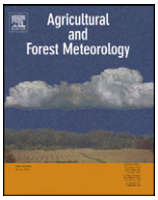
Agricultural and Forest Meteorology 150 (2010) 1258–1271

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet



Impact of climate change on agricultural productivity under rainfed conditions in Cameroon—A method to improve attainable crop yields by planting date adaptations

Patrick Laux[a,*], Greta Jäckel[a], Richard Munang Tingem[b], Harald Kunstmann[a]

[a] Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT), Kreuzeckbahnstr. 19, 82467 Garmisch-Partenkirchen, Germany
[b] Climate Change Adaptation Unit, Division of Environmental Policy Implementation (DEPI), United Nations Environment Programme (UNEP), Nairobi, Kenya

ARTICLE INFO

Article history:
Received 25 September 2009
Received in revised form 3 May 2010
Accepted 18 May 2010

Keywords:
Crop modelling
CropSyst
Monte Carlo approach
Onset of the rainy season
Planting date
Climate change
Attainable crop yield

ABSTRACT

Rainfed farming systems in sub-Saharan Africa are suffering from low productivity. Prolonged dry spells and droughts often lead to significant crop losses, a situation that is expected to be exacerbated by climate change. In this study, the impact of climate change on attainable yields of maize and groundnut, as major alimentary crops in sub-Saharan Africa, is evaluated at five stations in Cameroon under rainfed conditions. It is focussed on the contribution of future climate change in terms of the direct fertilisation effect of the expected CO_2 alteration and the indirect effects of the expected temperature and precipitation change. As improved agricultural management practices in rainfed systems are crucial to increase agricultural productivity, the impact of the planting date is analysed in detail. For this purpose, a fuzzy logic-based algorithm is developed to estimate the agriculturally relevant onset of the rainy season (ORS) and, thus, the optimal planting date. This algorithm is then connected to the physically based crop model *CropSyst*, hereinafter referred to as *optimal planting date following crop modelling system*. A Monte Carlo approach is used to optimise the ORS algorithm in terms of maximising the mean annual crop yields (1979–2003). The *optimal planting date following crop modelling system* is applied to past and future periods, mainly for two reasons: (i) to derive optimal fuzzy rules and increase mean attainable crop yields; and (ii) to reliably estimate the impact of climate change to crop productivity with ('optimal planting date scenario') and without planting date adaptations ('traditional planting date scenario').

It is shown that the fuzzy rules derived for assessing the optimal planting dates may allow for significantly increased crop yields compared to the existing planting rules in Cameroon under current climatic conditions, especially for the drier northern regions. A change in the climatic conditions due to global warming will reduce the growing cycle and, thus, the crop yields. However, the positive effect of CO_2 fertilisation is likely to outweigh the negative effects of precipitation and temperature change for the 2020s and partly for the 2080s. When additionally considering planting date adaptations, groundnut yield is expected to increase for the 2020s and the 2080s, with maximum yield surpluses of about 30% for the 2020s compared to the extended baseline period. For maize, crop yield is likely to increase (decrease) for the 2020s (2080s) by approximately 15%. For the driest stations analysed, the negative impacts of temperature and precipitation change could be mitigated significantly by planting date adaptations.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Eighty-two percent of the cropland worldwide is cultivated under rainfed conditions. The importance of rainfed agriculture varies regionally, but it is of utmost significance for sub-Saharan Africa. There, agriculture accounts for 35% of GDP and employs 70% of the population (Worldbank, 2000). Approximately 95% of the total cropland is managed under rainfed conditions (FAOSTAT, 2005, http://faostat.fao.org). The spatial and temporal variations of crop yield may have a profound impact on the national economies of sub-Saharan countries, which are primarily dependent on the agricultural sector.

1.1. Rainfall variability and agricultural productivity under rainfed conditions

The high spatial and temporal variability of rainfall, reflected by dry spells and recurrent droughts and floods, may be considered the most important factor affecting agricultural productivity in sub-Saharan Africa. The intra-seasonal and inter-annual vari-

---

* Corresponding author.
E-mail addresses: patrick.laux@kit.edu, patrick.laux@imk.fzk.de (P. Laux).

0168-1923/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.agrformet.2010.05.008

ability is often given as the main reason for crop failure and food shortages (e.g. Sivakumar, 1988; Paeth and Hense, 2003; Usman et al., 2005; Sultan et al., 2005; Mishra et al., 2008). Wheeler et al. (2005) demonstrated the simulated effect of evenly and unevenly distributed intra-annual rainfall on crop yield, independently of the total annual amount. Plant water availability strongly depends on the onset, cessation, and length of the rainy season. The onset of the rainy season (ORS) is the most important variable for agricultural management (e.g. Stewart, 1991; Ingram et al., 2002; Ziervogel and Calder, 2003). It directly affects farming management practices, especially planting which, in turn, significantly affects crop yield and the probability of agricultural droughts (Kumar, 1998). For sowing, it is important to know whether the rains are continuous and sufficient to ensure enough soil moisture during planting and whether this level will be maintained or even increased during the growing period to avoid total crop failure (Walter, 1967). Planting too early might lead to crop failure and, in turn, planting too late might reduce valuable growing time and crop yield. However, there is still no consensus in literature about the question of how much rain over which period defines the ORS for agro-climatological impact studies. The definition of Stern et al. (1981), hereinafter referred to as the *Stern definition*, is possibly the most widespread rainfall-based definition used to estimate local ORS dates. This approach states that the wet season has started when, for the first time after March 1st, 25 mm of rain falls within 2 consecutive days, and no dry period of 10 or more days occurs in the following 30 days. Prior to its application, however, the user must adapt these criteria, which strongly depend on local weather conditions, soil types, the evaporative demands of crops, cropping practices, etc. Laux et al. (2008) extended the *Stern definition* to regional usability in a case study for the Volta basin (West Africa) using a fuzzy logic approach. Furthermore, they derived trends of the ORS dates and developed methodologies for predicting the ORS on the regional scale. Recommendations for agricultural decision support, including maps of optimal planting dates and rainfall probabilities for the Volta basin, are presented in another paper (Laux et al., 2009b). Based on the *Stern definition*, Kniveton et al. (2009) performed a grid-based analysis of the temporal and spatial ORS variability on a continental scale covering Africa and parts of southern Europe and the Middle East as a function of different definition parameterisations.

Similarly to the *Stern definition*, instances of definition approaches with fixed definition parameterisations are presented by Marteau et al. (2009) for the west and central Sahel (Senegal, Mali, and Burkina Faso), Mugalavai et al. (2008) for Kenya or Raes et al. (2004) for Zimbabwe. A comparison of existing approaches to estimating the ORS for Nigeria is given by Ati et al. (2002).

1.2. Impact of climate change on agricultural productivity

Providing sufficient food for the world's increasing population is becoming more difficult as land, water, and vegetative resources are progressively degraded through prolonged overuse. In the future, this difficulty will be exacerbated by climate change (Rosenzweig and Hillel, 1998). Climate change alters the biophysical environment in which crops grow and howcrops respond to some factors of climate change, such as CO_2, temperature, precipitation, and evapotranspiration.

Atmospheric CO_2 accumulation without changing temperature and precipitation patterns, might likely be of benefit for crop production. Plants commonly respond to higher levels of CO_2 with increased rates of photosynthesis, because CO_2 absorption is facilitated by the stronger gradient between the atmosphere and air spaces inside the leaves. C3 plants, such as rice, soybean, and groundnut, exhibit lower rates of net photosynthesis than C4 plants (e.g. maize) at the current CO_2 level ($\approx$ 385 ppm). At elevated levels, C3 plants may become more competitive than C4 plants, due to larger increases in photosynthetic rates. In addition to the enhanced photosynthesis rates, plants respond with a partial closure of their stomata, thus reducing transpiration per unit leaf area and improving their water use efficiency (Rosenzweig and Hillel, 1998). However, a significant impact in terms of the direct fertilisation effect of CO_2 cannot be expected before 2050 when CO_2 is likely to reach twice the preindustrial level (Nakicenovic and Swart, 2000).

Initial studies dealing with the climate change impact on crop productivity focussed on the effects of an increased CO_2 level, followed by studies that additionally took the change of average climate conditions into account, such as a rise in the mean global temperature and/or change in rainfall (Porter and Semenov, 2005). Rosenzweig and Parry (1994) combined data from several individual studies on a regional/national level to draw a global picture of the simulated change in crop yield associated with different climate change scenarios. Additionally, they simulated the economic consequences of the simulated crop yield changes using a world food trade model. They found negative changes to the modelled yield in low latitudes, where many developing countries are located, and is contrary to the increased yield in middle and high latitudes, the predominant location of developed countries.

Estimates of climate change impacts on agricultural productivity yields are often characterised by large uncertainties that reflect an ignorance of many processes and hamper efforts to adapt to climate change (Lobell and Burke, 2008).

According to Diepen and van der Wall (1996), these processes/factors can be categorized as:

(i) abiotic factors, such as soil moisture, soil fertility, weather;
(ii) farm management factors, such as soil tillage, sowing date, harvesting techniques;
(iii) land development factors, such as irrigation;
(iv) socioeconomic factors, such as distance to markets, population pressure, education levels; and
(v) catastrophic factors, such as droughts, floods, and pests.

A key to reducing these uncertainties is the improved understanding of the relative contribution of each individual factor (Lobell and Burke, 2008).

As crops are subject to combinations of stress factors that affect their growth (and yields) and respond non-linearly to changes in their growing conditions, Porter and Semenov (2005) stressed the importance of climatic variability. According to the IPCC (2001), crop yield responds to three sources of climatic variability:

(i) change in the mean conditions, such as annual mean temperature and/or precipitation;
(ii) change in the distribution, such that there are more frequent extreme events (physiologically damaging temperatures or longer drought periods); and
(iii) a combination of changes of the mean conditions and the variability.

According to Monteith (1981), the two largest causes of yield variation are temperature and rainfall. Their independent effects are three to four times larger than those caused by the variation in solar radiation. The increased variation and changes in mean temperature and precipitation are expected to dominate future changes in climate, as they affect crop productivity. Various studies dealing with the effects of climatic variability have pointed to the conclusion that an increased annual variability of weather, as expected due to global warming, causes an increased variation of yields (e.g. Semenov et al., 1993; Porter and Semenov, 2005). Short-term extreme temperatures, often referred to as crop temperature

Download English Version:

https://daneshyari.com/en/article/82228

Download Persian Version:

https://daneshyari.com/article/82228

Daneshyari.com