RESEARCH ARTICLE **(Open Access)**

Using integrated assessment analysis for evaluating the climate change impact on crop management options: A case study in the Korça region, Albania

ALMA AHMETI[1], SPIRO GRAZHDANI[1], ADRIANA ZYFI [1]

[1]Department of Physics and Applied Sciences, Faculty of Forestry Sciences, Agricultural University of Tirana, Albania

*Corresponding author; E-mail: aahmeti@yahoo.com

Abstract

The impact of production risks and risk aversion on crop choices is a major research question in agricultural economics. Portfolio optimization is an adequate tool to find optimal crop management options in adapting to climate change. The risk farmers have to face can be caused by different sources. In our study, we focus on the risk arising from unknown weather conditions. Therefore, we developed stochastic climate change scenarios for the Korça region. The climate change scenarios have been statistically tested to assure physical and spatio-temporal consistencies. Two portfolio models have been applied in the time periods 2008-2020, 2021-2030 and 2031-2040: a traditional non-linear mean-variance (E-V) model and a model using the Conditional Value at Risk (CVaR) as risk metric. Investigated crops are corn, winter wheat, sunflower and spring barley with different crop management alternatives. Minimum tillage appears in all portfolios. We found a decreasing share of winter wheat that gets partially substituted by sunflower over the time periods. When including environmental constraints (soil organic carbon content, nitrate leaching) the reverse effect on the resulting portfolio shares is observed with corn being included. The E-V model reveals more diversification with respect to the crops, whereas the CVaR model shows more diversification with respect to crop management options. Another result is that minimum tillage always appears in the optimal portfolios, however, with different management alternatives with respect to straw harvesting and fertilization. In contrast, irrigation is not part of the optimal portfolio, as the increasing revenues through higher crop yields cannot compensate the higher production costs. However, the optimal portfolio results strongly depend on the assumptions made with respect to irrigation management (i.e. fixed irrigation amounts are taken into account) and the calculation of production costs (e.g. level of water price in case of irrigation). This study, therefore contributes to the literature in applying a portfolio optimization approach (CVaR) to analyze the impact of climate change on crop production risks and consequently on the choices of crops and crop management.

Keywords: climate change; conditional value at risk; mean-variance (E-V) model; meteorological consistency; portfolio optimization model; risk management.

1. Introduction

Knowing the advantages and disadvantages of the statistical climate change scenarios, for estimation of the biophysical and economic impact analyses of climate change on crop production, in this study is applied the biophysical process model EPIC (Environmental Policy Integrated Climate) (Williams, 1995; Izaurralde et al., 2006). Biophysical process simulation models are well suited for this task, because all anticipated combinations and variations of input data (i.e. climate, soil, topography, and crop management) can be simulated to depict the potential impact spectrum on crop production and environment, on which also economic impact analyses are often built (i.e. economic optimization models). EPIC is able to simulate important natural processes in agricultural land management such as photosynthesis, evapotranspiration, runoff, erosion, mineralization, nitrification and respiration. In addition, EPIC is also able to provide biophysical data for several economic impact analyses. Economic optimization models are well suited to help finding optimal land use and crop management options as well as investment strategies in the context of production risks and uncertainties due to changing climatic conditions. The integration of biophysical data in economic optimization models allows a better representation of the biophysical heterogeneity and interrelationships in spatial and temporal contexts. In the course of this study, optimal crop management portfolios under climate change have been detected for the Korça region in southeastern Albania. In addition, the biophysical and economic potentials of large scale poplar plantations for bioenergy production have been analyzed on Albanian croplands. This case study analyses should exemplify the capability of an integrated modeling framework for climate change impact analyses in agriculture as well as for developing cost-effective adaptation strategies (i.e. management and investment) to better cope with the adverse effects of climate change. In this paper is illustrated that using integrated assessment and farming systems analysis gives a broader and more nuanced picture of climate change impacts, with a case study for Korça, Albania. The aim of our study is to identify crop management portfolios for the Korça region by taking into account the uncertainties coming from future stochastic climate change scenarios as done in Barkley and Peterson (2008). We consider two model types in this study, the traditional non-linear E-V model (Freund, 1956) and the model of the Conditional Value at Risk (Rockafellar and Uryasev, 2000). Whereas Larsen et al. (2009), using a CVaR portfolio model, are interested in a geographical diversification, we focus on crop management diversification. Both models optimize the portfolio using profit distributions as an input and maximizing/minimizing an objective function. In the E-V model risk aversion is introduced by a risk aversion parameter discounting standard deviation in the objective function, whereas in the CVaR model the risk aversion is represented by different confidence levels of the profit distributions. Agricultural production is a dynamic process affected by different sources of uncertainty, among the most essential being weather, technology advancement, individual farming practices, and price fluctuations in commodity markets. Assessing optimal crop management is one instrument to develop adaptation strategies to climate change in agricultural production. Portfolio optimization, developed by Markowitz (1952) is one of the methodologies to identify optimal agricultural management options under risk. He shows that as the allowed variance increases, the maximal expected return also increases and all the optimal portfolios chosen from the efficient frontier depend on the investor's risk aversion level. Alternatively, Rockafellar and Uryasev (2000) implemented a new risk measure, namely the Conditional Value at Risk (CVaR) in their portfolio analysis. In contrast to the variance of the returns used by Markowitz (1952), which describes the spread of a distribution, the CVaR focuses on the tails of a distribution. The source of risk comes from the developed stochastic climate change scenarios. Inputs to the portfolio models are computed profit distributions which differ among crops, crop managements and climate change scenarios. The standard diversification effect can be shown such that the more risk averse a farmer, the more diversification occurs. The impact of risk aversion on crop choice is therefore still a major research question in development and agricultural economics. Further applications of portfolio theory to risky decisions in agriculture can be found in e.g. Barkley and Peterson (2008) and Larsen et al. (2009). In this paper, is argued that integrated assessment (Rotmans and van Asselt, 1998;van Ittersum et al., 2008) and farming systems analysis (Janssen and van Ittersum, 2007) are needed for climate change impact assessments in agriculture. Integrated assessment provides added value compared to disciplinary research, as it allows to better understand the complexity of the system (Rotmans and van Asselt, 1998). Climate change impact assessments in agriculture are usually based on crop simulation models, as the crop level is the basic level at which climate directly affects agriculture (Rötter et al., 2011;Challinor et al., 2014;Rosenzweig et al., 2014). Additionally, statistical models are used to assess impacts on crop yields and farmers' income, implicitly including adaptation (Mendelsohn, 2007;Antle and Capalbo, 2010;Lobell and Burke, 2010). Recently, much effort has been going into the improvement of crop and economic models and their coupling (Rosenzweig et al., 2013; Nelson et al., 2014). Modeling impacts of climate change on crop production for the next three decades requires climate change scenario data with a high degree of meteorological consistency and spatial and temporal resolution.

2. Material and Methods

Our model framework consists of three main models: the weather and climate change model, the biophysical process model EPIC (Environmental Policy Integrated Climate)(Williams, 1995; Izaurralde et al., 2006) and the portfolio optimization models. Historical weather time series from 1975-2007 from a weather station in the Korça region feed into the weather model. Based on the method of Strauss et al. (2009), we have developed stochastic climate scenarios for the period 2008-2040. Residuals from maximum and minimum temperature have been reallocated randomly together with the observed values of the weather parameters precipitation, solar radiation, relative humidity and wind. The climate scenarios are among other site specific data important input to the EPIC model. Typical crop management variants for the region are conventional, reduced or minimum tillage operations, with or without irrigation, with or without straw removal, and different fertilizer application rates. The crops investigated are corn, winter wheat, sunflower, and spring barley. EPIC simulates output among others for crop yields, nitrate leaching and topsoil organic carbon contents for different weather scenarios, site conditions, and crop management variants. We use the simulated crop yields together with data on variable costs and mean commodity prices from 1995-2008 to calculate profit distributions:

$$\pi_{m,i} = y_{m,i} p_m - c_m \qquad (1)$$

where π are the profits in €/ha, y are the simulated crop yields in t/ha, p is the price in €/t, and c are the variable costs in €/ha for each time period (2008-2020, 2021-2030, 2031-2040), the index m denotes the sites, crops and crop management variants and $i$is the weather scenario index.

The various profit distributions are input to the portfolio models (also distributions on nitrate leaching and topsoil organic carbon contents when considering environmental constraints). The output of our portfolio optimizations are optimal shares of crops and crop management variants in three time periods. Before we present the portfolio models we provide the definition of CVaR (Rockafellar and Uryasev, 2000). The Value at Risk (VaR) captures extreme events providing information on the tail of a distribution. The VaR of a portfolio is then the lowest amount α such that – with specified probability level β – the portfolio loss will not exceed α. The CVaR is the conditional expectation of losses above that amount α. So, the VaR corresponds to the β-percentile of the distribution, whereas CVaR is the mean of the values exceeding VaR. We consider two types of objective functions using different risk measures. One maximizes the expected profits with a penalization of standard deviation as described in the E-V model (Freund, 1956). The other one minimizes the expected value of losses exceeding a defined percentile as described in the CVaR model of Rockafellar and Uryasev (2000). In the E-V model, a weighted sum of expected profits discounted by the standard deviation is maximized (Freund,1956):

$$\text{Max} \sum_{m,i} x_m E(\pi_{m,i}) - \lambda\left[\frac{1}{N}\sum_{m,i}(\pi_{m,i} - E(\pi_{m,i}))^2\right]^{1/2} \qquad (2)$$

where E denotes the expected value across weather scenarios, N is the number of weather scenarios, x is the portfolio variable giving the specification of crop, management, and fertilizer rates, and λ is the risk aversion parameter (π, m and $i$as in eq. 1). We maximize independently for the three time periods. The conditions to be satisfied are that the portfolio shares have to sum up to1. The CVaR model is linear where CVaR is minimized subject to a constraint on minimum expected profits (Rockafellar and Uryasev, 2000):

$$\text{Min}\left(a + \frac{1}{N(1-\beta)}\sum_{m,i} u_{m,i}\right) \qquad (3)$$

were $u_{m,i} \geq 0$ and $u_{m,i} \geq -(y_{m,i} p_m - c_m)x_m - a \,\forall i$

$$\frac{1}{N}\sum_{m,i}(y_{m,i} - c_m)x_m \geq R$$

where $u_{m,i} = [u_1, u_2, \ldots, u_N]T \in R$ is an auxiliary variable, α is a threshold (with probability β profits will not fall short of α), and β is the confidence level. Also, the portfolio shares have to sum up to 1, all $x_m$and $u_{m,i}$ must be greater than or equal to zero and a constraint on minimum expected profits, R, has to be fulfilled. In the experiments, we employ values for this required expected profit R such that it is not binding. The CVaR and E-V approaches could, in the case where profit distributions are non-normal, lead to quite different optimal solutions (Rockafellar and Uryasev, 2000). The choice of the risk measure depends on how we assume the farmers to behave under risk. Since we were interested in the portfolios of crops and crop management variants with respect to increasing degrees of risk aversion, we conducted the following experiments. In the E-V model, we gradually increased the risk aversion parameter from zero (risk-neutral) to 2.5. In the CVaR model, we solved the problem for two values of confidence levels: in the case where β =75%, a farmer would be assumed to be relatively indifferent to tail risk. Along the same lines, requiring a 99% level of confidence can be interpreted as a situation of relatively high loss-aversion. Finally, we included in both models environmental constraints on nitrate leaching and topsoil organic carbon (optional), whereby the thresholds are less than 2 kg/ha for nitrate leaching and more than 55 t/ha for topsoil organic carbon. However, we have not conducted extensive sensitivity analysis to examine the impact of less and more stringent environmental requirements yet.

3. Results and Discussion

The simulated crop yields decrease over time. Crops usually grow at or near their thermal optimum, so even a minor temperature increase during the growing season can reduce crop yields. Furthermore, the Korça is known as a region with low annual precipitation sums, which also affect crop yields. The evaporation of soils increases so that less soil water is available for the plants. The profits drop significantly in all crop and management cases (Table 1). In line with portfolio optimization, the farmer has to accept a lower level of expected profits for lower levels of risk (Table 1). That is, increasing risk aversion should have a negative impact on the expected portfolio profit. When considering environmental constraints, the expected profits turn out to be a bit lower than without these constraints (Table 1), and the values of expected profits are very similar over the risk measures in each time period. Furthermore, risk aversion loses its impact on expected profits until 2040. Under environmental constraints, the expected profits are even completely independent from risk aversion level, because variability within profits does not differ much.

Table 1. Expected profits in €/ha in three time periods and different levels of risk aversion (CVaR 75: 75% confidence level, CVaR 99: 99% confidence level, RN: risk-neutral λ=0, RA: risk-averse λ=2.5 in the E-V model)

Without environmental constraints	CVaR 75	CVaR 99	RN	RA
2008-2020	227.6	220.4	229.6	219.4
2021-2030	200.0	197.4	203.8	198.2
2031-2040	192.1	190.3	192.4	190.7
With environmental constraints				
2008-2020	210.3	203.4	210.3	204.1
2021-2030	193.8	191.2	193.8	191.2
2031-2040	186.8	186.8	186.8	186.8

In the figure 1 we show portfolio shares for each time period (2008-2020, 2021-2030, 2031-2040) for both the E-V model and the CVaR model. RA (risk-averse; λ=2.5) and RN (risk-neutral; λ=0) are the output shares of the E-V model, while CVaR 75 (75% confidence level) and CVaR 99 (99% confidence level) are the output shares of the CVaR model.

The six-digit coding of management options in figure are: 'M' for minimum tillage, 'R' for reduced tillage, 'N/I' for no irrigation/irrigation, 'N/S' for without straw removal or with straw removal, '080/100/120' for fertilizer application rates of 80%/100%/120% of the recommended amounts. Straw is removed from the fields only for winter wheat and spring barley, even at the level of crop rotation corn/winter wheat/sunflower/spring barley. The model results show that portfolios with minimum tillage are optimal with different crop management alternatives. Spring barley is never part of the optimal portfolio, and corn enters the portfolio only when considering the environmental constraints. Irrigation does not seem to become an interesting option under climate change, as the marginal higher crop yields cannot compensate the higher production costs. The standard diversification effect is observable: the more risk- averse a farmer, the more diversification occurs. Without consideration of environmental constraints (Figure 1), the relative share of winter wheat declines over the time periods, while the share of sunflower increases in most cases. We found some deviations between the results of the two models, which points to the fact that profits are not normally distributed. For example, the CVaR model produces the same pattern as the other model only when the confidence level is very low. For cases with higher loss aversion, there is diversification within winter wheat management variants and the share of winter wheat rises in the second period. So, if a farmer is loss averse then his portfolio contains only one crop, but he diversifies more over management options.

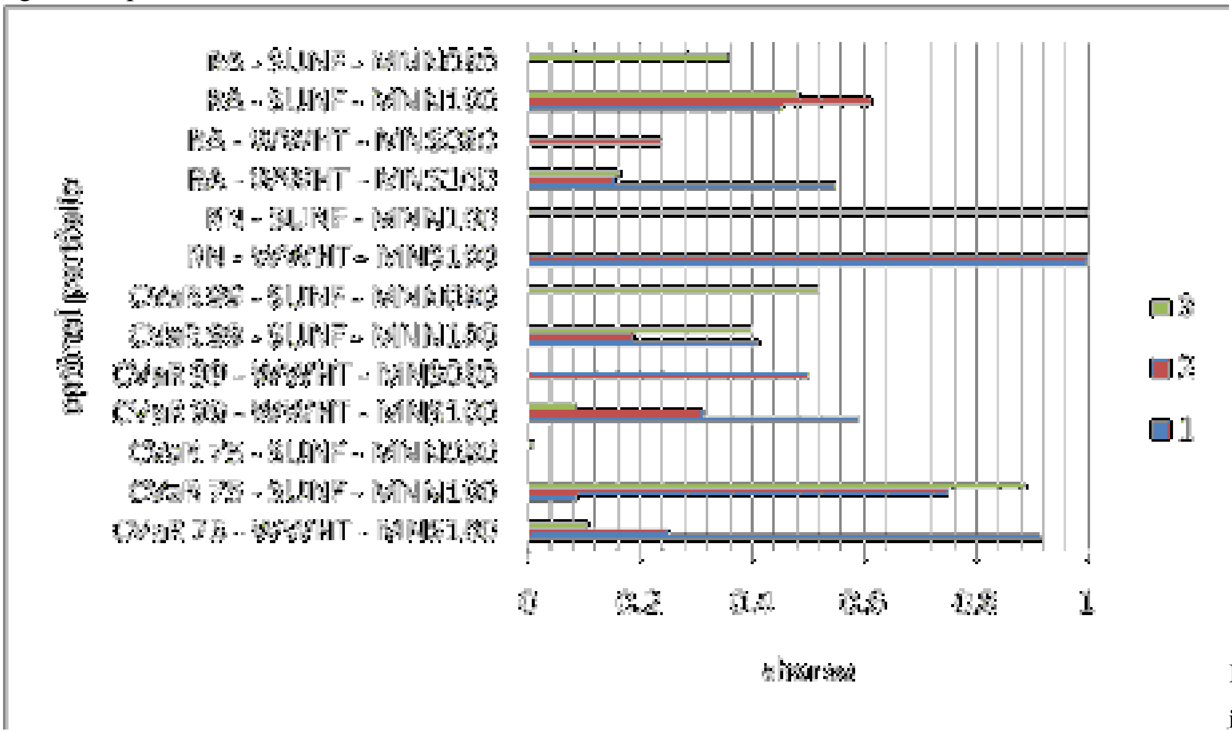

Figure 1: Portfolio shares in each time period (period 1 to 3) and for each portfolio model. Note: RA (risk-averse), RN (risk-neutral) concerns the E-V model, CVaR75 (75% confidence level), CVaR 99 (99% confidence level) of CVaR model; WWHT=winter wheat, SUNF=sunflower; 6-digit coding: 'M' for minimum tillage, 'R' for reduced tillage, 'N/I' for no irrigation/irrigation, 'N/S' for without straw removal or with straw removal, '080/100/120' for fertilizer application rates of 80%/100%/120% of the recommended amounts

The portfolio shares change when including environmental constraints in the portfolio optimization (not shown). Minimum tillage is still chosen in both models. But, the CVaR model with 99% confidence level shows a high share of winter wheat, and a very low share of corn only in the first period and some management diversification for sunflower, where the reduced tillage comes into solution with a very low amount. In the E-V model, high level of risk aversion leads also to similar results.

4. Conclusions

We have analyzed the impact of climate change on crop production risks. The source of risk comes from stochastic climate change scenarios. We have applied two portfolio models - a non-linear E-V model and a CVaR model - using profit distributions which differ among crops, crop managements and weather scenarios. The effects of climate change lead to a decline in expected profits due to lower crop yields. The results show that the relative share of winter wheat is Integrative Assessment of Crop Management Portfolios substituted by sunflower over the three time periods. The optimal portfolios differ when considering environmental constraints. Particularly, the share of winter wheat remains the most important in all three periods, whereas the share of sunflower is relatively low and corn is being included in the portfolio. In the optimal portfolios, minimum tillage always appears with different production alternatives concerning straw management, irrigation and fertilizer application rates. Another important finding is about the risk modeling approaches: the E-V model diversifies more across crops whereas the CVaR model diversifies more across crop management options. Therefore, research should be focused on comparing these different model approaches and their consequences for optimal portfolios. Finally, with increasing temperatures, expected portfolio profits are found to decrease due to more evaporation and therefore less available soil water. This effect is independent of the type of risk metric used in the objective function. The results indicate that climate change will have a negative impact on agricultural productivity, which dominates outcomes and the scope to hedge against risks emanating from uncertain weather condition shrinks.

5. References

1. Antle, J.M. and Capalbo, S.M. (2010) Adaptation of agricultural and food systems to climate change: an economic and policy perspective. Appl. Econ. Perspect. Policy 32:386–416.
2. Barkley, A. and Petersen, H.H. (2008): Wheat Variety Selection: An Application of Portfolio Theory to Improve Returns, Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management, St. Louis, MO.
3. Challinor, A.J., Watson, J., Lobell, D.B., Howden, S.M., Smith, D.R. and Chhetri, N. (2014).A meta-analysis of crop yield under climate change and adaptation. Nat. Clim. Change 4:287–91.
4. Freund, R. (1956): The Introduction of Risk into a Programming Model. *Econometrica* 21: 253-263.
5. Izaurralde, R.C., Williams, J., R., McGill, W.B., Rosenberg, N.J. and Quiroga, M.C. (2006): Simulating soil C dynamics with EPIC: Model description and testing against long-term data. Ecological Modelling 192(3-4): 362-384.
6. Janssen, S. and van Ittersum, M.K. (2007). Assessing farm innovations and responses to policies: a review of bio-economic farm models. Agric. Syst. 94:622–36.
7. Larsen,R.,Vedenov,D.andLeatham,D.(2009):Enterprise-levelriskassessmentof geographically diversified commercial farms: a copula approach, Southern AgriculturalEconomicsAssociationAnnualMeeting,Atlanta,Georgia.
8. Lobell, D.B. and Burke M.B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agric.* Forest Meteorol. 150:1443–52.
9. Markowitz, H. (1952): The Utility of Wealth, Journal of Political Economy, Vol. 60, S 151-158.
10. Mendelsohn, R. (2007). Measuring climate impacts with cross-sectional analysis. Clim. Change **81**:1–7.
11. Nelson, G.C. et al. (2014). Climate change effects on agriculture: economic responses to biophysical shocks. Proc. Natl Acad. Sci. *USA* 111:3274–9.
12. Rockafellar, R.T. and Uryasev, S. (2000): Optimization of Conditional Value-At- Risk. The Journal of Risk 2: S 21-41.
13. Rosenzweig C. et al. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proc. Natl Acad. Sci. *USA* 111:3268–73.
14. Rosenzweig, C. et al. (2013). The agricultural model intercomparison and improvement project (AgMIP): protocols and pilot studies. Agric. Forest Meteorol. 170:166–82.
15. Rotmans J. and van Asselt, M. (1998). Integrated assessment: a growing child on its way to maturity. Clim. Change 34:327–36.
16. Rötter, R.P., Carter, T.R., Olesen, J.E., Porter, J.R. (2011). Crop-climate models need an overhaul. Nat. Clim. Change 1:175–7.
17. Strauss, F., Schmid, E., Formayer, H., Moltchanova, E. and Wang, X. (2009): Climate Change and Likely near Future Development of Ecological Indicators in the Korça Region of Lower Austria, submitted.
18. vanIttersum M.K. et al. (2008). Integrated assessment of agricultural systems—a component-based framework for the European Union (SEAMLESS). Agric. Syst. 96:150–65.
19. Williams, J.R. (1995): The EPIC Model, In: Singh, V.P. (eds.), Computer Models of Watershed Hydrology, Water Resources Publications, Highlands Ranch, Colorado, S 909-1000.