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Mapping the sensitivity of citrus crops to freeze stress using a geographical information system in Ramsar, Iran

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ABSTRACT

Citrus, a cold-sensitive plant, often suffers from low temperature, which seriously affects citrus productivity. Environmental constraint factors have mixed impacts on horticulture that differ among the areas, periods and crops. This study presents a statistical analysis to investigate the freeze stress (FS) conditions and morphometry, especially altitude and minimum temperature on citriculture at a regional scale. Based on the temperature isolines map and topography, this paper highlights the impact of altitude and minimum temperature on the citrus crop production using geographic information system (GIS) techniques, statistical analysis and climatic data in Ramsar, Iran over a period of 30 years from 1980 to 2010. This study shows that the suitability varies in relation to the critical temperature and concludes that both minimum temperature and altitude have significant negative impact on citrus crop production. Climate change, in particular, occurring cold fronts in recent years during the citrus harvest time have been complicating this issue and increased the importance of freezes stress (FS). The results highlight that citrus crop orchards were more strongly affected by the minimum temperature, and along with the elevation ranges theses are major challenging factors.

1. Introduction

Climate change can induce an increase in the frequency and intensity of weather events at the global and regional scale (IPCC, 2012). To evaluate the sustainability of economic growth and welfare, it is crucial to have a deeper understanding of how regional economic development affects vulnerability of local communities, that is to say the propensity to be adversely affected by the weather (IPCC, 2012).

Citrus plants are one of the world's most important fruit cash crops. Citrus is commercially grown in more than 100 countries around the world in the tropical, subtropical and borderline subtropical areas, approximately 40°N and 40°S of the equator (CDCGC, 2004; FAO, 2009). Citrus is primarily valued for the fruit, which is either eaten alone (sweet orange, tangerine, grapefruit, mandarin, etc.) as fresh fruit, processed into juice, or added to dishes and beverages (lemon, lime, etc).

Iran has always been a major provider of citrus production in the world. According to FAO, 2007, Iran has the seventh ranking production of grapefruit, lemon and sweet orange, and fifth ranking in mandarin production in the world. Cold temperature causes huge agricultural losses and its effects on crop growth and yield are well known (Beck et al., 2007). Temperature effects are one of the variable environmental factors during at ripening and maturing stages. Exposure to low and very low temperature are one of the most common environmental stresses on plants (Sahin-Cevik and Moore, 2006; Chen et al., 2011; Haghighi et al., 2014; Kalisz et al., 2014; Dürr et al., 2014; Vico et al., 2014; Loel and Hoffmann, 2014) and its productivity is seriously affected by low temperature (Zhang et al., 2005). In citrus low temperature causes chilling and freezing injuries on plants and thus limits crop production and yield (Zhang et al., 2011). The optimal temperature for citrus growth and development ranges from 13 to 37 °C (Wu et al., 2012). The thermal integral was calculated by means of the following formula: IT =(Tm −12.8) dm, where 12.8 represent the base temperature of citrus (Bustan et al., 1996), Tm is the daily average temperature, and dm is the number of days of the month.

The study area has a temperate climate zone, not ideally suited to sub-tropical fruits, such as citrus.

During the last decade, frost damages have become one of the major challenges in the study area (frost event by year of 2008, 2014). Typically, in this region, the harvesting time is coincident with late autumn and early winter seasons (end of November to February). This suggests a likely relationship between the spatial distributions of citrus

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orchards and FS conditions.

On a global scale, minimum temperatures have increased about twice as fast as maximum temperatures (Vose et al., 2005; Skansi et al., 2013). In Spain, Martínez et al. (2010) reported increases in annual minimum and maximum temperatures during spring and summer, and only for maximum temperatures in winter. In France, a mapping of temperature trends has been established by Moisselin et al. (2002). They showed a significant increase in minimum temperatures and moderate increase in maximum ones. Minimum temperatures presented an east-west gradient, whereas maximum temperatures exhibited a north-south gradient.

The present study attempts to determine suitable regions for future planning and how these FS challenges can be addressed by conducting DEM data associated with extreme minimum temperatures as a critical climate variable. Only a few studies have considered the effects of environmental parameters on crop production including climate change (Chartzoulakis and Psarras, 2005; Lobell et al., 2006, 2007a; Tao et al., 2008; Quiroga and Iglesias, 2009; White et al., 2011; Gohari et al., 2013; Smith et al., 2013; Wei et al., 2014; Anwar et al., 2015), low temperature, cold shock, crop load and bud age of sweet orange and mandarin (Valiente and Gene Albrigo, 2004; Barry and van Wyk, 2006; Crifò et al., 2011), air temperature (Lobell, 2007; Thakur et al., 2010; Luo, 2011; Chen et al., 2011; Jumrani and Bhatia, 2014). Current studies have shown that phenological stages are closely related to temperature characteristics of the cropping site during months preceding the phenological evolution (Osborne et al., 2000; Lopez and Dejong, 2007).

This paper, therefore, focuses only on the influence of minimum temperature and altitude as crucial factors in response to citrus crop production. To our knowledge, no research to date has examined the interaction effect of altitude and minimum temperature and applying suitable frameworks on citrus crop at regional scale.

The purpose of this paper are (1) to provide insight of critical minimum temperature and altitude dataset on citrus crop production (2) to determine the impact of minimum temperature and altitude on citrus crop (3) examine the roles of FS and reveal regions prone to FS using GIS techniques. As such the paper contributes to geographical and scientific debates on the mapping of suitable citrus cultivation regions, integrating with climate variable and altitude along with GIS techniqes. Furthermore, this study has policy implication as it identifies regions and districts prone to optimum production and provide policy makers, decision-makers, and growers to feed into a more targeted climate adaptation.

2. Research background and related works

In the area of environmental parameters, Lobell (2007) considered the difference between daily minimum and maximum temperatures (DTR) on rice, maize, and wheat. The aim of his study was to evaluate historical datasets and climate model projections. The relations between average temperatures, DTR and crop yields were assessed. A study by Quiroga and Iglesias (2009) focused on climate risks, including extreme temperatures and precipitation variability, on cereal, citrus, olive and grapevine without focusing on altitude. Statistical models of yield response functions addressed how temperature and precipitation variability affect the crops of a traditional Mediterranean farming system. Responding the critical need for knowledge on crop response to extreme events, Lobell et al. (2007a) analyzed the relationship between temperature and precipitation on 12 major California crop yields, over a period of 23 years. The results showed that recent climatic trends have had mixed effects on crop yields. In USA the effect of changes in temperature, CO2, and precipitation; on crop production was analyzed by Hatfield et al. (2011). They found that the temperature effects on soybean could potentially cause yield reductions in the South US but an increase of 1.7% in the Midwest.

Tao et al. (2008) presented a relationship between climate–yield and the impacts of recent climate trends on crop productivity on a large scale. In their study, major crops (i.e. rice, wheat, maize and soybean) were considered and they found that major crop yields were significantly related to climate during the growing season. A study conducted by Valiente and Albrigo (2004) during the 1999 and 2000 seasons, to monitor the flower bud induction response of two sweet orange trees to naturally occurring winter weather conditions showed that low temperature, was an important factor. They indicated that low temperature inductive conditions resulted in the transition of buds from vegetative to reproductive. Vegetative buds were thus reduced in favour of reproductive buds under low temperature inductive conditions. Similarly, Thakur et al. (2010) reported that cold temperatures are the cause of enormous agricultural losses, especially in sub-tropical and temperate grain crops. The aim of their paper was to describe the effects of low temperature on various stages of the reproductive phase, from meiosis to grain filling, and temperature sensitivity of different reproductive organs. Cold stress during the reproductive phase causes structural and functional abnormalities in reproductive organs, leading to failure of fertilization or premature abortion of seed or fruit (Thakur et al., 2010).

Jumrani and Bhatia, 2014 performed a study on the impact of elevated temperatures on growth and yield of chickpea (*Cicer arietinum* L.). They concluded that for heat tolerance in chickpea, breeding efforts needs to be focused on improving the reproductive efficiency. Chen et al. (2011) investigated whether minimum temperatures increase corn production in China based on correlation and regression analyses of climate records. The results showed that the minimum temperature was the dominant factor to corn production. Mphahlele et al. (2014) found that differences in climatic conditions, altitudes and maturity stages have profound influence on the bioactive compounds of pomegranate fruit.

Thus, in comparison with research efforts found in the literature, our work has the following differences. In this research:

i. We highlight linear regression analysis using GIS techniques for FS monitoring. The purpose is to provide the necessary background to fully understand the requirements of these applications.
ii. The analysis can solve complex problems and adequately consider the relationship between FS, citrus production and spatial distribution of citrus.
iii. Accordingly, this study provides further insight by incorporating a more comprehensive approach to the measurement of both minimum temperature and altitude performance by statistical method that influence on perennial plants including citrus plants.

3. Materials and methods

3.1. Case study

The region investigated in this study is located in the northern part of Iran. It is about 250 km north of the capital of Iran. Ramsar region situated in the west part of Mazandaran province, borders the Caspian Sea to the north and the Alborz Mountains range to the south. The population is approximately 70,000 at the end of 2010 census (statistical center of Iran, 2010). This region is one of the most important citrus production areas in Iran with approximately 7000 ha of citrus orchards. The geographic coordinates of the study area are located between latitudes 36°32′00″ to 36°59′11″ N and longitudes 50°20′30″ to 50°47′12″ E. The total study area covers approximately 729.7 km^2. The altitude of Ramsar County starts at a height of −20 m near The Caspian Sea to 3620 m above sea level. A map of the study area is presented in Fig. 1. This study was conducted from December 2013 to January 2014.

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