Science of the Total Environment 613–614 (2018) 250–262

Contents lists available at ScienceDirect

Science of the Total Environment

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

Forecasting wheat and barley crop production in arid and semi-arid regions using remotely sensed primary productivity and crop phenology: A case study in Iraq

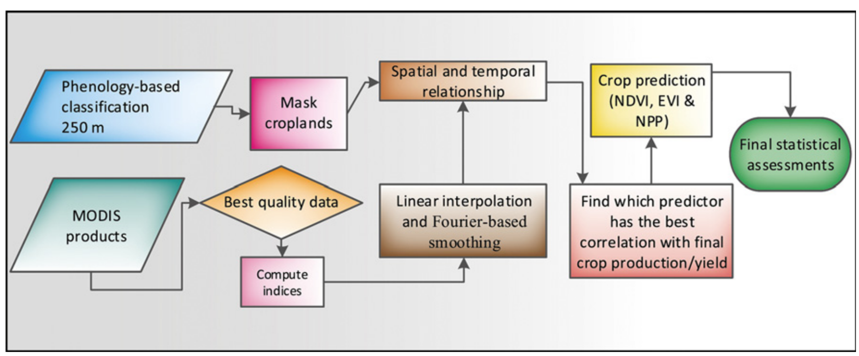
Sarchil Hama Qader [a,b,*], Jadunandan Dash [a], Peter M. Atkinson [c,d]

[a] Geography and Environment, University of Southampton, Southampton SO17 1BJ, UK
[b] Soil and Water Science Department, Faculty of Agriculture, University of Sulaimani, Kurdistan Region, Iraq
[c] Faculty of Science and Technology, Lancaster University, Bailrigg, Lancaster LA1 4YR, UK
[d] School of Natural and Built Environment, Queen's University Belfast, Belfast BT7 1NN, Northern Ireland, UK

HIGHLIGHTS

- First demonstration that crop production can be forecasted in Iraq.
- The peak of the growing season produced the largest correlation with crop production.
- NDVI, EVI and NPP produced similar results.
- Remotely sensed metrics performed better than simple crop area.
- This forecasting could have utility in relation to tackling food insecurity.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 28 February 2017
Received in revised form 6 September 2017
Accepted 7 September 2017
Available online 12 September 2017

Editor: D. Barcelo

Keywords:
Vegetation phenology
Crop yield/production forecasting
MODIS
NDVI
EVI
NPP and Iraq

ABSTRACT

Crop production and yield estimation using remotely sensed data have been studied widely, but such information is generally scarce in arid and semi-arid regions. In these regions, inter-annual variation in climatic factors (such as rainfall) combined with anthropogenic factors (such as civil war) pose major risks to food security. Thus, an operational crop production estimation and forecasting system is required to help decision-makers to make early estimates of potential food availability. Data from NASA's MODIS with official crop statistics were combined to develop an empirical regression-based model to forecast winter wheat and barley production in Iraq. The study explores remotely sensed indices representing crop productivity over the crop growing season to find the optimal correlation with crop production. The potential of three different remotely sensed indices, and information related to the phenology of crops, for forecasting crop production at the governorate level was tested and their results were validated using the leave-one-year-out approach. Despite testing several methodological approaches, and extensive spatio-temporal analysis, this paper depicts the difficulty in estimating crop yield on an annual base using current satellite low-resolution data. However, more precise estimates of crop production were possible. The result of the current research implies that the date of the maximum vegetation index (VI) offered the most accurate forecast of crop production with an average $R^2 = 0.70$ compared to the date of MODIS EVI (Avg $R^2 = 0.68$) and a NPP (Avg $R^2 = 0.66$). When winter wheat and barley production were forecasted using NDVI, EVI and NPP and compared to official statistics, the relative error ranged from −20 to 20%, −45 to 28% and −48 to 22%, respectively. The research indicated that remotely sensed indices could characterize and

* Corresponding author at: Global Environmental Change and Earth Observation research group (GECEO), Geography and Environment, University of Southampton, Worldpop (Building 55/2001), University Road, UK.
E-mail addresses: S.Qader@soton.ac.uk (S.H. Qader), J.DASH@soton.ac.uk (J. Dash), pma@lancaster.ac.uk (P.M. Atkinson).

http://dx.doi.org/10.1016/j.scitotenv.2017.09.057

forecast crop production more accurately than simple cropping area, which was treated as a null model against which to evaluate the proposed approach.

1. Introduction

1.1. Challenges of food security in arid and semi-arid regions

At present, 15% of the Earth's population (841 million people) live in arid and semi-arid regions, of which about 524 million live in semi-arid regions (Barakat, 2009). Rapid population growth (Barakat, 2009) together with rising living standards in arid and semi-arid regions imply that more food will be required to meet the demands of these populations. This is a major driver of land conversion to agricultural and grazing land within these regions (Millennium Ecosystem Assessment, 2005). Therefore, crop production forecasting is potentially a crucial tool for tackling food insecurity in arid and semi-arid regions as well as an essential input to decision-making for agricultural insurance. However, this is one of the most challenging tasks in crop research because of the highly variable climate in arid and semi-arid regions.

In many parts of the world, wheat and barley are major grain crops and their production influences local food security (Macdonald and Hall, 1980; FAO, 2003a). At the global scale, >541 $\times$ 10^{10} and 49 $\times$ 10^{10} m^2 (harvested area) was dedicated to growing wheat and barley, respectively, of which over 649 $\times$ 10^6 and 130 $\times$ 10^6 MT of cereal was produced in 2013 (FAO aquastat, 2013). Furthermore, wheat and barley play an essential role in international trade, and it has been reported that food shortages are commonly attributable to a lack of wheat and barley (d'Amour et al., 2016; Fellmann et al., 2014; Mellor, 1972). In both developing and developed country contexts, timely and accurate estimation of wheat and barley yield and production before harvesting are, therefore, vital at different governance levels including regional, national and international levels. Such forecasts could increase regional food security, through improved policy setting and local decision-making, as well as playing a crucial role in informing international markets (Justice and Becker-Reshef 2007).

In part, due to the likelihood of unfavourable climatic events across many arid and semi-arid regions of the world, local communities are often food insecure and at risk of famine. Weather extremes such as droughts and floods can have a direct impact on food production and can negatively affect the storage and distribution of food (Haile, 2005; Wheeler and von Braun, 2013). For example, in Turkey, the drought in 2008–2009 caused sizeable declines in crop yields, which cost $1–2 billion and 435,000 farmers were affected while in Iraq the total wheat production was reduced by 45% compared to the previous year (USDA FAS, 2008a).

Another factor which makes many of the regions in the world food insecure, and in particular regions in the Middle East such as Iraq, is political instability and its consequences. War and conflict can damage the economy and incomes, and cause disease, forced immigration, refugee populations, a collapse of social trust, and severe food insecurity (WFP, 2011). Conflict was the main cause of undernourishment in more than half of the Middle East countries in the 1990s (FAO, 2003b). The main drivers of >35% of food emergencies from 1992 to 2003 were economic issues and conflict; in contrast, this value was 15% in the period between 1986 and 1991 (FAO, 2003a). Therefore, timely monitoring and forecasting of crop production is especially required in regions where the potential for drought occurs in the context of conflict.

Over the last decade crop production in Iraq has been negatively affected by both natural and anthropogenic events. For instance, Iraq was involved in a war 'Post-Gulf' mainly to oppose the previous regime. Due to political instability during the war, many farmers either abandoned their land or were unable to grow their crops effectively, and this affected overall crop production in the country. In addition, due to its geographical location, Iraq is affected by irregularity in precipitation resulting in the frequent occurrence of droughts. Both factors have made the region vulnerable to irregularities in food production.

1.2. Review of crop yield forecasting

A wide range of the techniques to estimate and forecast crop yield have been employed during the past decades with different degrees of utility and accuracy. Crop yield estimation in many countries still relies on traditional approaches based on data collection on the ground and reporting (crop cutting experiments). Such data are frequently time consuming to obtain, costly and prone to large errors because of incomplete ground observations, leading to uncertain crop area estimation and crop yield assessment (Reynolds et al., 2000). Crop yield can also be forecasted through either statistical or agronomic models based on historical weather, crop management and crop production data. In some countries, weather data have been employed to monitor and forecast crop production (Andarzian et al., 2008; Liu and Kogan, 2002; Paul et al., 2013; de Wit and Boogaard, 2001). Missing data, a lack of continuity in weather data and the sparse spatial distribution of ground weather stations for a large diverse crop area limit the utility of these approaches (Liu and Kogan, 2002; Dadhwall and Ray, 2000; de Wit and Boogaard, 2001).

With the development of satellite sensors, there has been increased interest in utilizing satellite remotely sensed data for crop monitoring and crop production forecasting due its ability to provide data synoptically, with greater spatial coverage, potentially at the global scale. In addition, remote sensing can provide timely (and potentially real-time) and objective data on crop growth at relatively low cost. In this regard, the NDVI has a long history of use for monitoring crop condition and estimating crop yield (Doraiswamy et al., 2004; Groten, 1993; Kastens et al., 2005). Either remotely sensed data can be used as an input to crop simulation models or remotely sensed biophysical variables measured within-season can be used as a surrogate of crop production for use in monitoring and forecasting. One such approach involves biophysical crop simulation models, which are calibrated and driven through remotely sensed information on crop characteristics within-season. Examples of crop simulation models include the World Food Studies (WOFOST) (Vandiepen et al., 1989), Simulateur mulTIdisciplinaire pour les Cultures Standard (STICS) (Brisson et al., 1998) and Crop Systems Simulation (CROPSYST) models (Van Evert and Campbell, 1994). These models assimilate several factors that affect crop growth and development such as temperature, wind, water availability and type of management practice which lead them to be capable of capturing soil-environment-plant interactions (Moriondo et al., 2007). However, the high computational and data demands of these models make them generally difficult to use in some regions for which data are sparse. In addition, their complexity, method of analysis and large number of tuning parameters have led them to be impractical, particularly capturing field level information in a heterogeneous landscape.

The most widely used approach to estimate crop yield at the regional scale is based on simple regression between a satellite-derived vegetation index within-season and actual crop yield (Wall et al., 2008). A linear regression model was established by Hamar et al. (1996) to estimate wheat and corn yield at the county level based on vegetation indices