D24

Measuring Water-use in Response to Climate Change: An Analysis of the Efficiency of Italian Crop Production System

S. Auci | Università degli Studi di Palermo | Palermo | Italy
D. Vignani | Istat | Rome | Italy

DOI: 10.1481/icasVII.2016.d24b

ABSTRACT

Official meteo-climatic statistics show the variability of weather conditions. Their effects on socio-economic and natural environments should be analyzed in multi-dimensional studies. Among sectors, agriculture is expected to be the most sensitive as well as water resources availability. The aim of our analysis is to measure the performance of Italian regions in crop production by estimating both production technology - including a measure of irrigation water used as input - output elasticities and returns to scale and productive efficiency or technical efficiency where rainfalls and temperatures are proxies of CC conditions in the period 2000-2010 at Italian regional level, using the stochastic frontier approach (SFA). The scarce official statistics on irrigation water in agriculture make our analysis challenging. Our results point out the need i) to strengthen official statistics on irrigation water to improve the analysis on inputs of farmer's crop production in Italy; ii) to update meteo-climatic and hydrological measures according to the official international guidelines.

Keywords: Climate Change, Crop Harvested, Irrigation Water, Stochastic Frontier Efficiency.

PAPER

1. Introduction

As climate is an essential component of the natural ecosystem, the exasperation of weather conditions can have some effects on socio-economic and natural environments. Several sectors can be affected by climate change (CC) and climate variability but water resources and agriculture are expected to be the most sensitive. Both the IPCC (2014) and the OECD (2014) confirm that the increase of greenhouse gases (GHGs) will cause positive changes modifying the speed of crop growth and negative changes in temperatures and rainfalls. Hence, CC will alter the water cycle, changing temporal and spatial redistribution of water resources, such as the frequency of occurrence of droughts and floods, which are expected increasing in many areas. These changes in rainfall and temperature patterns may affect crop water requirements and more generally crop production system since water is the most critical input for sustainable agricultural development – as irrigated areas will increase in forthcoming years. CC can affect the amount of water available (supply-side) and of crop water requirements (demand-side) due to changes in rainfall patterns. Whether understanding of how CC can influence local water availability is widely analyzed, CC effects on crop production function considering water resources used for irrigation as an input are not well deepened. The majority of studies has focused on climate projections investigating the impacts of CC on global agricultural water requirements (Döll, 2002; Zhang and Cai, 2013); on water resources and water availability for Africa (Kusangaya et al. 2014) for China (Tao et al., 2003); on groundwater recharge rates (Döll et al., 2002; Taylor et al., 2012). A brief review of studies mainly based on the Ricardian method to evaluate the impact of CC on rural areas is described in Dasgupta et al. (2014). Other studies have investigated the economic effects of CC on agricultural sector (Giupponi and Shechter, 2003) based on long-term analyses at the aggregate level, i.e. continental or national scales (Xiong et al., 2010). In contrast, few studies have performed short-term analyses at a sub-regional level. In the case of agriculture, models based on discrete stochastic programming model have been used to forecast the effects of changes in water availability on agriculture due to CC (Dono and Mazzapicchio, 2010). A three-stage discrete stochastic programming model has been used to represent the choice process of the farmer based on the expectation of possible scenarios of rainfalls and higher minimum temperatures for a specific irrigated area of Italy in the next future.

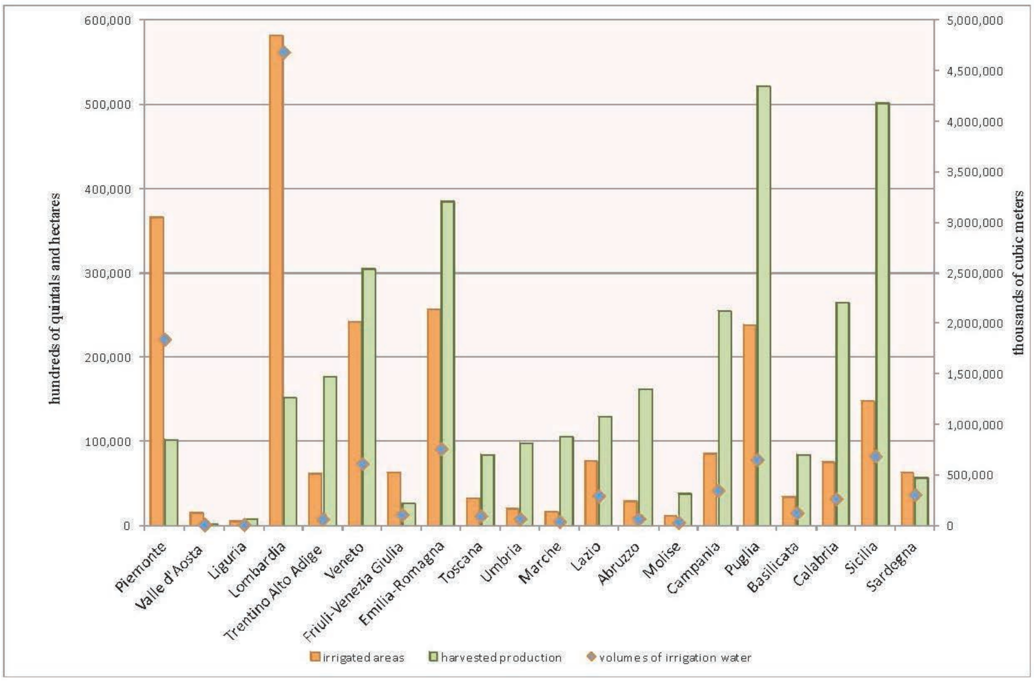
These variables affect the availability of water for agriculture and the water requirements of irrigated crops (Dono et al., 2011). Our study is a critical contribution within the literature on the impacts of CC on agriculture. The chosen model considers a crop production function for Italy where water resources are considered as inputs. By using an empirical analysis such as the Stochastic Frontier Approach (SFA), the technical efficiency of crop production and the inputs' efficiency have been estimated at local scale while meteo-climatic statistics show that CC has been taking place in these last decades. The inadequate official statistics on water resources for irrigation in agriculture make our analysis challenging. Comparability issues and data-lacking both at spatial and temporal scale forces us: i) to consider only the period 2000 2010; ii) to construct an ad hoc variable to measure the volume of irrigation water to complete our panel data and iii) to provide estimates at regional level instead of at farmer's level. By applying the SFA methodology, we can as well estimate efficiency at regional scale in the Italian crop production system. Empirical estimate results can be useful tools for policy makers in defining the optimal climate mitigation and adaptation policy actions in agriculture. In addition, our results recommend the urgency of increasing collection of data and official statistics production at local level on irrigation water volume and on meteo-climatic and hydrological measures, issued by Istat. Therefore, multidimension phenomenon datasets fitting for the purpose of CC effects could be improved by either integrating already existing datasets from different sources (such as administrative archives, official statistical surveys, trade associations, land reclamation authority) or developing ad hoc sections within existing surveys more respondent to the economic needs of measuring the efficiency of 3 farmers and their capability to adapt to CC. The paper is organized as follows. In Section 2 we briefly analyze data used for the crop production function in the SFA model. In section 3, we present our empirical model and the main results. Finally, we summarize the findings of our research.

2. Italian crop production and CC related data

Agricultural sector is one of the most susceptible as changes in meteorological conditions heavily affects crop production trends, yield variability and reduction of areas suitable to be cultivated, specifically in the Mediterranean countries. Many studies have evaluated the effects of CC on agriculture in Europe taking into account important regional differences (Reidsma, et al., 2007, Olesen and Bindi, 2002; Iglesias et al., 2009). CC is expected to intensify problems of water scarcity and irrigation requirements in all the Mediterranean regions and thus in Italy (IPCC, 2014; Goubanova and Li, 2006; and Rodriguez Diaz et al., 2007). The geographical position of Italy at the centre of the Mediterranean basin and its historical high agricultural vocation make Italy vulnerable to the negative consequences of CC. Italy is the second largest producer of "*fruit and vegetable*" in Europe after Spain offering a wide range of high quality and typical Mediterranean products, officially recognized as IGP and DOP. Weather conditions could lead to inefficiency in the agricultural sector, even because it includes many small firms with a lower capability to adapt to a new climatic situation. In the last twenty years, changes in weather conditions occurred in Italy and a rise of water used for irrigation especially in the South, traditionally suited to agriculture activities, have contributed to threaten crops and reduce areas suitable for cultivation.

To evaluate climate-related impacts on the agricultural sector across Italian regions, long run time series of data should be necessary. Forced by data availability, the focus of our analysis is mainly on the Italian regions' efficiency in the period 2000 to 2010, analyzing the short-term effects of CC on Italian agriculture. To estimate CC effects on the efficiency of agricultural yields at Italian regional level (NUTS2), a dataset of CC and agriculture sector at regional level has been collected by using official statistics, mainly produced by Istat. All variables are measured in physical units.

Figure 1. - Volumes of irrigation water, irrigated areas, harvested production Italian Regions, Year 2010 (thousands of m3, hectares, hundreds of quintals)



These statistics regard both inputs and output of the production function and inefficiency determinants as proxies of CC. A panel dataset has been collected on the following variables: i) agricultural harvested crops production and production areas (source Istat survey of Estimate of Crop, Flower and Plot Plant Production and Area); ii) irrigated areas, seeds and fertilizer used, days of work of farm employees (source Istat Survey on Agricultural Holding Structure and Output, V and VI Agricultural Census, Survey on seeds and Survey on fertilizer); finally iii) temperatures and rainfall (source Meteo-Climatic and Hydrological Istat Survey). To develop our analysis, two aspects have to be considered. Firstly, although meteo-climatic and hydrological official statistics have been produced until 2014, meteo-climatic time series have been updated only for Italian regional capitals. This reason forces us to base our analysis on 2000-2010 time series containing statistics suitably spatialized. Secondly, because of the lack of data on volumes of irrigation water used in agricultural crops, we constructed a proxy. In the SFA model, we should have included the variable "*volumes of irrigation water*" jointly with "*irrigated areas*" but official statistics on volumes of irrigation water used by crop in Italian agriculture was provided, once in 2010, in occasion of Istat VI Agricultural Census. Figure 1 compares *irrigated areas* and *total harvested production with volumes of irrigation water* and underlines the multifaceted situation for each Italian region. What is the most amazing consideration is that Lombardy uses about 42.26% of the total of irrigation water to obtain only 4.39% of the harvested production with respect to the total 4 production. While, in the opposite case, we find Emilia-Romagna and Puglia, where respectively they use only 6.84% and 5.90% of total volume of irrigation water to obtain a harvested production of 11.17% and 15.13% with respect to the total harvested crops. Quite certainly, this situation could be the consequence of meteo-climatic variability, different typologies of crops cultivated, irrigation technology used, and environmental conditions in each region.

Starting from the Census, we constructed *ad hoc coefficients* for 2010 by dividing volumes of irrigation water with respect to irrigated areas (K_{ij}=*irrig_waterij/irrig_areaij*) by each crop (i) and Italian region (j). To fill our dataset, we reconstructed the variable "*volumes of irrigation water*" for each year considered in our analysis, by multiplying the 2010 Kij coefficients for irrigated areas by crop and region.

3. Empirical model and main results

By applying the SFA proposed by Battese and Coelli (1995) to our sample, the performance of Italian regions in crop yields is evaluated by estimating production technology and productive efficiency. The production technology allows the study of production inputs (labour and physical capitals), output elasticities and returns to scale, while the productive efficiency, or technical efficiency, allows the analysis of getting the maximal output from available resources, given the level of inputs. This efficiency can be directly affected by observable exogenous variables such as CC conditions (rainfalls and temperatures), which reflect the heterogeneity of Italian regions in the agricultural sector. Two are the advantages of using the SFA methodology. Firstly, production inputs and efficiency factors are estimated simultaneously using two distinct functions. Secondly, distances from the efficient frontier between those due to systematic components and those due to noise are disentangled. The main idea is that the maximum output frontier for a given input set is assumed to be stochastic in order to capture exogenous shocks beyond the control of individuals.

The parametric estimation of the SFA is based on the standard Cobb-Douglas (CD) production function, whose practical advantage - with respect to more flexible forms such as the translog function - is the limited number of variables required. Expressing output and inputs in natural log values, the CD function can be written as:

$$(1) \qquad ln(Y)_{it} = \beta_0 + \beta_1 ln(Kseed)_{it} + \beta_2 ln(Kfert)_{it} + \beta_3 ln(Kvol\_irr)_{it} + \beta_4 ln(Kirrig\_area)_{it} + \beta_5 ln(Citrus\_area) + \beta_6 ln(Fruit\_area) + \beta_7 ln(Vegetable\_area) + \beta_8 ln(L)_i + v_{it} - u_{it}$$

where Y is the agricultural yield measured by the ratio between harvested production (in kilos) and cultivated areas (in hectare), physical capitals are measured by Kseed which represents the amount of seeds used for the cultivations, *Kfert* which stands for the tons of fertilizers used in agriculture, Kvol_irr which is the irrigation water volumes, Kirrig_area which means the hectares of irrigated areas, Citrus_area which represents citrus plant cultivated areas (in hectare), Fruit_area which is fresh fruits cultivated areas (in hectare), Vegetable_area which means vegetables cultivated areas (in hectare), and L is labour force measured by the days of work in farms. While the technical inefficiency model is characterized by several observable explanatory variables as follows:

$$(2) \qquad u_{it} = \gamma_0 + \gamma_1 Rainfall_{it} + \gamma_2 Temp\_min_{it} + \gamma_3 d\_North-west_{it} + \gamma_4 d\_North-east_{it} + \gamma_5 d\_Centre_{it} + \gamma_6 d\_South_{it} + \varepsilon_{it}$$

where Rainfall is measured by the deviation of annual total rainfall average from the CLINO 1971-2000 rainfall average value and Temp_min is defined as the deviation of annual minimum temperature average from the CLINO 1971-2000 minimum temperature average value. The dummy macro-areas are as usual: North-west, North-east, Centre, South while Islands is missing due to collinearity.

The stochastic frontier estimation allows us to measure the value of productive efficiency of harvested production in each Italian region. The technical inefficiency of the i-th region in the t-th period is given by:

$$(3) \qquad TE_{it} = e^{(-u_{it})} = e^{(-z_{ti}\delta - \varepsilon_{ti})}$$

The technical inefficiency values will oscillate between 0 and 1, being the latter the most favourable case. If TEit←1 then the observable output is less than the maximum feasible output, meaning that the statistical unit is not efficient.

In Table 1, we present both the CD stochastic production function estimated coefficients and the technical inefficiency equation estimated coefficients. The coefficients of the CD function can be interpreted as the partial output elasticities, which show the percentage change of output in response to one percent change in an input. Not all the estimated output elasticities are positive.

Physical capitals measured by fertilizers used (Kfert), seeds used (*Kseed*), and areas cultivated with citrus plant (*Citrus_area*) and with fresh fruit (*Fruit_area*) show positive and significant elasticities, indicating that these specific capital inputs are productive inputs for increasing agricultural annual yields (Tasnim et al., 2015). The estimated values of the coefficients of irrigated areas (*Kirrig_area*) and vegetable cultivated areas (*vegetable_area*) are negative and significant. There is no scope of increasing production by further increase of those inputs. The input labour force (L) shows a positive coefficient and significant in the annual Italian regional agricultural yields differently from Tasnim et al. (2015). The elasticity of irrigation water volume (*Kvol_irr*) is positive and significant showing that an increase in the demand of water for irrigation has positive effects on agricultural yields. Moreover, since output elasticities for irrigation water volumes and for irrigated areas show the greatest values, the empirical findings confirm that water for irrigation remain the most important factor in the crop production function. The returns to scale (RTS), calculated as the sum of the output elasticities, measure the percentage change of output due to a one percent increase in all inputs. The RTS coefficient is smaller than unity, meaning that the Italian regional crop production presents decreasing returns to scale. Considering the inefficiency model, rainfall variable shows a negative and significance sign, while minimum temperature variable coefficient is positive but not significant.

Table 1. – Estimates of the Cobb-Douglas production function and of the inefficiency model

Stochastic production frontier model			**Technical inefficiency model**		
	coef	**p-value**		**coef**	**p-value**
Kseed	0.028	0.211	*Rainfall*	-0.004***	0.001
Kfert	0.297***	0.000	*Temp_min*	0.082	0.169
Kvol_irr	1.035***	0.000	*d_South*	-1.876***	0.000
Kirrig_area	-1.137***	0.000	*d_Centre*	-1.789***	0.000
Citrus_area	0.520***	0.000	*d_North-east*	-7.028***	0.000
Fruit_area	0.308***	0.000	*d_North-west*	-1.759***	0.000
Vegetable_area	-0.602***	0.000	constant	2.767***	0.000
L	0.182***	0.001			
constant	-11.918***	0.000	**Returns to scale**	0.632	
sigma_v	-2.535***	0.000	**TE_{it} Scores:**		
sigma_u	-4.291***	0.000	Mean	0.471	
lambda	2.406	0.000	Standard Deviation	0.287	
N. of obs.	200		Minimum	0.027	
Log-Likelihood	-7.228		Maximum	0.986	

note: *** p<0.01, ** p<0.05, * p<0.1.

The more is the deviation of the annual total rainfall average from the 1971-2000 rainfall average value the more efficient is the crop yields for Italian regions. Therefore, Italian regions in term of agricultural yields become more inefficient when the annual rainfall value diminishes with respect to the 1971-2000 rainfall average value. This is in line with the IPCC (2014) analysis where in the Mediterranean area the annual rainfall average will tend to decrease in the next future.

Instead, the more is the deviation of the annual minimum temperature average from the 1971-2000 minimum temperature average value the more is the inefficiency of Italian regions in crop yields, even if this effect is not statistically relevant. Italian regions' agricultural crop yields decrease due to more inefficiency caused by an increase of annual minimum temperature. This negative effect, foreseen and analysed even by the IPCC (2014), implies that an increase in temperature will influence negatively crop yields in the Mediterranean basin. The negative signs of the estimated coefficients of geographical dummies indicate a positive effect on efficiency, meaning that regions belonging to one of those macro-areas – South, Centre, North-east and North-west of Italy – with respect to Islands are more efficient. The summary statistics of estimated technical efficiency (TE) scores are even reported in Table 1. The TE scores show a low mean value meaning that Italian regions in mean are quite distant from the efficient frontier.

In Table 2, by splitting our sample on Italian macro-areas, the analysis of variance (ANOVA) is proposed in order to test for differences in the means of technical inefficiency. Results confirm that differences in the Italian macro-area means of technical inefficiency are significant. Thus, regions belonging to North-east like Trentino-Alto Adige, Friuli-Venezia-Giulia and Veneto are the more efficient where the mean is 0.98. On the opposite case, Sardinia and Sicily, belonging to Islands macro-area, are the worst efficiency regions in terms of agricultural yields and they are the weaker regions in case of changing weather conditions.

Table 2. – Anova of TE by Italian macro-areas

Region Code	mean
North-east	0.98
South	0.42
Centre	0.37
North west	0.34
Islands	0.07
F	488.51
Prob > F	0.00

4. Conclusions

In the 2001-2014 period, Italy recorded a special "warming" because the annual mean temperature (equal to 15.1°C) has increased of about 1°C with respect to CLINO 1971-2000 temperature. In the same period, Italy recorded a change in rainfall pattern, because the total annual mean precipitation has been equal to 740.8mm, a reduction of about 1.1% with respect to the same CLINO period. Such weather changes has had a negative influence on agriculture production that is the most susceptible sector to changing weather conditions and have contributed to rise volumes of water used for irrigation, especially in the South. In our empirical and short-term effects of CC analysis, economic impacts of CC on Italian regional agricultural production and technical efficiency have been analyzed for the period 2000-2010. Among inputs, irrigation water volume, the most important factor in the crop production function, shows a positive and significant elasticity. Therefore, an increase in the demand of water for irrigation has certainly positive effects on agricultural crop yields. Moreover, the inefficiency model shows that when rainfall declines and annual minimum temperature increases, Italian regions become more inefficient. Results confirm that differences in the Italian macro-area means of technical inefficiency are significant. Regions belonging to North-east are the more efficient while Sardinia and Sicily, belonging to Islands macro-area, are the worst efficient regions in terms of agricultural yields. They could be the weaker and more vulnerable regions in facing changes in meteo-climatic and hydrological conditions. As CC affects many dimensions, official statistics on different thematic issues need to be integrated and harmonized to provide a solid basis for empirical analyses on CC impacts on agriculture. Strengthening the production of official statistics at adequate temporal and spatial scale on irrigation water to ameliorate the analysis on water resources required by farmers is needed.

Updating meteo-climatic and hydrological variables according to the latest official international guidelines to develop long-run CC analyses. Aiming the target to develop CC Related Statistics (CCRS) and new indicators following the 2014 UN Conference of European Statisticians Recommendations[1] is a necessity coming from international institutions. Therefore, multidimension phenomenon datasets fitting for the purpose of CC effects could be improved by either integrating already existing datasets from different sources, such as administrative archives, official statistical surveys, trade associations, land reclamation authority, or developing ad hoc sections within existing survey questionnaires more respondent to the economic needs of measuring the efficiency of farmers and their capability to adapt to CC. In a context characterized by uncertainty inherent in climate variability, the role of policy is crucial in managing water resources across space and time to prevent agricultural yield fluctuations causing welfare loss.

REFERENCES

Battese G.E. and Coelli T.J., (1995) A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data, Empirical Economics, 20, 325-332.

Dasgupta P., Morton J.F., Dodman D., Karapinar B., Meza F., Rivera-Ferre M.G., Toure Sarr A., and

[1] The CES Recommendations are organized into five conceptual areas: drivers, emissions, impacts, mitigation and adaptation. The primary drivers of CC are anthropogenic emissions of GHGs from production and use of fossil fuels, agricultural and forestry practices and manufacturing processes.

Vincent K.E., (2014), Rural areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 613-657

Döll P. (2002) Impact of Climate Change and Variability on Irrigation Requirements: A Global Perspective, Climatic Change 54, 269–293.

Dono G., and Mazzapicchio G., (2010) Uncertain water supply in an irrigated Mediterranean area: an analisys of the possible economic impact of Climate Change on the farm sector, Agricultural Systems, 103(6).

Dono G., Cortignani R., Doro L., Ledda L., Roggero P., Giraldo L., Severini S.(2011) "Possible impacts of climate change on Mediterranean irrigated farming systems", Paper presented at the EAAE 2011 Congress, "Change and Uncertainty Challenges for Agriculture, Food and Natural Resources", August 30 to September 2, 2011, Zurich, Switzerland

Giupponi C. and Shechter M., (2003) Climate Change in the Mediterranean", Socio-economic Perspectives of Impacts, Vulnerability and Adaptation, Edward Elgar Publishing, 2003.

Goubanova K. and Li L., (2006), "Extremes in temperature and precipitation around the Mediterranean in an ensemble of future climate scenario simulations", Global and Planetary Change, doi:10.1016/j.globaplacha.2006.11.012.

Iglesias A., Garrote L., Quiroga S., Moneo M. (2009) "Impacts of climate change in agriculture in Europe" PESETA-Agriculture study. JRC Scientific and Technical Research series EUR 24107 EN, European Commission, Joint Research Centre.

IPCC, (2014), "Climate Change 2014: Impacts, Adaptation, and Vulnerability", Contribution of WGI to the 5th Assessment Report of the IPCC, Geneva.

Kusangaya, S., Warburton, M. L., Van Garderen, E. A., & Jewitt, G. P. (2014) Impacts of climate change on water resources in southern Africa: A review, Physics and Chemistry of the Earth, 67- 69, 47-54.

OECD (2014), "Climate Change, Water and Agriculture: Towards Resilient Systems", OECD Studies on Water, OECD Publishing. http://dx.doi.org/10.1787/9789264209138-en

Olesen J.E. and Bindi M. (2002) "Consequences of climate change for European agricultural productivity, land use and policy" European Journal of Agronomy 16, (4) 239-262.

Reidsma P., Ewert F. Lansink A.O. (2007) "Analysis of farm performance in Europe under different climatic and management conditions to improve understanding of adaptive capacity" Climatic Change 84, 403–422

Rodriguez Diaz, J.A., Weatherhead, E.K., Knox, J.W., Camacho, E. (2007), "Climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain", Regional Environmental Change, 7, 149–159.

Tao, F., M. Yokozawa, Y. Hayashi and E. Lin (2003) Future climate change, the agricultural water cycle, and agricultural production in China, Agriculture, Ecosystems and Environment, 95(1), 203-215

Tasnim, Z., Hafeez, A.G., & Majumder, S. (2015) Climate Change and Wheat Production in Drought Prone Areas of Bangladesh-A Technical Efficiency Analysis. Journal of Agricultural Science, 7(1), 43.

Taylor, R.G., Scanlon B., Döll P., Rodell M., van Beek R., Wada Y., Longuevergne L., Leblanc M., Famiglietti J.S., Edmunds M., Konikow L., Green T.R., Chen J., Taniguchi M., Bierkens M.F.P., MacDonald A., Fan Y., Maxwell R.M., Yechieli Y., Gurdak J.J., Allen D.M., Shamsudduha M., Hiscock K., Yeh P.J.-F., Holman I. and Treidel H. (2012) Ground water and climate change, Nature Climate Change, 3(1).

Xiong W., Holman I., Lin E., Conway D., Jiang J., Xu Y. and Li Y., (2010), "Climate change, water availability and future cereal production in China", Agriculture, Ecosystems & Environment, Vol.135, Issues 1-2.

Zhang, X. and Cai X. (2013) Climate Change Impacts on Global Agricultural Water Deficit, Geophysical Research Letters, Vol. 40, Issue 6, pp. 1111-1117.