. Following Reinhard et al. (1999) we estimate technical and environmental efficiency separately. The technical efficiency is estimated as given in Equation (2) and mathematical representation of the environmental efficiency is made as below:

$$EE = min\{\phi : f(X, \phi Z) \geq Y\} \leq 1 \qquad (3)$$

[1] The selection of distribution of U_i is not affecting the efficiency calculations [Kebede (2001) and Wadud (1999)] and therefore, present study is not considering other distributions.

where, $F(X, \phi Z)$ is the new production frontier and $(X, Z) \epsilon R+$ (a set of positive real numbers) while X and Z are, respectively a vector of conventional and environmentally detrimental input and $Y \epsilon R+$ is revenue of each farmer which is estimated by employing maximum likelihood estimation technique. To obtain the environmental efficiency index, a new frontier production function as defined in Equation (3) is developed by replacing the observed environmentally detrimental input vector Z with ϕZ and setting $U_i = 0$, representing a function at full technical efficiency. By following the definition of Reinhard, et al. (2000; 2002), the environmental efficiency is explained as $EE = \phi Z/Z$ and then by taking natural logarithm on both sides of the equation it can be written as below:[2]

$$LnEE = Ln\phi = Ln\phi = Ln\left(\frac{\phi Z}{Z}\right) = Ln\phi Z - LnZ \qquad (4)$$

Where, $LnEE$ is the logarithm of environmental efficiency and is equal to the logarithm of new frontier function with $U_i = 0$ minus the original frontier function with $U_i \neq 0$.

2. *Empirical Framework*

There is only one output in terms of revenue and hence, as discussed by Wu (2007), the present study estimates a stochastic production frontier rather than a stochastic distance function to relate the environmental performance of individual farms to the best of environment-friendly farming. In order to minimize the misspecification of error, stochastic translog production function is employed [Reinhard et al., (1999)]. A stochastic translog production frontier function under the assumption of one environmentally detrimental variable X_4 (which is represented by Z as an environmentally detrimental variable) can be written as;[3]

$$\begin{aligned} LnY = {} & \beta_0 + \beta_1 LnX_1 + \beta_2 LnX_2 + \beta_3 LnX_3 + \beta_4 LnZ + \beta_5 LnX_5 + \beta_6 LnX_6 + \\ & \beta_7 D_{mp} + 0.5\beta_{11} Ln^2 X_1 + 0.5\beta_{22} Ln^2 X_2 + 0.5\beta_{33} Ln^2 X_3 + 0.5\beta_{44} Ln^2 X_4 + \\ & 0.5\beta_{55} Ln^2 X_5 + 0.5\beta_{66} Ln^2 X_6 + \beta_{12} LnX_1 LnX_2 + \beta_{13} LnX_1 LnX_3 + \\ & \beta_{14} LnX_1 LnZ + \beta_{15} LnX_1 LnX_5 + \beta_{16} LnX_1 LnX_6 + \beta_{23} LnX_2 LnX_3 + \\ & \beta_{24} LnX_2 LnX_3 + \beta_{25} LnX_2 LnX_5 + \beta_{26} LnX_2 LnX_6 + \beta_{34} LnX_3 LnZ + \\ & \beta_{35} LnX_3 LnX_5 + \beta_{36} LnX_3 LnX_6 + \beta_{45} LnZ LnX_5 + \beta_{46} LnZ LnX_6 + \\ & \beta_{56} LnX_5 LnX_6 + (V_i - U_i) \end{aligned} \qquad (5)$$

[2] According to Reinhard, et al. (2000, 2002), the environmental efficiency is the ratio of minimum feasible to an observed input of environmentally detrimental variable, given the technology, observed levels of output and conventional inputs.

[3] In wastewater area, Farm Yard Manure (FYM) is not used by any farmer. However, it is commonly used by farmers in freshwater area and that is why it is added as an additional variable (X7= Farm Yard Manure) in the estimation of production function for freshwater farmers.

Where *Ln* denotes the natural logarithm, in above translog production function and,

Y = Revenue per acre;[4]
X_1 = tractor used for land preparation and other operations in (Hours/acre);
X_2 = active nutrients of nitrogen in (Kg/acre);
X_3 = cost of seed in (Kg/acre);
X_4 = Z= cost of pesticide (insecticide + fungicide) in (Rs/acre) and
X_5 = amount of labor in (Hours/acre);
X_6 = total irrigation time in (Hours/acre) by wastewater or by Canal and Tube well water;
D_{mp} = Dummy for seed, if purchased from market =1, otherwise = 0.

It should be noted that X_2 and X_4 are used as environmentally detrimental variables. The equation (5) is estimated by employing Frontier Version 4.1 developed by Coelli (1994). The new stochastic frontier function as discussed above in conceptual framework is obtained by replacing Z with ØZ in equation (5) in such a way that technical inefficiency of each farmer approaches to zero i.e. ($U_i = 0$). Here Ø is the environmental efficiency index. Therefore, new stochastic frontier with full technical efficiency is written as;

$$\begin{aligned} LnY = {} & \beta_0 + \beta_1 LnX_1 + \beta_2 LnX_2 + \beta_3 LnX_3 + \beta_4 Ln\phi Z + \beta_5 LnX_5 + \beta_6 LnX_6 + \\ & \beta_9 D_{mp} + 0.5\beta_{11} Ln^2 X_1 + 0.5\beta_{22} Ln^2 X_2 + 0.5\beta_{33} Ln^2 X_3 + 0.5\beta_{44} Ln^2 \phi Z + \\ & 0.5\beta_{55} Ln^2 X_5 + 0.5\beta_{66} Ln^2 X_6 + \beta_{12} LnX_1 LnX_2 + \beta_{13} LnX_1 LnX_3 + \\ & \beta_{14} LnX_1 Ln\phi Z + \beta_{15} LnX_1 LnX_5 + \beta_{16} LnX_1 LnX_6 + \beta_{23} LnX_2 LnX_3 + \\ & \beta_{24} LnX_2 Ln\phi Z + \beta_{25} LnX_2 LnX_5 + \beta_{26} LnX_2 LnX_6 + \beta_{34} LnX_3 Ln\phi Z + \\ & \beta_{35} LnX_3 LnX_5 + \beta_{36} LnX_3 LnX_6 + \beta_{45} Ln\phi Z LnX_5 + \beta_{46} Ln\phi Z LnX_6 + \\ & \beta_{56} LnX_5 LnX_6 + V_i \end{aligned} \tag{6}$$

By Subtracting Equation (6) from Equation (5), the resultant equation after little mathematical manipulation is written as;

$$\begin{aligned} & 0.5\,\beta_{44}\,[Ln\phi Z - LnZ]^2 + [\beta_4 + \beta_{44} LnZ + \beta_{14} LnX_1 + \beta_{24} LnX_2 + \beta_{34} LnX_3 + \\ & \beta_{45} LnX_5 + \beta_{46} LnX_6]\,[Ln\phi Z - LnZ] + U_i = 0 \end{aligned} \tag{7}$$

By using the result of equation (4) in equation (7) it is modified as follow;

$$\begin{aligned} & 0.5\,\beta_{44}\,[LnEE]^2 + [\beta_4 + \beta_{44} LnZ + \beta_{14} LnX_1 + \beta_{24} LnX_2 + \beta_{34} LnX_3 + \\ & \beta_{45} LnX_5 + \beta_{46} LnX_6]\,[LnEE] + U_i = 0 \end{aligned} \tag{8}$$

[4] Due to high variation in yields of different vegetable crops, revenue as a dependent variable is considered to estimate Maximum Likelihood Estimates of Translog production function. This is common practice to estimate production function for different vegetables (Zhang and Xue., 2005; Abedullah et al, 2006)..

Now equation (8) can be solved for *LnEE* by using quadratic equation formula as below;

$$\begin{aligned} LnEE = {} & [-\beta_4 + \beta_{44} LnZ + \beta_{14} LnX_1 + \beta_{24} LnX_2 + \beta_{34} LnX_3 + \beta_{45} LnX_5 + \beta_{46} LnX_6] + \\ & \{(\beta_4 + \beta_{44} LnZ + \beta_{14} LnX_1 + \beta_{24} LnX_2 + \beta_{34} LnX_3 + \beta_{45} LnX_5 + \beta_{46} LnX_6)^2 - 2\beta_{44} U_i\}^{0.5} / \beta_{44} \end{aligned} \tag{9}$$

The environmental efficiency "EE" is estimated by taking exponent of Equation (9) i.e.

$$EE = exp(LnEE) = \phi = \left({}^{\phi Z}\!/_{LnZ} \right) \tag{10}$$

Here ϕ is the environmental efficiency index as discussed earlier. By employing exactly the same methodology as described above, the environmental efficiency of active nutrients of nitrogen is also estimated.

Finally, in case of two environmental detrimental variables X_2 and X_4 (i.e. active nutrients of nitrogen and pesticide cost), the joint environmental efficiency "*LnEE*" for two detrimental variables is estimated by employing the Equation as given below;[5]

$$\begin{aligned} LnEE = {} & [-(\beta_2 + \beta_4 + \beta_{22} LnZ + \beta_{44} LnZ + \beta_{12} LnX_1 + \beta_{22} LnZ + \beta_{32} LnX_3 + \\ & \beta_{42} LnX_4 + \beta_{25} LnX_5 + \beta_{26} LnX_6 + \beta_{14} LnX_1 + \beta_{24} LnZ + \beta_{34} LnX_3 + \\ & \beta_{44} LnZ + \beta_{45} LnX_5 + \beta_{46} LnX_6 + \{(\beta_2 + \beta_4 + \beta_{22} LnZ + \beta_{44} LnZ + \\ & \beta_{12} LnX_1 + \beta_{22} LnZ + \beta_{32} LnX_3 + \beta_{42} LnX_4 + \beta_{25} LnX_5 + \beta_{26} LnX_6 + \\ & \beta_{14} LnX_1 + \beta_{22} LnZ + \beta_{34} LnX_3 + \beta_{44} LnZ + \beta_{45} LnX_5 + \beta_{46} LnX_6)^2 - \\ & 2\beta_{22} + 2\beta_{44} + 4\beta_{24})(U_i)\}^{0.5}] / \beta_{22} + \beta_{44} + 2\beta_{24} \end{aligned} \tag{11}$$ [6]

These individual environmental efficiencies of two inputs (when we consider pesticide or fertilizer environmentally detrimental variable) and joint environmental efficiency (when we consider both inputs environmentally detrimental variable simultaneously) allow to test the hypothesis whether these inputs are used at environmentally efficient level and if not then whether over utilization or under utilization is taking place. Further it allows to test, if over utilization is taking place then how much reduction is possible by maintaining the revenue at maximum achievable level. For Cobb-Douglas type of production function, parameters are directly elasticities but in case of translog production function output elasticity are different than the parameters of production function. In case of translog production function, the elasticities are estimated as follow;

[5] This equation is derived by using the same procedure followed in case of one detrimental variable.
[6] In the quadratic formula there are both positive and negative (±) outside the under root term but we took only positive because $U_i = 0$, if only positive sign is considered outside the under-root term.

$$S_j = \frac{\partial LnY}{\partial LnX_j} \qquad (12)$$

where, j stands for number of variables and in wastewater area $j=1, 2, \ldots\ldots, 6$ but in freshwater area $j=1, 2, \ldots\ldots, 7$ because Farm Yard Manure (FYM) is not being used in wastewater area as explained earlier.

The cross elasticity of substitution for input factor "j" and "k" can be written by following the formula developed by Ferguson (1969) as follow;

$$H_{jk} = \left[\frac{\beta_{jk}}{(S_j \times S_k)}\right] + 1 \qquad (13)$$

Where, H_{jk} is the cross elasticity of substitution between input j and k, while S_j and S_k are the output elasticities of input j and k, respectively and β_{jk} is the value of coefficient of interaction term of input j and k in the translog production function.

From the result of this method, a positive substitution elasticity value implies that the input factors j and k are jointly complimentary. On other side negative substitution elasticity value indicates a competitive relationship.

3. *Data Collection Procedure*

A well designed, field pre-tested comprehensive farm household survey is used to collect site-specific primary input-output data from 275 farm households in Rabi season by using stratified random sampling technique from two core vegetable producing districts (Gujranwala and Faisalabad) of Punjab in 2010. Each district is further divided into two stratums, named as wastewater and freshwater because vegetable production with wastewater and freshwater are assumed to be two different production technologies and therefore, need to be dealt separately. Seventy and sixty five farmers growing vegetables with wastewater from Gunjranwala and Faisalabad districts respectively are selected and seventy farmers growing vegetables with freshwater are selected from each of the two districts. The data collection from wastewater farmers in Faisalabad district could not reach seventy because limited availability of wastewater farmers in the area.

III. Results and Discussions

The mean values of different inputs and outputs on per acre basis for two groups (wastewater and freshwater) are estimated and the results are reported in Table 1. Average revenue per acre from vegetable production in wastewater and freshwater area is Rs.39553 and Rs.43354, respectively. Low average revenue in wastewater area is probably due to deterioration of soil productivity because intensive use of wastewater accumulates poisonous chemicals on upper layer of soil which results in lower soil productivity. Average value of tractors hours in wastewater and freshwater area is 5 and 4.6 hours, respectively. Intensive use of plowing by farmers in both

(wastewater and freshwater) results in greater than the recommended level of 3-4 plowings per crop season. Excessive plowing leads to negative impact on the productivity. Average dose of fertilizer nutrients (NPK) used by wastewater farmer is 43.1 kg per acre which is significantly lower compared to 82 kg per acre used by their counterpart in the freshwater area. Wastewater contains 39% more nitrogen than the recommended level set by WHO (Ensink et al., 2002), implying that wastewater farmers are not required to use any amount of fertilizer.

Average value of seed cost in wastewater area is Rs.1774 per acre while in freshwater area it is Rs.1437 per acre, implying that farmers in wastewater areas are spending more on seed than farmers in freshwater areas. Average value of pesticide cost in wastewater area is Rs.1072 while in the freshwater area it is Rs.792. The high pesticide costs of wastewater users are due to favorable environment for pests to grow in wastewater fields. Average labor use in wastewater area is 145 hours per acre while in freshwater area it is 133 hours per acre. The labor use is slightly higher in wastewater area because farmers face more severe problems of weed in these areas which requires more hoeing practices to overcome these problems. Average value of irrigation hours in two production technologies (wastewater and freshwater) is 26 and 13 hours per acre, respectively. The high velocity of wastewater irrigation and significantly higher irrigation hours in wastewater area is indicating that farmers in wastewater areas are using more water than in freshwater area. This is because of the availability of wastewater at very nominal prices. Large numbers of farmers (73%) used farmyard manure in freshwater area but in wastewater area no farmer is observed engaging in this practice, indicating that farmers consider wastewater as a substitute for farmyard manure as well as for fertilizer.

The program FRONTIER 4.1 developed by (Coelli, 1994) is used to generate the maximum likelihood estimates of stochastic translog production frontier function. The coefficients of production function for the two production technologies (wastewater and freshwater) are summarized in Table 2.

The results of these production functions are used to estimate the elasticities of output with respect to different inputs as defined in Equation (12). The mean values and summary statistic of output elasticities for the two groups (wastewater and freshwater) are reported in Table 3. The output elasticities of tractor hours (used in land preparation) in wastewater and freshwater areas are -0.15 and -0.07, respectively. The negative values of elasticities indicates that 100 percent increase in tractor hours leads to 15 and 7 percent decline in revenue in wastewater and freshwater area, respectively. On an average 30 minutes are required to plow once on one acre with tractor and 3 to 4 plow in total is recommended i.e. 2 hours of tractor but the average value in our sample is significantly higher, implying that over utilization of tractor is being practiced in the study area. The negative elasticities of tractor hours might be due to excessive number of plowing in both areas because mean values of plowing are higher than the recommended level of (3-4) plowings. However, elasticities are consistent with those of Bakhsh et al., (2006).

The output elasticities of NPK (active ingredients of fertilizer) are 0.05 and 0.23 in wastewater and freshwater area, respectively, indicating a positive contribution of active ingredients of fertilizer in the revenue of both vegetable production technologies

The low contribution of active ingredients of fertilizer in wastewater area is due to surplus use of fertilizer nutrients in the area because wastewater itself contains fertilizer more than the required amount of fertilizer nutrients as discussed above. The output elasticities of seed cost in wastewater and freshwater area is 0.19 and 0.13, respectively. Both elasticities have positive sign, implying that increase in seed cost has positive impact on the revenue in both production technologies. These elasticities are also consistent with the findings of Ahmad et al., (2003) and Abedullah et al., (2006).

The output elasticities of plant protection cost are 0.07 and 0.11 in wastewater and freshwater area, respectively. The sign of output elasticities are according to prior expectation. The average amount of plant protection cost is higher in wastewater area but its percentage contribution in revenue is lower compared to freshwater area. This is because of high intensity of pests in wastewater area which makes the use of chemicals less effective and thus reduces its contribution in revenue. The output elasticities of labor hours are 0.13 and 0.17 in wastewater and freshwater area, respectively. The contribution of labor in revenue is higher in freshwater area as compared to wastewater area. The positive elasticities indicate that labor is positively contributing in the revenue in both production technologies. The sign and size of these elasticities are consistent with those of Bakhsh et al., (2004), Hassan (2004) and Abedullah et al., (2006).

The output elasticities of irrigation hours are -0.01 and 0.04 in wastewater and freshwater area, respectively. In wastewater area irrigation is contributing negatively in the revenue but in freshwater area it is contributing positively. Farmers are using wastewater in the area since years which is affecting the soil productivity adversely because of the accumulation of poisonous chemicals on the surface of the soil. Moreover, there is no constraint in using wastewater because of its unlimited availability and negligible prices per acre in the study area. The surplus use of wastewater is not only affecting the productivity in the short run but the accumulation of poisonous chemicals on the surface of the soil is also affecting the vegetable production in the long run. These irrigation elasticities clearly demonstrate that land degradation is taking place in wastewater area and it demands the attention of policy agents. Bakhsh and Hassan (2005) also observed that the application of sewage water affects the productivity of radish negatively, implying that their results also support our conclusion. The output elasticity of farmyard manure in freshwater area is 0.05 with a positive sign.

The sum of mean output elasticities in wastewater and freshwater area are 0.28 and 0.66, respectively, indicating a decreasing return to scale in the area of both production technologies. However, very low sum of elasticities in wastewater area once again warrant the policy makers that resources are degrading hastily in wastewater area which requires immediate attention of planners to take appropriate measures to revert the situation.

The technical efficiency of vegetable production in Pakistan's Punjab in wastewater and freshwater area is estimated by employing Equation (11) and the results are summarized in Table 4. It is observed that technical efficiencies of vegetable production in freshwater area are impressively high, ranging from 0.85 to 0.94 with a mean of 0.91. These high technical efficiency scores indicate that only little potential exists which can be explored through resource use efficiency. More precisely only 9 percent additional revenue in freshwater area can be achieved through resource use efficiency from given set of resources. However, the technical efficiencies of vegetable production in wastewater areas are ranging from 0.32 to 0.94 with a mean of 0.72, implying that revenue in wastewater area could be increased up to 28 percent from the given set of resources just by using the available resources more efficiently. The comparison of technical efficiency in two production technologies depicts that freshwater farmers are technically more efficient than wastewater farmers, implying that farmers in wastewater area are using their resources less efficiently compared to their counterparts in freshwater area.

The individual environmental efficiencies of pesticide (Pesticide + weedicide) cost and active nutrients of fertilizer is estimated by employing equation 12 while joint environmental efficiency of these inputs is estimated by employing equation 14 both for wastewater and freshwater area. The results are summarized in Table 5, 6 and 7, respectively.

The mean environmental efficiency of pesticide cost in wastewater and freshwater area is 47 and 43 percent, respectively, implying that environmental efficiency of pesticide cost is considerably less than technical efficiency in both wastewater and freshwater area. Our findings reveal that 53 and 57 percent of pesticide cost can be reduced by sustaining the output at maximum achievable level in wastewater and freshwater area, respectively. The environmental efficiency estimates of pesticide costs in wastewater areas are ranging from 0.01 to 0.87. Our results show that 55.8 percent farms have less than 50 percent environmental efficiency of pesticide cost and remaining 44.2 percent farms fall in the range of 50 to 87 percent category of environmental efficiency in wastewater area. There is no farm in our sample that has more than 90 percent environmental efficiency of pesticide cost in wastewater area. The environmental efficiency of pesticide cost in freshwater areas is ranging from 0.13 to 0.72. The results reported in Table 5 demonstrate that 67.3 percent farms have less than 50 percent environmental efficiency and remaining 32.7 percent farms fall in the range of 50 to 80 percent category of environmental efficiency of pesticide cost in freshwater area. There is no farm in our sample that has more than 80 percent environmental efficiency of pesticide cost in freshwater area.

The mean environmental efficiency of active nutrients of fertilizer (NPK) in wastewater area is only 14 percent. It is observed that distribution is skewed towards low efficiency group because 91.85 percent farms have less than 50 percent environmental efficiency and remaining 8.15 percent farms fall in the range of 50 to 69 percent category of environmental efficiency of active nutrients of fertilizer. There is no farm in wastewater area that has more than 80 percent environmental efficiency of active nutrients of NPK in vegetable production. The results reported in Table 6 reveal that 86 percent of active nutrients of fertilizer (NPK) can be reduced by maintaining the revenue at maximum achievable level. These findings demonstrate that large amount of fertilizer used in vegetable production in wastewater area is environmentally inefficient. This is because wastewater itself contains the amount of fertilizer more than needed for vegetable crops (WHO, 1989). The mean environmental efficiency of active nutrients of fertilizer (NPK) in freshwater area is 69 percent ranging from 24 to 89 percent, implying that environmental efficiency is considerably less than technical efficiency (91 percent) in freshwater area. Our findings reveal that 31 percent of NPK can be reduced by maintaining the revenue at maximum achievable level in freshwater area. The distribution of environmental efficiency of NPK in freshwater area depicts that highest number of farmers fall in the range of 70 to 80 percent category followed by 80 to 90 percent range of the environmental efficiency (Table 6).

As discussed above, only 47 and 43 percent of pesticide cost is being used environmentally efficient, implying that 53 and 57 percent of pesticide cost can be reduced in wastewater and freshwater areas, respectively. It can be translated into monetary value which is equal to Rs.568 and Rs.451.5 per acreage in wastewater and freshwater area, respectively. The lower reduction in percentage (53 percent) in wastewater area compared to large reduction in freshwater (57 percent) translates into large monetary value (Rs.568), simply because of large mean value of pesticide cost in wastewater area. Similarly, reduction in active nutrients of fertilizer (NPK) can be made up to 86 and 31 percent to achieve the environmentally efficient level in wastewater and freshwater areas, respectively. This reduction in percentage terms can also be translated into monetary values which are equal to Rs.1850 and Rs.1525.2 per acre in wastewater and freshwater areas, respectively. Our results clearly depicts that both pesticide and fertilizer are not used at environmentally efficient level, a significant amount of saving both from pesticide and fertilizer is possible by maintaining the revenue at maximum achievable level.

The results can be extended to the province level under the assumption that conclusions drawn from a sample of two major vegetable growing districts are valid for the whole province and environmental efficiency measures behave in a similar way in all districts of Punjab province. Per acre value of saving in monetary value can be used to estimate the saving from the total area allocated to vegetable production in the province of Punjab. Total saving at the province level in one crop season (Rabi season) due to reduction in both pesticide and fertilizer use are Rs.56.79 and Rs.1318.62 million rupees from vegetable production in wastewater and freshwater areas, respectively (Table 8). The significantly higher benefits in freshwater area are because of higher freshwater vegetable area (28 times) compared to the wastewater vegetable area in the province. However, the total saving from the reduction in pesticide cost both in wastewater and freshwater areas is Rs.314.5 million but from active nutrients of fertilizer is Rs.1060.9 million (Table 8). It is observed that saving from the reduction in fertilizer use is more than three times than saving from the reduction in pesticide use, implying that extension agents need to focus more on the reduction of fertilizer use especially in wastewater vegetable production areas. These results clearly demonstrate that significant amount of resources can be saved by reducing considerable amount of pesticide and fertilizer use in vegetable production by maintaining the revenue at maximum achievable level. This not only helps to improve the profitability of vegetable growers through reduction in cash input use but it also helps to produce comparatively safer vegetables for consumers with cleaner environment.

It should be noted that joint environmental efficiency of pesticide cost and active nutrient of fertilizer (NPK) is not simple addition of the two as it can be seen from equation 11 and results are reported in Table 7. The joint mean environmental efficiency of pesticide cost and NPK is 0.25 and 0.72 in wastewater and freshwater area, respectively which is less than the simple addition in each case. These results demonstrate that simultaneously both pesticide and fertilizer can be reduced by 75 and 28 percent in wastewater and freshwater area, respectively my maintaining the revenue at maximum achievable level. These findings once again reveal that that both pesticide and fertilizer are being used at environmentally inefficiently level. The joint environmental efficiency of two environmentally detrimental variables is significantly higher in freshwater area but lower in wastewater area than the environmental efficiency of pesticide cost alone. This is because of drastic variation in environmental efficiency of active nutrients of fertilizer in both production technologies (wastewater and freshwater). In wastewater area environmental efficiency of NPK alone is less than the environmental efficiency of pesticide cost alone (only 14 percent) and this is because of over utilization of fertilizer in wastewater area. The environmentally inefficient use of fertilizer in wastewater areas lead to declines in the joint environmental efficiency (25 percent) of two detrimental variables compared to the pesticide alone (47 percent). However, in freshwater areas the joint environmental efficiency of two detrimental variables (72 percent) is significantly higher than the environmental efficiency of pesticide alone (43 percent). This is because of efficient use of fertilizer in freshwater area.

IV. Summary and Conclusions

The vegetable data used in the present study was collected from 275 vegetable farmers (140 from wastewater and 135 from freshwater area) from two major vegetable producing districts (Gujranwala and Faisalabad) in the province of Punjab.

Our empirical findings depict that only 47 and 43 percent of pesticide cost is used environmentally efficient which implies 53 and 57 percent of pesticide cost can be reduced in wastewater and freshwater areas, respectively by maintaining the revenue at maximum achievable level. In monetary terms this reduction is Rs.568 and Rs.451.5 per acreage in wastewater and freshwater area, respectively. Similarly, in case of fertilizer, 86 and 31 percent of active nutrients of fertilizer (NPK) can be reduced to achieve the environmentally efficient level in wastewater and freshwater areas, respectively by maintaining the revenue at maximum achievable level. This reduction in percentage terms can be translated into monetary values which are equal to Rs.1850 and Rs.1525.2 per acre in wastewater and freshwater areas, respectively. Total saving at the province level in one crop season (Rabi season only) due to reduction in both pesticide and fertilizer use are Rs.56.79 and Rs.1318.62 million rupees from vegetable production in wastewater and freshwater areas, respectively.

Reduction in input uses likely to alleviate the problem of environmental pollution with sustainable vegetable production in the areas of both production technologies (Wastewater and freshwater). The improvement in environmental quality will not only increase the agricultural productivity but it is also expected to increase the productivity of agriculture laborers in both areas (wastewater and freshwater) through reduction in health related problems because higher amount of chemical use leads to higher probability of sickness (Jeyaratnam, 1990). Moreover, it will also help to provide safe vegetable for consumption to the consumers. Hence, effective and efficient extension services are required to achieve these objectives. This implies that extension department of the province needs to be strengthened with dedicated and knowledgeable workers to give site-specific recommendation to farmers about the use of pesticide and chemical fertilizers in the targeted area (freshwater or wastewater). Such reduction in poisonous chemicals and fertilizers use could significantly contribute to increase the foreign reserves indirectly because the country heavily depends on import to fulfill its demand for these chemicals. Reduction in poisonous chemical use is also expected to increase the quality of natural resources such as ground water and environmental quality for future generations. The cleaner environment is found to be positively associated with agricultural productivity (Wahid et al, 1995ab). This implies that reduction in poisonous chemical use is also expected to have positive impacts on agricultural productivity and finally on profitability of farmers. Thus implication of reduction in poisonous chemical use in agriculture sector is multidisciplinary, indicating a win-win situation.

TABLE 1

The comparison of mean value of two sample groups (wastewater and freshwater)

	Wastewater			**Freshwater**		
Variables	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Revenue (Rs./acre)	39553^{ns}	75000	17625	43354^{ns}	99750	13800
Tractor (Hrs/Acre)	5.0^{ns}	10.0	2.0	4.6^{ns}	10.0	2.5
NPK (Kg./acre)	43.1*	124	.01	82*	220	23
Seed Cost (Rs./acre)	1774***	4800	300	1437.23***	5000	100
Pesticide cost (Rs./acre)	1072*	3000	.01	792*	2100	140
Labor (Hrs/acre)	145.3**	293.3	85.0	132.7**	191	72.12
Irrigation (Hrs/acre)	13.0*	18.0	7.0	25.9*	60.0	7.0
FYM cost (Rs./acre)	-	-	-	1271.9^{sd}	10000	.01

*** = significant at 5%, ** = significant at 2%, * = significant at 1%, SD = statistically different, ns = non-significant
Source: Estimated from the sample data

TABLE 2

Coefficients of translog production function for freshwater and wastewater with Maximum Likelihood Estimation (MLE) technique

Parameters	**Coefficients**	**t-ratio**	**Parameters**	**Coefficients**	**t-ratio**
Wastewater					
B0	-10.4	-0.5	B_{14}	-0.1	-0.6
B1	-1.9	-0.6	B_{15}	0.3	0.6
B2	1.8	1.3	B_{16}	-0.9	-1.6
B3	2.2	1.1	B_{23}	-0.1	-1.3
B4	0.9	0.4	B_{24}	0.0	1.3
B5	4.1	0.8	B_{25}	-0.3	-1.0
B6	-2.0	-0.4	B_{26}	-0.1	-0.4
B7	-0.2	-2.0	B_{34}	0.0	-0.1
B11	-1.1	-1.6	B_{35}	-0.3	-0.7
B22	0.0	-1.4	B_{36}	0.2	0.5
B33	-0.2	-0.9	B_{45}	-0.3	-1.0
B44	-0.1	-0.6	B_{46}	0.6	1.8
B55	-0.3	-0.3	B_{56}	0.7	1.2
B66	-1.9	-1.7			
B12	0.5	2.5	Log Likelihood	-38.01	
B13	0.4	1.5			
Freshwater					
B0	2.89	0.14	B_{16}	0.00	-0.74
B1	0.02	0.02	B_{17}	-0.09	-1.30
B2	-5.14	-1.72	B_{23}	1.18	1.83
B3	5.77	0.70	B_{24}	0.12	1.03
B4	-1.23	-1.87	B_{25}	0.22	0.63
B5	-1.38	-0.75	B_{26}	0.02	0.75
B6	-0.14	-0.89	B_{27}	-0.33	-1.45
B7	1.69	0.87	B_{34}	0.23	1.34
B8	-0.10	-0.94	B_{35}	0.57	1.20
B11	0.08	1.06	B_{36}	0.01	0.25
B22	-0.47	-0.73	B_{37}	-0.11	-0.28
B33	-2.49	-1.34	B_{45}	-0.05	-0.38
B44	0.03	1.97	B_{46}	0.00	0.82
B55	0.11	0.29	B_{47}	0.01	0.09
B66	0.01	1.53	B_{56}	0.01	0.98
B77	0.16	0.72	B_{57}	-0.11	-0.79
B12	-0.10	-0.83	B_{67}	0.00	0.49
B13	0.17	0.79			
B14	0.01	0.12	Log Likelihood	-9.48	
B15	-0.20	-2.35			

Source: Estimated from the sample data

TABLE 3

The comparison of mean value of two sample groups
(wastewater and freshwater)

	Wastewater			Freshwater		
Variables	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Tractor (hrs/acre)	-0.15	1.3	-3.2	-0.07	0.77	-1.84
NPK (kg./acre)	0.05	0.5	-0.4	0.23	0.78	-0.30
Seed Cost (Rs./acre)	0.19	0.8	-0.3	0.13	0.49	-0.22
Plant protection cost (Rs./acre)	0.07	0.5	-0.4	0.11	0.28	-0.18
Labor (hrs/acre)	0.13	2.1	-0.8	0.17	1.64	-2.84
Irrigation (hrs/acre)	-0.01	1.9	-1.7	0.04	0.52	-0.41
FYM Cost (Rs./acre)	-	-	-	0.05	0.13	-0.10

Source: Estimated from the sample data

TABLE 4

The Distribution of Technical Efficiency in Wastewater and Freshwater Area

Range/Value	Count	Percent	Cumulative count	Cumulative percent
Wastewater				
[0.3, 0.49]	15	11.2	15	11.2
[0.5, 0.59]	17	12.6	32	23.8
[0.6, 0.69]	17	12.6	49	36.4
[0.7, 0.79]	34	25.2	83	61.6
[0.8, 0.89]	40	29.6	123	91.2
[0.9, 1.0]	12	8.8	135	100
Total	**135**	**100**	**135**	**100**
Freshwater				
[0.3, 0.49]	0	0	0	0
[0.5, 0.59]	0	0	0	0
[0.6, 0.69]	0	0	0	0
[0.7, 0.79]	0	0	0	0
[0.8, 0.89]	42	30	42	30
[0.9, 1.0]	98	70	140	100
Total	**140**	**100**	**140**	**100**

Source: Estimated from the ample data.
(1) No observation lies in these ranges of efficiency for freshwater and therefore, cumulative counts and cumulative percentage are zero.

TABLE 5

The Distribution of Environmental Efficiency of
Plant Protection Cost in Wastewater and Freshwater Area

Range/Value	Count	Percent	Cumulative count	Cumulative percent
Wastewater				
[0.0, 0.09]	7	5.2	7	5.2
[0.1, 0.19]	9	6.7	16	11.9
[0.2, 0.29]	23	17.1	39	29
[0.3, 0.39]	15	11.2	54	40.2
[0.4, 0.49]	21	15.6	75	55.8
[0.5, 0.59]	14	10.4	89	66.2
[0.6, 0.69]	20	14.8	109	81
[0.7, 0.79]	19	14.1	128	95.1
[0.8, 0.89]	7	5.2	135	100
Total	**135**	**100**	**135**	**100**
Freshwater				
[0.1, 0.19]	6	5.2	6	5.2
[0.2, 0.29]	16	13.8	22	19
[0.3, 0.39]	19	16.4	41	35.4
[0.4, 0.49]	37	31.9	78	67.3
[0.5, 0.59]	23	19.8	101	87.1
[0.6, 0.69]	13	11.20	114	98.3
[0.7, 0.75]	2	1.72	116	100
Total*	**116**	**100**	**116**	**100**

* Nineteen EEs could not be solved and the score of five EEs was higher than 1. These observations are not included in the estimation of mean value.

TABLE 6

The Distribution of Environmental Efficiency of
Active Nutrients of Fertilizer (NPK) in Wastewater and Freshwater Area

Range/Value	Count	Percent	Cumulative count	Cumulative percent
Wastewater				
[0.0, 0.09]	79	58.52	79	58.52
[0.1, 0.19]	15	11.12	94	69.64
[0.2, 0.29]	18	13.34	112	82.98
[0.3, 0.39]	7	5.19	119	88.17
[0.4, 0.49]	8	5.93	127	94.1
[0.5, 0.59]	4	2.96	131	97.06
[0.6, 0.69]	1	0.74	132	97.8
[0.7, 0.79]	3	2.22	135	100
Total	**135**	**100**	**135**	**100**
Freshwater				
[0.2, 0.29]	1	1.06	1	1.06
[0.3, 0.39]	3	3.2	4	4.31
[0.4, 0.49]	4	4.2	8	8.51
[0.5, 0.59]	15	15.95	23	21.46
[0.6, 0.69]	19	20.21	42	41.67
[0.7, 0.79]	29	30.85	71	72.52
[0.8, 0.89]	23	24.46	94	100
Total*	**94**	**100**	**94**	**100**

* Thirty nine EEs could not be solved and the score of six EEs are higher than 1. These observations are not included in the estimation of mean value.

TABLE 7

The Joint Distribution of Environmental Efficiency of
Plant Protection Cost and Fertilizer (NPK) in Wastewater and Freshwater Area

Range/Value	Count	Percent	Cumulative count	Cumulative percent
Wastewater				
[0.0, 0.09]	44	32.59	44	32.59
[0.1, 0.19]	22	16.3	66	48.89
[0.2, 0.29]	25	18.52	91	67.41
[0.3, 0.39]	14	10.37	105	77.78
[0.4, 0.49]	8	5.92	113	83.7
[0.5, 0.59]	9	6.7	122	90.4
[0.6, 0.69]	8	5.92	130	96.32
[0.7, 0.79]	4	2.96	134	99.28
[0.8, 0.85]	1	0.74	135	100
Total*	**135**	**100**	**135**	**100**
Freshwater				
[0.1, 0.19]	3	2.4	3	2.4
[0.2, 0.29]	1	.8	4	3.2
[0.3, 0.39]	3	2.4	7	5.6
[0.4, 0.49]	1	.8	8	6.4
[0.5, 0.59]	14	11.2	22	17.6
[0.6, 0.69]	13	10.4	35	28
[0.7, 0.79]	42	33.6	77	61.6
[0.8, 0.89]	45	36	122	97.6
[0.9, 1.0]	3	2.4	125	100
Total	**125**	**100**	**125**	**100**

* Nineteen EEs could not be solved and the score of five EEs was higher than 1. These observations are not included in the estimation of mean value.

TABLE 8

Saving in Monetary Value in Rabi Season from
Environmental Efficiency Management in Wastewater and Freshwater Area

Technology/ Variables	Per Acre Saving		Area (acres)	Saving from pesticides & fertilizer at the province level (million Rs.)		Total Saving from Pesticides & fertilizer (million Rs.)
	Pesticide	Fertilizer		Pesticide	Fertilizer	
Wastewater	568	1850	23486.74	13.34	43.45	56.79
Freshwater	451.5	1525.2	667080.80	301.19	1017.43	1318.62
Total			690567.54	314.53	1060.88	1375.41

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