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Recent changes in the climatic yield potential of various crops in Europe

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Recent changes in the simulated potential crop yield and biomass production caused by changes in the temperature and global radiation patterns are examined, using the Crop Growth Monitoring System. The investigated crops are winter wheat, spring barley, maize, winter rapeseed, potato, sugar beet, pulses and sunflower. The period considered is 1976–2005. The research was executed at NUTS2 level. Maize and sugar beet were the crops least affected by changing temperature and global radiation patterns. For the other crops the simulated potential yield remained stable in the majority of regions, while decreasing trends in simulated potential yields prevailed in the remaining regions. The changes appear in a geographical pattern. In Italy and southern central Europe, temperature and radiation change effects are more severe than elsewhere, in these areas potential crop yields of more than three crops significantly decreased. In the UK and some regions in northern Europe the yield potential of various crops increased.

In a next step the national yield statistics were analyzed. For a large majority of the countries the yield increases of wheat, barley and to a lesser extent rapeseed are leveling off. Several explanations could be given, however, as the simulated yield potential for these crops decreased in various regions, the changing temperature and radiation patterns may also contribute to the diminishing yield increases or to the stagnation. In more than 50% of the investigated countries the maize, potato and sugar beet yields continue to increase. This can be attributed to improving production techniques, new crop varieties, sometimes in combination with an improving climatic potential. In some regions in northern Europe, yields continue to increase.

1. Introduction

As argued in the Fourth Assessment Report of the UN International Panel on Climate Change (IPCC) published in 2007 (Bernstein et al., 2007; Solomon et al., 2007) the global climate is changing and will continue to change in the near future. Increasing surface temperatures, sea water levels and changes in the intensity and precipitation amounts are to be expected. These changes may accelerate the hydrological cycle resulting in changes in evapotranspiration, run-off, and in the intensity and frequency of floods and droughts (Watson et al., 1996). Both changes in rainfall and temperature affect crop growth and development. For example, Estrella et al. (2007) describe a shortening of the growing season for various agricultural and horticultural crops in Germany. Williams and Abberton (2004) reported earlier flowering of white clover in the UK. Guereña et al. (2001) showed that higher air temperatures during winter and early spring accelerated crop development in Spain.

The changing weather patterns also affect crop production and the climate change impact on food security is widely debated and investigated (Miraglia et al., 2009). For example, Ludwig et al. (2009) investigated the impacts of the climate change on the wheat production in western Australia. Pathak et al. (2003) researched the decline/stagnation of the rice and wheat yields in the Indo-Gangetic Plains. Peltonen-Sainio et al. (2009) investigated cereal yield trends in Finland. Richards (2002) discussed the environmental challenges in Australian agriculture. Olesen and Bindi (2002) elaborate on the consequences of climate change for European agricultural productivity.

Weather pattern changes are not evenly distributed in time and space. Various studies have indicated that the global warming has a pronounced seasonal dependence and a diurnal asymmetry (Weber et al., 1997). Vogelsang and Franses (2005) reported that winters in various northern European countries warmed up whereas the summer temperatures remained stable. Makowski et al. (2008) demonstrated that the trend in the diurnal

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temperature range has reversed from a decrease to an increase in the 1970s in western Europe and during the 1980s in eastern Europe.

Land use, soil type and soil properties show large variations over Europe (Bouma et al., 1998; Rabbinge and van Diepen, 2000) and since crops respond nonlinearly to changes in their growing conditions, responses to climatic change are expected to show large seasonal and spatial variations (Parry, 2000), depending on the region, the season and the crop type. On the other hand as a result of improved or new plant protection techniques, increased fertilizer application and new varieties (e.g. Hough, 1990; Vossen, 1992; Falisse, 1992) crop yields have increased over the past decades. As many studies on the effects of the increasing atmospheric CO_2 concentration on crop yield suggest, also the augmented CO_2 levels may have contributed to the yield increase (e.g. Amthor, 2001; Miglietta et al., 1998; Cure and Acock, 1986). However, in recent years reduced rates of yield improvement in various crops have been observed. For example, Peltonen-Sainio et al. (2007) mention a worldwide decline of the cereal yield improvement rates and according to Berry and Spink (2006) oilseed rape yields have not increased in several countries, including the UK, since the mid 1980s. One explanation could be that the potential yield has been reached as a result of technical improvements such as for example better crop protection means, higher fertilizer applications doses etc. On the other hand, it might be that the potential yield itself diminished as a result of changing weather in the past years.

In previous research (Supit et al., 2010) we investigated seasonal trends in global radiation and mean temperatures. We found that the mean temperature increased in large areas in western Europe in spring. In large areas in eastern Europe, north western Europe and Italy the mean temperatures increased in summer. The global radiation showed a seasonal and spatial variation. In central and eastern Europe, in winter the global radiation increased in various regions, downward trends were noticed in the UK and southern Russia and Ukraine.

In this study we investigate changes in the simulated yield potential and the biomass production per unit area for the major European crops, caused by changes in the temperature and global radiation patterns over the period 1975–2005. We analyzed whether these changes could explain the declining yield improvement or yield stagnation of various crops in Europe. The potential yield is determined by radiation, temperature, cultivar characteristics and is not limited by biotic or abiotic factors; while attainable yield is limited by water or nutrient supply (van Ittersum and Rabbinge, 1997).

We used the Crop Growth Monitoring System (CGMS) as applied by the Joint Research Centre (JRC) of the European Commission (EC). Several previous studies have shown that crop simulation models can be applied to analyze impact of soil, climate, water availability on plant growth and crop production Ewert et al. (2005), Parry et al. (2004), Easterling et al., (2001) and Brown and Rosenberg (1997). CGMS has been developed to monitor the year to year effects of weather on crop development and yield formation across Europe. It contains a near pan-European weather data base and a crop simulation model and thereby constitutes a unique and independent tool to assess climate change effects over the past 30 years.

The study region covers a large part of the pan European area including 24 EU countries. The spatial distribution of available meteorological stations for the Scandinavian countries was deemed not to be dense enough and therefore these countries were excluded from the analysis. Due to incomplete data series the following countries were excluded: Switzerland, Belorussia, northern parts of Russia, Moldova, part of west Balkan and Turkey. The crops covered by CGMS Europe are: winter wheat, spring barley, grain maize, winter rapeseed, sunflower, potato, sugar beet and field beans.

2. Data

Historical climate data are provided by the Monitoring Agricultural Resources (MARS) Unit of the Institute for the Protection and Security of the Citizen (IPSC) of the JRC of the EC at Ispra, Italy. These data consist of daily values of maximum and minimum temperature, wind speed, global radiation and vapor pressure, rainfall, interpolated from station data to a 50×50 km climatic grid (Beek et al., 1992; van der Voet et al., 1993). These station data have been collected from the Global Telecommunication System (GTS) of the World Meteorological Organization as well as from national and sub national station networks. Presently, data from nearly 7000 stations is available. Of these stations about 2500 receive daily meteorological information. Missing global radiation values are computed automatically from data from the GTS: sunshine duration, a combination of cloudiness and the temperature range or only the temperature range. Other missing data are replaced by long term average values. From 1976 a more or less complete European coverage is available.

In CGMS the administrative regions of the European Union, the so called NUTS regions are used (http://ec.europa.eu/eurostat/ramon/nuts/codelist_en.cfm?list=nuts). Four NUTS levels can be distinguished, however in CGMS only three are used: the national level (NUTS0), the regional level (NUTS1) and the sub-regional level (NUTS2). The IPSC also provided historical data on the planted areas on NUTS2 level. Information on actual crop yields and additional information on planted areas was retrieved from the Eurostat database (http://epp.eurostat.ec.europa.eu/).

Boons-Prins et al. (1993) constructed the initial crop files that describe the specific growth potentials of individual crops based on field trials executed in Belgium, United Kingdom and the Netherlands. In the framework of the MARS project these crop files were extended based on the research of Russell and Wilson (1994), Carbonneau et al. (1992), Falisse (1992), Narciso et al. (1992), Bignon (1990), Falisse and Decelle (1990), Hough (1990) and Russell (1990). Since new crop varieties are constantly introduced, crop parameters that describe crop growth and development are regularly updated and calibrated (e.g. Gisat, 2003; Willekens et al., 1998). Region specific crop files have been constructed. For all crops the average planting date of the regional crop varieties have been collected and for some crops that may not reach maturity (i.e. sugar beet, potato, and maize) the end of season as well. Region and specific sowing dates are not available. For each crop-region combination a fixed sowing date and a fixed crop parameter set are assumed during the entire 30 year period.

Detailed crop maps on the exact cultivated locations are not available. Therefore, the soil map is used to construct a proxy land use map, by assuming that in all regions where a given crop is grown this crop is cultivated on all suitable soils. In fact, CGMS considers a potential cropping pattern. In addition, each crop is assigned to one of the following groups: grasses, cereals and root crops, of which the root crops are the most demanding in terms of soil quality. The requirements per crop group with respect to soil related characteristics such as rootable soil depth, agricultural limiting phase, drainage, presence of stones, texture, alkalinity and salinity is accounted for and differ per crop group. Missing weather data and missing planted area values for NUTS2 level (used in the aggregation procedure) are replaced with long term average values.