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Detecting soil temperature trends in Northeast Iran from 1993 to 2016

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ABSTRACT

Soil temperature is a fundamental agrometeorological variable which has a measureable influence on the development of plants. A comprehensive analysis of daily soil temperature trends at predetermined depths can provide a quantitative understanding for the sustainable management of agricultural systems, such as mitigating the adverse effects of anticipated temperature stress, supporting confidence levels of ideal seed sowing dates, as well as irrigation treatment durations and intervals. In this paper, daily soil temperature trends were analyzed (using the Mann-Kendall test) at depths of 5, 10, 20, 30, 50 and 100 cm at seven discrete meteorological stations located throughout northeastern Iran during a consecutive period from 1993 to 2016. The results of this research indicate that in most of the study stations there exists a non-significant negative trend in soil temperature in the first half of January and also in the second half of December; these trends become significant as the soil gets deeper. For the warmer months of the year, especially from April to the end of August, soil temperature trends are positive and significant (or near significant) and these positive trends are of greater significance with a corresponding increase in soil depth. Agri-environmental agencies and practitioners may benefit from the approach used in this research (i.e. using the Mann-Kendall test to analyze trends in daily soil temperature time series) since it is an easily transferable approach that can provide a comprehensive geospatial and temporal analysis of crop and plant patterns in different regions and environmental conditions. Additionally, farmers may use daily soil temperature trends as a means to encourage the protection and mitigation of a variety of projected environmental stresses, such as water scarcity, irrigation demands, seasonal temperature fluctuations, and redundant crop rotation.

1. Introduction

Soil temperature is a strong diagnostic environmental indicator in the determination of the rate and direction of soil physical processes (e.g. thermal fluxes, humidity gradient, etc.) and is most apparent in plant growth and distribution. The temperature of the soil substrate plays a principal role in a variety of biological and microbiological processes, such as in germination, seedling emergence and growth, and root development (Hillel, 1998). In comparison to air temperature, variations in soil surface temperature are much more pronounced as a result of varying physical and biological soil attributes. The ideal soil temperature band for plant growth is, by contrast, significantly narrower than ambient air temperature, as plant root structure is inherently more sensitive to excessive temperature variations. Accordingly, soils may be more tolerant of severe early season short-lived frost events as the soil acts as a natural insulator of the germinating seed (Pessarakli, 2002). If soil temperature (as well as other climatic conditions) is closely monitored and farmers can plant at appropriate times based on soil temperature trends, the benefit would be that a longer-season hybrid could be selected with a corresponding higher yield potential, as the soil temperature is one of the most influential factors of the growing season (Sadras and Calderini, 2009). In addition to agriculture, soil temperature can have major effects on climatological and hydrological processes. For instance, evaporation rate and water loss from the soil surface, as well as snow-melting rate, are some of the hydro-climatological processes that are affected by soil temperature. These processes have an important role in producing atmospheric humidity, especially in land areas, and consequently, the precipitation rate and type can be affected indirectly by soil temperature in such regions. Soil temperature varies in response to changes in the radiant and thermal energy, as well as the latent heat exchange that takes place through the soil surface (Hillel, 1998; Zhang et al., 2001). As such, the soil thermal regime is affected by a variety of climatic and environmental conditions such as precipitation, snowfall depth, vegetation type and density, and soil moisture and texture (Oelke and Zhang, 2004; Huang et al., 2012). In micrometeorological terms, soil is a significant

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Fig. 1. Spatial distribution of the seven synoptic stations in the study region.

sink (as well as potential source) of energy and has a correlation with the adjacent surface air temperature and humidity (Ogée et al., 2001). Focusing on the ecological health and resilience of plant life, soil temperature has considerable influence, as roots in subzero soil temperatures regularly fail to survive while other parts of the plant or tree may remain relatively unaffected. Evidence of this is demonstrated in seed germination, as different crop types are known to occur within an optimal soil temperature range (Paul, 2007; Crawford, 2008; Dixon and Tilston, 2010).

While air temperature trends have widely been investigated on different spatial and temporal scales in most regions of the world (Gadgil and Dhorde, 2005; Makokha and Shisanya, 2010; Martínez et al., 2010; Tabari and Hosseinzadeh Talaee, 2011a,b; Croitoru et al., 2012; Saboohi et al., 2012; Safeeq et al., 2013; Espírito Santo et al., 2014; Araghi et al., 2015b), soil temperature variations have received comparatively minimal attention and are rarely reported as indicators of climate change (Helama et al., 2011; Bai et al., 2014). The majority of publications on soil temperature are primarily focused on the modeling, prediction or estimation of temperature values at various soil depths (Carson, 1963; Parton and Logan, 1981; Hinzman et al., 1998; Chen et al., 2003; Gao et al., 2007; Herb et al., 2008; Lei et al., 2011; Ouzzane et al., 2015), while the number of studies investigating trends in soil temperature and changes in thermal regime characteristics of soil are lacking in comparison (Beltrami, 2001; Beltrami and Kellman, 2003; García-Suárez and Butler, 2006; Qian et al., 2011; Bai et al., 2014). In regions with insufficient agri-planning, food production, forestry, natural resource management, and successive crop and environmental data, there is a need for a comprehensive analysis of long-term trends in soil temperature and other meteorological variables (Decker, 1994; Hatfield, 1994; Hoogenboom, 2000; Venäläinen and Heikinheimo, 2002). An important issue related to this is the unavailability or lower accessibility of soil temperature data compared to other hydro-climatological variables, such as air temperature. Current methodologies favor monthly or annual time-scale data, however this fails to encompass the frequency and intensity of daily variations in meteorological variables since these short-term changes can negatively affect (or sometimes terminate) plant growth (Taiz and Zeiger, 2002; Carena, 2009; Beck, 2010). This paper explores daily soil temperature data over a consecutive twenty four-year period from 1993 to 2016 in northeast Iran. Individual daily soil temperature trend analyses were performed separately, in order to capture temperature events that could have otherwise been absent through weighted long-term scaling averages. By performing this analysis, the resulting high-resolution trend of daily soil temperatures can help increase agricultural responsiveness to daily-dependent activities (e.g. selecting the appropriate planting date, protecting from heat or freezing stresses, etc.). Providing a new perspective on daily soil temperature trends can facilitate the sustainable management of agricultural and agronomical activities, which can result in higher and more sustainable crop yields (Halbe et al., 2013; Kolinjivadi et al., 2014; Straith et al., 2014; Inam et al., 2015).

The main objective of this study was to detect soil and air temperature trends from 1993 to 2016 in Northeast Iran. To this end, soil temperature time series at depths of 5, 10, 20, 30, 50 and 100 cm were examined. The main method used in this study was the Mann-Kendall test, which is a widely-used method in trend analysis studies. We selected the same time period and tested the trend at different stations to allow us to examine the spatial variation in trends. We also examined trends for each day of the year separately, since this kind of analysis can be useful for farmers and agricultural managers, who can use day by day variations in soil temperature.

2. Materials and methods

2.1. Study region and data

Iran is located in Southwest Asia between 25°N and 40°N latitude and between 44°E and 63°E longitude. Currently the second-largest nation in the Middle East, Iran has a total area of 1,648,000 km^2 and is generally characterized by an arid or semiarid climate (Araghi et al.,