Agricultural Economics Research Review
Vol. 28 (No.1) January-June 2015 pp 103-116
DOI: 10.5958/0974-0279.2015.00008.7

Climate Adaptation in Agriculture through Technological Option: Determinants and Impact on Efficiency of Production[§]

K. Vijayasarathy[a]* and K.R. Ashok[b]

[a]Institute for Social and Economic Change, Bengaluru-560 072, Karnataka
[b]Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu

Abstract

The climate variability has a direct influence on the quantity and quality of agricultural output. In response to changing climate, adaptation is becoming an urgent priority because large reductions in negative impacts of climate change are feasible when adaptation is fully implemented. This study is based on the data collected from 180 farmers in the Western Zone of Tamil Nadu, where climate variability is high. The determinants of climate adaptation technologies have been studied using a multinomial logit model. The education level , sex, household size, farm size, extension contact, temperature and rainfall have been founded to influence the adoption of technologies to mitigate the impact of climate variability. The impact of technology adoption on technical efficiency of production of major crops using stochastic frontier production function has shown that technical efficiency is higher among technology adopters. The lack of finance, lack of knowledge about technology and high cost of adaptation have been reported to be the constraints to climate adaptation. The study has concluded that technology adoption significantly helps the smallholder farmers to continue farming in the changing climate.

Key words: Climate variability, agricultural production, technology adoption, technical efficiency, Tamil Nadu

JEL Classification: Q1, Q16, Q54

Introduction

Climate variability and climate change have a direct, influence on the quantity and quality of agricultural production. The elements like temperature, rainfall, humidity and sunshine influence crop production significantly. India is heavily dependent on the monsoons to meet its water needs for agriculture. Over 70 per cent of India's population still being agriculture dependent, even a small impact of climate change on monsoons, erratic occurrences of floods and droughts would contribute enormously to the vulnerabilities of people. Adaptation is widely recognized as a vital component of any policy response to climate change. The role of technology continues to become more ingrained in strategic thinking of agricultural adaptation to climate change (Smithers and Blay-Palmer, 2001). Studies have shown that without adaptation, climate change is generally detrimental to

* Author for correspondence
Email: vijsaraec@gmail.com

§ This study is part of PhD thesis entitled, "Impact of Climate Variability on Agriculture and the Determinants of Climate Adaptation through Agricultural Technologies in the Western Zone of Tamil Nadu", of first author submitted to the Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu in 2013 under the guidance of second author.]

the agriculture sector, but with adaptation, vulnerability can largely be reduced (Easterling *et al.*, 1993; Rosenzweig and Parry, 1994; Smith, 1996; Mendelsohn, 1998; Reilly and Schimmelpfennig, 1999; Smit and Skinner, 2002). Farmers have a number of technological options to adapt to climate variability like, for example, intercropping, mixed cropping, agro-forestry, animal husbandry, and improved new seed varieties to cope with the changes in climate. Focus of this study is on the adoption of technologies generated by the State Agricultural Universities (SAUs) and Indian Council of Agricultural Research (ICAR) system for climate adaptation, specifically on the determinants of key factors affecting the adoption of such climate-resilient technologies and its impact on efficiency of agricultural production.

Data and Methodology

Tamil Nadu state is classified into seven distinct agro-climatic zones, namely North Eastern Zone, North Western Zone, Western Zone, Cauvery Delta Zone, Southern Zone, High Rainfall Zone, Hilly Zone based on rainfall distribution, irrigation pattern, soil characteristics, cropping pattern and other ecological, social and physical status. The trends in temperature and precipitation in these seven zones were studied with 30-year data, from 1980-81 to 2010-11 by estimating the linear trend and Mann-Kendall test and it was found that Western Zone had a significant climate variability in terms of temperature and precipitation (Appendix-I). Hence, the Western Zone was selected to study the adaptation strategies of farm households with respect to climate variability.

The Western Zone encompasses the districts of Coimbatore, Tiruppur, Erode, Dindigul, Theni and Karur. The farmers have access to weather-related information from the Automatic Weather Station (AWS) installed at each block. The farmers were selected at random around 1km from the Automatic Weather Station. From each district, five AWS were selected at random and from around the AWS, 90 technology adopters and 90 non-adopters were selected at random, making a total of 180 sample farmers. An adoption index was constructed to identify the adopters and non-adopters of climate resilient technologies[1]. The respondents were classified as adopters if the adoption index was 50 or above.

The primary data on family composition, cropping pattern, income, cost of cultivation, farmer perception and technology adoption were collected through a well-structured, pre-tested interview schedule.

Analytical Tools

Climate Adoption Technologies

The recommended practices for crop production are given in the 'Package of Practices' approved by the State Department of Agriculture in consultation with the Tamil Nadu Agricultural University. From this package of practices, the technologies recommended for rainfall variability/water stress were identified. The technologies considered in the present study were: System of Rice Intensification for paddy, Change in cropping pattern, Change in variety, Change in irrigation method, Drought-tolerant varieties, Mulching, Summer ploughing and Agricultural allied activities like animal husbandry.

Determinants of Adoption of Climate Resilient Technologies

To identify the determinants of adoption of climate resilient technologies, the multi-nomial logit (MNL) model is used. It permits the analysis of decisions across more than two categories, allowing the determination of choice probabilities for different categories (Madalla, 1983; Wooldridge, 2002). Moreover, Koch (2007) has also emphasized the usefulness of this model by describing the ease of interpreting estimates from this model.

To describe the MNL model, let y denote a random variable taking on the values $\{1, 2\ldots, J\}$ for J, a positive integer, and let $\boldsymbol{x}$ denote a set of conditioning variables. In this case, y denotes the adaptation options or categories and $\boldsymbol{x}$ contains household attributes like age, education, income levels, and so forth. The question is how *ceteris paribus* changes in the elements of x affect the response probabilities $P(y= j/x)$, j=1, 2,.., J. Since the probabilities must sum to unity, $P(y=j/x)$ is determined once we know the probabilities for J=2,…, J.

Let $\boldsymbol{x}$ be an l*k vector with the first element unity. The MNL model has response probabilities:

$$P(y=j/x) = \exp(x\beta_j) / \left[1 + \sum_{h=1}^{J} \exp(x\beta_h), j = 1,\ldots,J\right] \quad \ldots(1)$$

The eight adaptation options or response probabilities for this study are: System of Rice Intensification (SRI), Change in Cropping Pattern, Adoption of Drought Tolerant Crops/ Varieties, Application of Drip Irrigation Method, Digging of Bore-wells, Summer Ploughing, Mixed Farming, and No adaptation methods.

The assumption requires that the probability of using a certain adaptation method by a given household needs to be independent from the probability of choosing another adaptation method (that is, P_j / P_k is independent of the remaining probabilities).

The parameter estimates of the MNL model provide only the direction of the effect of the independent variables on the dependent (response) variable, but neither represents the actual magnitude of change nor probabilities. Differentiation of Equation (1) with respect to the explanatory variables provides the marginal effects of explanatory variables given by Equation (2):

$$\frac{\partial P_j}{\partial x_k} = P_j(\beta_{jk} - \sum_{J=1}^{J-1} P_j \, \beta_{jk}) \quad \ldots(2)$$

The marginal effects or marginal probabilities are functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable from the mean (Green, 2000; Koch, 2007).

The explanatory variables for this study included household characteristics such as education, gender, age of the household-head, household size, farm size, farm and off-farm income, and livestock ownership; institutional factors such as extension contacts on crop and livestock production, information on climate, access to credit, distance to input and output markets and agro-ecological characteristics such as temperature and rainfall.

Education is expected to increase one's ability to receive and understand the information to making innovative decisions. The way gender influences adaptation is location-specific. The effect of age is generally location- or technology-specific and experienced farmers have better knowledge and information on change in climatic condition and crop and livestock management. Household size as a proxy to labour availability may influence the adoption of new technology. Studies on adoption of agricultural technologies indicate that farm size has both negative and positive effects on adoption, showing that the effect of farm size on technology adoption is inconclusive (Bradshaw *et al*., 2004). Farm and off-farm incomes and livestock ownership represent wealth. Thus, household with a higher income and greater assets are in a better position to adopt new farming technologies. The extension contact and awareness about the climate change enhance the efficiency of making adoption decisions. Another variable that has received attention is access to credit which commonly has a positive effect on adaptation behaviour.

It is hypothesized that as distance to output and input markets increases, adaptation to climate change decreases. Proximity to market is an important determinant of adaptation, presumably because the market serves as a means of exchanging information with other farmers (Maddison, 2006). The climatic conditions, soil, and other factors vary across different agro-ecologies, influencing farmers' perceptions of climate change and their decisions to adapt.

Technical Efficiency Analysis

It is hypothesized that in districts where there is high climate variability, the adoption of climate resilient technologies increases technical efficiency and thus leads to higher productivity. A stochastic production function approach proposed by Battese and Coelli (1995), was used in the study. The stochastic production frontier is defined as per Equation (3):

$$\ln Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j \ln(X_{ij}) + (v_i - u_i) \quad \ldots(3)$$

where, the subscript i refers to the i^{th} farmer; ln represents the natural logarithm; Y is the observed farm yield (kg/ha); X_1 is the total seed rate (kg/ha); X_2 is the amount of chemical fertilizers (mainly, nitrogen, phosphorus, and potassium) applied (kg/ha); and X_3 is the total amount of organic fertilizer applied in the farm (kg/ha), X_4 is the pre-harvest labour-use of family and hired labour (persondays/ha) (Battese,1997).)

Equation (3) has two error-terms: one, "v_i", to account for random shocks (weather conditions, disease, measurement errors in the output variable, etc. and the combined effects of unobserved/uncontrollable inputs on production) and the other "u_i", to account for technical inefficiency in production. The v_i is a random error that is assumed to be independently and identically distributed N (0, σ_v^2) and independent of the u_i; u_i is a non-negative random variable. The model, defined by Equation (3), is a stochastic frontier function because the random error (v_i) can be positive or negative and the output values are bounded above by the stochastic (random) variable, exp (X_i β+v_i).

The farm-specific technical efficiencies (TE_i) are computed by taking the exponentiation of the negative of u_i, that is

$$TE_i = \exp(-u_i) \qquad \ldots(4)$$

The estimation of technical efficiencies is based on the conditional expectation of exp (-u), given the model specification (Coelli, 1996; Battese and Broca, 1997). Among different forms of production function, the Cobb Douglas production function, which gave the best fit, was selected. The yield of paddy, in tonnes per hectare, was taken as dependent variable and it was regressed on seed rate (kg/ha), organic fertilizer (kg/ha), inorganic fertilizer (kg/ha) and labour use (persondays/ha) using software package FRONTIER 4.1. The parameters were estimated by maximum likelihood estimation.

Garrett Ranking Technique

To rank the constraints or problems faced by the farmers in adopting climate resilient technologies, Garrett's ranking was used. The orders of the merit assigned by the respondent were converted into ranks. As a first step, the per cent position of each rank was found out by formula (5):

$$\text{Per cent position} = \frac{[100(R_{ij} - 0.5)]}{N_i} \qquad \ldots(5)$$

where,

R_{ij} = Rank given for the i^{th} items by the j^{th} individual, and N_j = Number of items ranked by the j^{th} individual.

The per cent position of each rank, thus, obtained was then converted into scores by referring to the table given by Garrett and Wood Worth (1971). The respondents were requested to rank the opinions/reasons relevant to them according to the degree of importance. The ranks given by each of the respondents was converted into scores. Then for each reason, the scores of individual respondents were added together and divided by the total number of respondents. These mean scores for all the reasons were arranged in the descending order and ranks were given. By this method, the accuracy in determining the preference was obtained.

Results and Discussion

Determinants of Adoption of Climate Resilient Technologies

Detailed analysis was carried out of the relationships between climatic variables, such as temperature and rainfall, and choice of adaptation methods. Table 1 gives the descriptive statistics of the independent variables and Appendix II gives the correlation matrix of the independent variables hypothesized to affect adaptation measures in this study.

Multinomial logit model was used to analyze the determinants of farmers' choice of technologies. An attempt was made to explore how farmers would make technology choices to adapt to changes in the exogenous factors such as climate along with the endogenous factors using a multinomial logit model.

The marginal effects from the multinomial logit model, which measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable. In all the cases, the estimated coefficients should be compared with the base category of no adaptation. The marginal effects along with the levels of statistical significance are presented in Table 2.

Education — The education level of household-head increased the probability of adaptation to climate change. It could be observed from the table that education significantly increases the adoption of system of rice intensification, drip irrigation and digging of new bore-wells as an adaptation method. A unit increase in the number of years of schooling would result in 0.03 per cent increase in the probability System of Rice Intensification (SRI); 0.01 per cent increase in drip irrigation and digging of bore-wells and 0.1 per cent increase in changes in variety to adapt to climate variability. The marginal value of education has been

Table 1. Description of independent variables

Explanatory variables	Mean	Standard deviation	Description
Year of education	9.367	4.204	Continuous
Size of household	4.917	1.720	Continuous
Gender of household-head	0.472	0.501	Dummy, takes the value of 1 if male and 0, otherwise
Age of household-head	50.917	11.086	Continuous
Farm income (₹)	66955.889	17406.215	Continuous
Livestock ownership	0.872	0.335	Dummy, takes the value of 1 if male and 0, otherwise
Extension contact (times/year)	16.200	4.575	Continuous
Climate change awareness	0.550	0.499	Dummy, takes the value of 1 if male and 0, otherwise
Access to loan	0.478	0.501	Dummy, takes the value of 1 if male and 0, otherwise
Off-farm income (₹)	414.450	2265.698	Continuous
Farm size (in acres)	10.003	11.448	Continuous
Distance to market for agricultural inputs (km)	4.956	3.297	Continuous
Temperature (°C)	26.535	2.397	Continuous
Rainfall (mm)	27.912	9.856	Continuous

found positive across all adaptation methods, indicating a positive relationship between education and adaptation to climate change.

Household Size — Household size significantly influenced the probability of adaptation. The increase in household size significantly decreases the probability of adaptation. It can be inferred that the larger the size of a household, the lesser is the adaptation of cropping pattern and summer ploughing to climate variability.

Gender of Household Head — The results indicated that male-headed households adopt more readily to climate resilient technologies to climate variability. The male-headed households were more likely to adopt SRI technology in rice cultivation.

Experience — The age of household-head, which represents experience, affected the adaptation to climate variability. The more experienced farmers were more likely to adopt to drip irrigation (0.01 %), mixed farming (0.24 %), and digging of new bore-wells (0.3%) than the less experienced farmers.

Farm Income — The farm income of a household had positive and significant impact on system of rice intensification, drip irrigation, digging of new bore-well and mixed farming. A unit increase in the farm income increases these probabilities by less than 0.01 per cent.

Farm Size — The farm size had a negative and significant influence on the climate resilient technologies like digging of new bore-wells and adoption of summer ploughing.

Extension Visit — Access to extension visit increased the likelihood of adopting drought- tolerant crop varieties, drip irrigation, digging of new bore-wells and mixed farming. Contact with extension persons has a positive and significant impact on adoption of these technologies.

Information on Climate Change — The farmers who have information on climate variability had a significant and positive impact on the likelihood of adopting system of rice intensification (1.18 %), change in the cropping pattern (6.22 %), drought-tolerant crop varieties (16.26 %), drip irrigation (0.36 %) and mixed farming (8.20 %).

Off-farm Income — Off-farm income significantly decreased the likelihood of adapting to change in cropping pattern, mixed farming and digging of new bore-well. A unit increase in off-farm income decreases the probability of adopting change in cropping pattern, mixed farming and digging of a new bore-well.

Livestock Ownership — The ownership of livestock had a positive and significant relationship with most of the adaptation methods. It was positively related to

Table 2. Marginal effects of multinomial logit model

Explanatory variable	SRI		Change in cropping pattern		Change in variety		Drought-tolerant crops		Drip irrigation	
	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level
Education level	0.0003**	0.0160	-0.0032	0.3211	0.0010**	0.0130	-0.0034	0.5421	0.0001***	0.0000
Household size	-0.0029	0.1240	-0.0026**	0.0510	0.0021	0.7210	-0.0089	0.3101	-0.0008	0.1232
Gender	-0.0014***	0.0020	-0.0245	0.7123	0.0053	0.3415	0.0157	0.2312	0.0008	0.1342
Age	-0.0005	0.8100	0.0010	0.6734	0.0003	0.9102	0.0028	0.3512	0.0001***	0.0000
Farm income	4.37e-07**	0.0701	-1.58e-06**	0.0125	-1.90e-07	0.3451	-2.40e-06**	0.0123	5.14e-08**	0.0618
Livestock ownership	0.0541	0.1851	0.0132**	0.0151	-0.0146	0.4321	-0.0038	0.8123	0.01806	0.2132
Extension contact	-0.0002	0.1272	0.0031	0.2545	0.0001**	0.0521	0.0040**	0.0210	0.0003**	0.0152
Climate change awareness	0.0118**	0.0572	0.0622**	0.0527	-0.0086	0.8152	0.1626***	0.0012	0.0036***	0.0013
Access to credit	0.0012	0.4532	0.1163	0.1151	-0.0066**	0.0215	0.1165**	0.0321	0.0005**	0.0821
Off-farm income	-6.22e-06	0.2912	-0.0001**	-0.031	-4.80e-06	0.7134	0.0003	0.8712	3.47e-06	0.3218
Farm size	-0.0008	0.5421	0.0030	0.1920	-0.0008	0.2534	0.0023	0.7431	-0.0003	0.3219
Distance to market	-0.0003	0.7431	0.0081	0.1521	-0.0015	0.8561	0.0162	0.2131	.0003	0.3212
Temperature	-0.0195**	0.0110	0.1082***	0.0012	0.1399**	0.0321	0.2413**	0.0343	0.05814***	0.0051
Rainfall	-0.0005***	0.0000	-0.0001***	0.0000	0.0003***	0.0012	0.0547**	0.0110	0.0027	0.2319

Contd...

Table 2. Marginal effects of multinomial logit model — *Contd*

Explanatory variable	Bore-well		Summer ploughing		Mixed farming		No adaptation	
	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level
Education level	0.0001***	0.0000	0.0003	0.1441	0.0254	0.1231	-0.0150***	0.0000
Household size	0.014	0.3210	-0.0178**	0.0740	-0.0217	0.3850	0.0172	0.3120
Gender	-0.041	0.1293	0.0226	0.3040	-0.0966	0.3461	0.0271	0.4210
Age	0.003**	0.0981	-0.0044	0.3501	0.0024**	0.0801	0.0060***	-0.0080
Farm income	4.93e-07***	0.0012	1.33e-06***	0.0000	-1.41e-07	0.1810	1.64e-06	0.5220
Livestock ownership	0.134	0.4311	0.0771**	0.0491	0.0310***	0.0034	-0.0736	0.7551
Extension contact	0.006**	0.0322	-0.0050	0.6702	0.0038**	0.0231	-0.0129	0.2912
Climate change awareness	-0.004	0.3211	-0.0511	0.6590	0.0820**	0.0125	0.0884***	0.0001
Access to the credit	0.056**	0.0562	-0.0017	0.3063	0.0223	0.3211	-0.0584	0.3170
Off-farm income	-.0001***	0.0021	-4.2e-05	0.2566	-0.0001***	0.0000	0.0002**	0.0880
Farm size	-0.001**	0.0123	-0.0011**	0.0991	-0.0001	0.1011	-0.0027**	0.0123
Distance to the market	-0.013	0.5210	0.0025	0.3531	0.0079	0.5432	-0.0087	0.8710
Temperature	-0.420**	0.0320	-0.1978**	0.0443	0.3514***	0.0021	0.1149**	0.0671
Rainfall	-0.019**	0.0210	0.0136**	0.0219	-0.0214**	0.0521	-0.0270**	0.0290

Note: *** and ** denote significance at 1 per cent and 5 per cent levels, respectively.

the adoption of adaptation technologies like change in cropping pattern, summer ploughing and mixed farming.

Access to Credit — Access to credit has depicted a positive and significant impact on the likelihood of using drought-tolerant crop varieties, drip irrigation and digging of new bore- wells. The result implies the important role of institutional support in promoting the use of adaptation options to reduce the negative impact of climate variability.

Temperature — The rising annual mean temperature has shown a positive influence on the adoption of different technologies. A rise of 1 °C in mean temperature would increase the probability of change in cropping pattern (10.8 %), sowing drought-tolerant crops (24.1 %), using drip irrigation (5.8 %) and following mixed farming (35.1 %). These results indicate that with more warming, the farmers would change their cropping pattern and use drought-tolerant varieties to cope up with the increasing temperatures. Moreover, the farmers would irrigate by using drip system to compensate for the loss of water associated with increased evapo-transpiration due to increased temperature. They would try to reduce the loss of income due to higher temperature through mixed farming.

Precipitation — The analysis has shown that the decreasing precipitation would significantly increase the likelihood of following SRI, change in cropping pattern, summer ploughing, mixed farming and digging of new bore-wells. The increasing precipitation would relax the constraint imposed by the increased temperature on soil moisture content and thus crop growth.

Technical Efficiency: Stochastic Frontier Production Function Analysis

It is generally expected that climate adaptation through adoption of climate resilient technology increases the efficiency in production. To analyse the influence of technology adoption on the efficiency of crop production, technical efficiency in production of the five major crops, viz. paddy, sorghum, maize, sugarcane and banana in different study areas, was estimated using stochastic frontier production function. Crop-wise specific technologies were available in those study areas. The following technologies were identified in the study area: system of rice intensification (SRI), crop diversification or change in cropping pattern, change in variety, adoption of drought-tolerant varieties, drip irrigation, summer ploughing, mixed farming and digging of new bore-wells. The adoption of these technologies was quantified by constructing a technology adoption index. The respondents were classified as adopters if the adoption index was 50 or above. In this study, 52.78 per cent respondents were adopters and 47.22 per cent of the farmers were non-adopters. The maximum likelihood estimation of technical efficiency and the distribution of technical efficiency are given in Table 3 and Table 4, respectively.

Paddy — In paddy, the use of organic fertilizer has shown a negative impact on output, in the case of technology adopters. The use of inorganic fertilizer was found influencing the output in the non-adoption category. A high value of gamma (1.00) indicates the presence of significant inefficiencies in the production of this crop. Almost 100 per cent of the difference between the observed and the frontier outputs was due to inefficient use of resources — a case similar to banana and maize production. The technical efficiency distributions of major crop growers are presented in Table 4. Most of the farmers (90 %) achieved technical efficiency in the range of 81-90 per cent in the adopter's category. Similarly, about 91 per cent non-adopter farmers achieved technical efficiency in the range of 81-90 per cent. The mean technical efficiency worked out to be 90.44 per cent and 89.33 per cent, respectively for the groups of adopters and non-adopters.

Sorghum — For technology adopters in this crop, human labour was found to have a significant and positive impact on its production. The variables organic fertilizer and labour have shown a negative and significant impact on output in the case of non-adopters. The high value of gamma obtained for this crop has also confirmed the existence of inefficiency in input-use. The Table 4 reveals that 51 per cent of adopters and 42 per cent of non-adopters have achieved the efficiency range of > 90 per cent. About 14 per cent of adopters and 24 per cent of non-adopters fall in the 81-90 per cent efficiency range. The mean technical efficiency of sorghum farmers has been found 89.59 per cent for adopters and 88.91 per cent for non-adopters.

Maize — For technology adopters in this crop, the seed rate and human labour have shown a negative

Table 3. Maximum likelihood estimates of technical efficiency in major crops

Particulars	Paddy		Sorghum		Maize		Sugarcane		Banana	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Constant	8.52***	4.97	7.67***	9.48***	10.37***	7.91***	-3.75***	10.75***	7.67***	9.48***
Seed rate (kg/ha)	0.02	0.96	0.05	-0.05	-0.61***	0.08	1.37***	-0.07	0.05	-0.05
Organic fertilizer (kg/ha)	-0.08**	-0.12	0.02	-0.02**	0.18	0.04***	-0.02***	0.01	0.02	-0.02**
Inorganic fertilizer (kg/ha)	0.17	0.32**	0.05	-0.02	0.22	0.03	-0.04	0.0009	0.05	-0.02
Labours use (persondays/ha)	-0.04	-0.29	0.09**	-0.08***	-0.66***	-0.03	0.04	0.28***	0.09**	-0.08***
Sigma squared	0.02***	0.02**	0.02***	0.02***	0.008***	0.007**	0.003***	0.03***	0.02***	0.02***
Gamma	1.00***	0.88***	1.00 ***	0.95***	1.00***	0.95***	0.99***	0.97***	0.99***	1.00***
log likelihood	42.11	30.55	56.14	42.59	67.83	46.68	62.84	26.03	56.15	42.59

Note: *** and ** denote significance at 1 per cent and 5 per cent levels, respectively.

Table 4. Distribution of technical efficiency in major crops

(No. of farmers)

Efficiency range (%)	Paddy		Sorghum		Maize		Sugarcane		Banana	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Less than 70	0	1	0	0	0	0	0	1	0	1
71-80	3	2	5	12	0	0	0	7	0	7
81-90	11	16	12	17	12	8	13	9	4	18
More than 90	16	16	18	21	28	22	17	13	41	14
Total number	30	35	35	50	40	30	30	30	45	40
Mean technical efficiency (%)	90.44	89.33	89.59	88.91	94.48	93.52	93.57	86.94	95.65	86.59

impact on output; the estimated coefficients being statistically significant. In the case of non-adopters, the use of organic fertilizer has depicted a positive and significant impact on output. About 100 per cent of the difference between the observed and the frontier outputs was mainly due to inefficient use of resources, which were under the control of sample farmers of technology adoption, and 94 per cent of the difference between the observed and the frontier outputs was due to inefficient use of resources in the case of non-adopters. The Table 4 reveals that 70 per cent of the farmers could achieve the technical efficiency range of more than 90 per cent in adopters category and 73 per cent in non- adopters category. The mean technical efficiency has been found 94.48 per cent for the former and 93.52 per cent for the later category of farmers.

Sugarcane — For this crop, the coefficient for seed rate has been found statistically significant, implying that production of sugarcane is much influenced by this variable in the case of adopters, while in the case of non-adopters, the labour-use has been found to have more influence over the output. The organic fertilizer has shown a negative impact on output, for the adopter category, may be due to its excessive use. A high value of gamma has indicated the presence of significant inefficiencies in sugarcane production. The majority in both the categories of farmers (57 % and 43 %) achieved technical efficiency in the range of more than 90 per cent. The mean technical efficiency of sugarcane farmers has been computed as 93.57 per cent for adopters and 86.94 per cent for non-adopters.

Banana — For banana crop, human labour has been found to have a positive significant influence on the yield of this crop. The variables organic fertilizer and human labour have depicted a negative influence over the output at one per cent significance level in the case of non-adopters, indicating the excessive use of these inputs. A high value of gamma (0.9945) has indicated the presence of significant efficiency or inefficiency in the production of this crop. This implies that about 99 per cent variation in the yield of banana crop for adopters and 100 per cent variation in the case of non-adopters were mainly due to the differences in their technical efficiencies or inefficiencies. In the study area, in the adopter category, the majority of the farmers (91 %) could achieve technical efficiency above 90 per cent, followed by 9 per cent of farmers falling in the technical efficiency range of 81-90 per cent. In the non-adopters category, 45 per cent of the farmers have depicted technical efficiency in the range of 81-90 per cent, followed by 35 per cent in the range of more than 90 per cent and about 17 per cent in the range of 71-80 per cent. It is noteworthy that the mean technical efficiency of banana farmers was 95.65 per cent for adopters and 86.59 per cent for non-adopters.

The technical efficiency of climate change for all crops has been found higher for adopters than non-adopters and the percentage of efficient farmers was more in the adopters category than in the non-adopters category in all crops, except maize.

Constraints to Climate Change Adaptation in Agriculture

Table 5 summarizes the constraints identified by the farmers to adopt climate resilient technologies. The Garrett ranking technique was used for ranking the constraints for adoption. The major constraints being faced by the farmers were lack of finance, lack of knowledge about technology, high cost of adaptation, lack of technical skill, inadequate size of landholdings and inadequate training and demonstration. The lack of finance for adopting new technologies has been

Table 5. Constraints for adoption of climate resilient technologies in Tamil Nadu

Reasons	Respondents	
	Mean score	Rank
Lack of finance	69.47	I
Lack of knowledge about technology	60.57	II
High cost of adaptation	54.17	III
Inadequate size of landholdings for adaptation	42.18	IV
Lack of technical skill	38.10	V
Inadequate training and demonstration	32.33	VI

found to be the most important constraint, followed by the lack of knowledge about technology. Strengthening of agricultural credit and extension for effective transfer of technologies have been found to be the important components to cope with climate variability.

Conclusions

This study has been focussed on the adoption of climate resilient technologies on climate adaptation in the Western Zone of Tamil Nadu where climate variability is high. It is revealed that education level increases the probability of adopting climate resilient technologies, while household-size and farm-size negatively influence the adoption of technologies. The experienced farmers and access to extension contact positively influence the adoption of technologies. The farm income of the household has shown a positive and significant impact on the adoption of system of rice intensification, drip irrigation, digging of new bore-wells and mixed farming.

The information on climate change has depicted a significant and positive impact on the likelihood of adopting technologies. Off-farm income decreases the probability of adoption of these technologies. A rise of 1 ^{o}C in mean temperature increases the probability of changing cropping pattern (10.8 %), growing drought-tolerant crop (24.1 %), installing drip irrigation (5.8%) and mixed farming (35.1%). The study has shown that the decreasing precipitation significantly increases the likelihood of using system of rice intensification (SRI), change in cropping pattern, summer ploughing, mixed farming and digging of new bore-wells. The technical efficiency in crop production has been found higher for technology adopters than non-adopters. The lack of finance to adopt the new technologies and lack of knowledge about technology have been reported as the major problems by the farmers in climate change adaptation strategies.

End-Notes

1. Adopters and non-adopters were identified based on the following index:

   Adoption Index = [*a/p*]* 100

   where, *a* is the number of practices adopted by the respondents, and *p* is the total number of practices recommended.

   The respondents were classified as adopters if the adoption index was 50 or above.

References

Battese, G.E. (1997) A note on the estimation of the Cobb-Douglas production function when some explanatory variables have zero values. *Journal of Agricultural Economics,* **48**: 250–252.

Battese, G.E. and Broca, S.S. (1997) Functional forms of stochastic frontier production functions and models for technical inefficiency effects: A comparative study for wheat farmers in Pakistan. *Journal of Productivity Analysis,* **8**: 395–414.

Battese, G.E. and Coelli, T.J. (1995) A model for technical efficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, **20**: 325–332.

Bradshaw, B., Dolan, H. and Smit, B. (2004) Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian Prairies. *Climatic Change*, **67:** 119–141.

Coelli, T.J. (1996) *A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation*. CEPA Working Paper 96/7. Center for Efficiency and Productivity Analysis (CEPA), University of New England, Armidale, Australia.

Easterling, W.E., Crosson, P.R., Rosenberg, N.J., McKenney, M.S., Katz, L.A. and Lemon, K.M. (1993) Agricultural impacts of and responses to climate change in the Missouri-Iowa-Nebraska region. *Climatic Change,* **24** (1–2): 23–62.

Garrett, Henry. E. and Wood Worth, R.S. (1971) *Statistics Psychology and Education*. Vakils, Fetter and Simons, Bombay.

Green, W.H. (2000) *Econometric Analysis*, 4th ed. Prentice Hall, New Jersey, USA.

Koch, S. (2007) *Lecture Notes,* presented to students in EKT 816 at the University of Pretoria in South Africa during the fall semester of 2006, University of Pretoria, Pretoria.

Madalla, G. (1983) *Limited Dependent and Qualitative Variables in Econometrics*. Cambridge University Press, Cambridge, UK.

Maddison, D. (2006) *The Perception of Adaptation to Climate Change in Africa*. CEEPA Discussion Paper

No. 10. Centre for Environmental Economics and Policy in Africa, University of Pretoria, South Africa.

Mendelsohn, R. (1998) Climate-change damages. In: *Economics and Policy Issues in Climate Change*, Ed: W.D. Nordhaus. Resources for the Future, Washington, DC, USA.

Reilly, J. and Schimmelpfennig, D. (1999) Agricultural impact assessment, vulnerability and the scope for adaptation. *Climatic Change* **43**: 745–788.

Rosenzweig, C. and Parry, M.L. (1994) Potential impact of climate change on world food supply. *Nature*, **367**(6450): 133-138.

Smith, J.B. (1996) Using a decision matrix to assess climate change adaptation. In: *Adapting to Climate Change: An International Perspective*, Eds. J.B. Smith, N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow and F. Rijsberman. Springer, New York, USA.

Smit B and Skinner, M.W. (2002) Adaptations options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change*, **7**: 85–114.

Smithers, J. and Blay-Palmer, A. (2001) Technology innovation as a strategy for climate adaptation in agriculture. *Applied Geography*, **21**: 175-197.

Wooldridge, J.M. (2002) *Econometric Analysis of Cross Section and Panel Data*. MIT Press, Massachueetts, USA.

Revised received: September, 2014; Accepted: November, 2014

Appendix-I

Maximum Temperature

Estimated linear trend in maximum temperature in different agro-climatic zones of Tamil Nadu, 1980-81 to 2010-11

Agro-climatic zones	Coefficient	t-value
North Eastern Zone	-0.0003	-0.0922
North Western Zone	0.0163**	2.2107
Western Zone	0.0228***	2.7384
Cauvery Delta Zone	-0.0101	-1.7519
Southern Zone	0.0010	0.2150

Note: *** and ** denote significance at 1 per cent and 5 per cent levels, respectively.

Estimated Mann-Kendall test for maximum temperature in different agro-climatic zones of Tamil Nadu, 1980-81 to 2010-11

Particulars	North Eastern zone	North Western zone	Western zone	Cauvery Delta zone	South zone
Kendall's tau	0.030	0.200	0.297	-0.131	0.030
S	13.000	87.000	129.000	-57.000	13.000
p-value	0.832	0.126	0.022	0.321	0.832
Alpha	0.05	0.05	0.05	0.05	0.05
Test interpretation	Accept H_0	Accept H_0	Reject H_0	Accept H_0	Accept H_0

Minimum Temperature

Estimated linear trend in minimum temperature in different agro-climatic zones of Tamil Nadu, 1980-81 to 2010-11

Agro-climatic zones	Coefficient	t-value
North Eastern Zone	-0.00802	-1.58229
North Western Zone	0.02196***	2.64598
Western Zone	0.04145***	4.51211
Cauvery Delta Zone	-0.00381	-1.02515
Southern Zone	0.00006	0.01262

Note: *** and ** denote significance at 1 per cent and 5 per cent levels, respectively.

Estimated Mann-Kendall test for minimum temperature in different agro-climatic zones of Tamil Nadu, 1980-81 to 2010-11

Particulars	North Eastern zone	North Western zone	Western zone	Cauvery Delta zone	South zone
Kendall's tau	-0.182	0.278	0.646	-0.087	0.018
S	-79.000	121.000	281.000	-38.000	8.000
p-value	0.166	0.032	< 0.0001	0.509	0.901
Alpha	0.05	0.05	0.05	0.05	0.05
Test interpretation	Accept H_0	Reject H_0	Reject H_0	Accept H_0	Accept H_0

Precipitation

Estimated linear trend in precipitation in different agro-climatic zones of Tamil Nadu, 1980-81 to 2010-11

Agro-climatic zones	Coefficient	t-value
North Eastern Zone	2.3876	0.4272
North Western Zone	4.0753	1.1440
Western Zone	7.7026**	2.0946
Cauvery Delta Zone	5.8335	1.1555
Southern Zone	4.9330	1.1770

Note: *** and ** denote significance at 1 per cent and 5 per cent levels, respectively.

Estimated Mann-Kendall test for precipitation in different agro-climatic zones of Tamil Nadu, 1980-81 to 2010-11

Particulars	North Eastern zone	North Western zone	Western zone	Cauvery Delta zone	South zone
Kendall's tau	0.085	0.145	0.205	0.145	0.163
S	37.000	63.000	89.000	63.000	71.000
p-value	0524	0.272	0.117	0.272	0.214
Alpha	0.05	0.05	0.05	0.05	0.05
Test interpretation	Accept H_0	Accept H_0	Accept H_0	Accept H_0	Accept H_0

Appendix-II

Correlation between independent variables

Variable	Education level	House-hold-size	Gender	Age	Farm income	Livestock ownership	Extension contact	Climate change awareness	Access to loan	Off-farm income	Farm size	Distance to market for agricultural inputs	Temp	Rainfall
Education level	1.00													
Household size	-0.02	1.00												
Gender	-0.02	0.01	1.00											
Age	-0.13	0.01	-0.01	1.00										
Farm income	0.27	0.03	-0.02	-0.04	1.00									
Livestock ownership	-0.05	0.08	-0.10	-0.06	0.13	1.00								
Extension contact	-0.01	0.00	-0.02	0.11	0.06	-0.03	1.00							
Climate change awareness	0.02	-0.09	0.07	-0.02	-0.05	-0.08	-0.04	1.00						
Access to loan	0.11	-0.13	-0.15	-0.14	0.07	-0.13	-0.06	-0.03	1.00					
Off-farm income	0.03	0.00	0.12	-0.03	0.01	0.07	-0.02	-0.01	-0.08	1.00				
Farm size	0.18	0.21	0.01	0.09	0.21	0.05	-0.01	-0.14	0.08	-0.06	1.00			
Distance to market for agricultural inputs	0.00	0.09	-0.03	0.11	-0.03	0.07	0.07	-0.03	0.04	-0.04	0.11	1.00		
Temperature	-0.02	0.01	0.03	-0.09	-0.01	0.22	-0.04	0.05	0.10	0.02	0.12	0.32	1.00	
Rainfall	-0.08	-0.01	-0.07	-0.12	0.03	0.13	-0.03	-0.14	-0.10	-0.14	-0.09	-0.01	0.00	1.00