# Assessing the impact of drought scenarios on crop production and water demand in Austria

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***Abstract* - We employ an integrated modelling framework consisting of the bio-physical process model EPIC (Environmental Policy Integrated Climate model) and a portfolio optimization model to quantify drought scenario impacts on crop production until 2040 and consequences of drought management on water resources in Austria. EPIC is applied to simulate drought impacts on crop yields and water balances at 1 km pixel resolution. The portfolio optimization model is applied to optimize crop management choices at homogenous response units within groundwater catchment areas in Austria. Results indicate that an increase in droughts will likely decrease average crop yields and gross margins and increase the pressure on ground water resources in the semi-arid regions in eastern Austria whereas the humid, mountainous regions are likely to benefit from higher mean temperatures and $CO_2$ fertilization.**

## INTRODUCTION

Droughts have been identified to be a major driver of global food insecurity (IPCC, 2014) and interannual yield variability in Central Europe (Hlavinka et al., 2009). For instance, the European drought and heat wave in 2003 affected a third of the EU territory causing an economic damage of around € 9 billion (European Commission, 2007). In 2013, Central Europe was hit by a severe summer drought and heat wave with negative impacts on late-harvested crops. In Austria, corn yields were 19% below the previous year's production and 18% below the ten years average as reported by Statistics Austria.

Due to climate change, drought conditions are expected to become even more important in the future leading to significant crop production losses (IPCC, 2014). To overcome such challenges, drought information systems have been developed at various scales with different spatial and temporal resolutions. For instance, the Global Agricultural Drought Monitoring and Forecasting System (GADMFS; http://gis.csiss.gmu.edu/GADMFS/; Deng et al., 2013) provides world-wide drought conditions and forecasts at ~1 km spatial resolution as well as daily and weekly temporal resolutions. The European Drought Observatory (EDO; http://edo.jrc.ec.europa.eu/) offers maps for drought-relevant indicators such as standard precipitation index, daily soil moisture, vegetation productivity, and vegetation water content. Some selected results feed into the GADMFS (Horion et al., 2012). A drought monitoring and forecasting system is currently being developed for Austrian agriculture.

Our analysis extends this on-going research by introducing a bio-physical and economic evaluation of drought scenarios focusing on two aspects: First, we investigate potential impacts of long-term drought scenarios on both rain-fed and irrigated agriculture at 1 km pixel resolution in Austria, expressed as expected changes in total agricultural production. Second, we identify optimal crop production portfolios for different levels of risk aversion to effectively manage drought risks by accounting for regional characteristics and opportunity costs. We further assess the increase in irrigated cropland under drought conditions and the resulting pressure on groundwater aquifers.

## INTEGRATED MODELLING FRAMEWORK

We apply the bio-physical process model EPIC (Williams, 1995) to simulate mean annual dry matter crop yields by considering the hydrological cycle, i.e. precipitation, evapotranspiration, percolation, surface and sub-surface runoff, as well as the $CO_2$ fertilization effect, on cropland at 1 km pixel resolution. The simulations are performed for major field crops under alternative crop management practices, including different crop rotation systems, fertilization and irrigation intensities as well as for three drought scenarios of the period 2010-2040. Farm-level autonomous adaptation is considered by adjusting sowing, plant protection, fertilizer input, and harvesting dates to projected changes in the growing season. For the simulations, we assume sufficient irrigation water supply across Austria. The drought scenarios are derived by combining a dry day index with block-bootstrapping from historically observed daily weather data of the period 1975-2007 (Strauss et al., 2013). In the reference scenario (S1), the distribution of the dry day index nearly resembles historically observed values. The other two drought scenarios (S2, S3) project an increase in dry days such that the probability that more than 60% of the total Austrian territory does not experience precipitation events increases from 0.38 in S1 to 0.50 and 0.59 in S2 and S3, respectively (Strauss et al., 2013). For each scenario, 30 realisations are provided for the period 2010-2040.

Annual gross margins for crops are computed by drought scenario, cropland pixel, and crop management practice. Variable production costs (including costs of seeds, pesticides, fertilizers, fuel, irrigation

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water, electricity, repair, insurances, and labor) and commodity prices are based on reported levels from the past and are kept constant for all drought scenarios in order to disentangle the impact of climate change from price or market effects. Additionally, we consider annualized capital costs for irrigation equipment and analyse when such an investment is profitable according to certain drought conditions.

EPIC outputs and the crop gross margin calculations serve as input into a non-linear mean-standard deviation model (similar to E-V model; Markowitz, 1987) which optimizes crop production portfolios depending on the farmers' level of risk aversion. The model maximizes a weighted sum of expected gross margins discounted by the standard deviation using a risk aversion parameter (Freund, 1956; Strauss et al., 2011). It is separately solved for the three drought scenarios, homogenous response units within groundwater catchment areas as defined by the Austrian Hydrographic Office, and four risk aversion levels. The model results allow us to quantify the increase in irrigation water demand. By comparing the water demand to the rate of regeneration of groundwater resources, we are able to identify regions where groundwater limitations could constrain irrigation activities and drinking water supply.

## Results and discussion

At national level, simulated average crop yields with high fertilization intensity decrease slightly under S2 (-1.6%) and S3 (-6.5%), compared to S1. However, the results differ between crops, crop management practices, and regions (e.g. due to differences in soil types, and topographic and climatic conditions). For instance, changes in average crop yields for S2 and S3 (using S1 as a reference) reveal that the semi-arid eastern parts of Austria are likely to suffer severely from droughts. By contrast, if soil water availability is not limiting, crop yields are increasing due to higher mean temperatures and $CO_2$ fertilization, i.e. in the mountainous regions. Table 1 presents differences in average yield changes between selected field crops ranging from -2% for soybean under S2 to -20% for winter rapeseed under S3.

**Table 1.** Changes in crop yields under S2 and S3 compared to S1 in % for high fertilization intensity.

| Scenario | Corn | Soybean | Rapeseed | Wheat |
|---|---|---|---|---|
| S2 | -5 | -2 | -9 | -2 |
| S3 | -14 | -7 | -20 | -10 |

If we allow for climate change adaptation, i.e. irrigation, crop yields are simulated to increase by 3% in S2 and 5% in S3, compared to S1. Additionally, irrigation water demand increases considerably particularly in eastern Austria with annual rates above 150 mm under S3 (see Fig. 1).

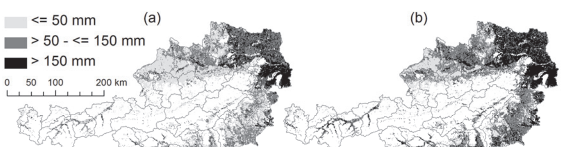


*Figure 1. Irrigation water demand under drought scenarios S2 (a) and S3 (b).*

## Conclusions

Droughts may increase production risks for farmers in Austria and beyond. Our integrated assessment reveals regional and crop-specific vulnerabilities in agricultural production and identifies crop management practices that are particularly useful to cope with droughts in the next decades. Irrigation appears as potentially useful though investment in infrastructure and governance structures would be required. The results allow us to identify spatially explicit adaptation requirements and to derive drought policy recommendations. In particular, water resource policies may be informed in order to avoid freshwater limitations and decreasing groundwater levels in heavily irrigated regions.

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