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Agro-ecological zoning for wheat (*Triticum aestivum*), sugar beet (*Beta vulgaris*) and corn (*Zea mays*) on the Mashhad plain, Khorasan Razavi province

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Abstract Climate is the most important factor determining the sustainability of agricultural production systems. A qualitative land evaluation was carried out for the Mashhad plain, Khorasan Razavi province, Iran, to assess the suitability of the land to grow the locally most important crops, i.e. wheat (*Triticum aestivum*), sugar beet (*Beta vulgaris*) and corn (*Zea mays*) using a Geographical Information System (GIS). The possible growing seasons were defined as early (10 September–20 June) and late (10 October–20 July) season for wheat, early (15 March–15 October) and late (15 April–15 November) season for sugar beet, and early (1 May–1 November) and late (15 May–15 November) season for corn. The study area covered approximately 99.915 ha^{-1}. Climate variables were taken into account including maximum, optimum and minimum daily average temperatures and were obtained from 30 years agro-meteorological data set from 12 synoptic stations. Growing

Abbreviations: DEM, Digital Elevation Model; DTM, Digital Terrain Model; E, Elevation; GDD, Growth Degree Day; GDUs, Growth Degree Units; GIS, Geographic Information System; RS, Remote Sensing; S, slope; T_b, base Temperature; T_{max}, maximum temperature; T_{min}, minimum temperature

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Degree Days (GDDs) were determined for wheat, sugar beet, and corn crops from sowing to harvest. To produce digital elevation model for Mashhad plain two sources were used on utilization of the IRS III satellite images with resolution that is 23.5 m, and topographic maps with scale of 1:25000. Aspect and slope layers were produced by Arc GIS 9.2 software. The study identified suitable elevation, slope, and GDDs for optimal growth and indicated that high yields are possible for wheat, sugar beet, and corn on the Mashhad plain. The study also identified the most suitable regions of the Mashhad plain for each crop.

1. Introduction

Rapidly rising population growth and diminishing arable land, particularly in the developing countries, have increased the stress on the natural resource bases. Lal (1991) showed that the amount of arable land per capita has progressively declined from about 0.3 ha^{-1} in 1990 to 0.23 ha^{-1} in 2000, future projections suggest 0.15 ha^{-1} in 2050 and 0.14 ha^{-1} for 2100. Combined with the growing concerns regarding the decline of non-renewable sources of energy and phosphorus and the ongoing degradation of environment, the world should take a good look at the use of natural resources which have been exploited so far with the sole objective of profitability rather than long term sustainability. Moreover, global change will add further threats to the sustainability of crop production but will also offer new opportunities (Meinke et al., 2009). Resources should be known, assessed in quantitative terms and they should be properly managed if they are to be used in a sustainable way. Climate is not an exception (Gommes and Fresco, 1998). To express direct links between agricultural production potential and climate, Bernard (1992) used the concept of climate fertility, after soil fertility. The fundamental similarities between climate and soil resources include the contribution to the general production potential of a region, both undergo spatial variation and they should be mapped at different scales (Gommes and Fresco, 1998). Moreover, climate and topography contribute to the potential of agricultural production in an integrated way, not as separate factors. Specifically topography genesis is climate dependent. Climate should be regarded as the driving variable for exploitation of plant and water resources. Many of the ecological implications of agricultural development require an improved understanding of interactions between the physical, biological, and climatic components. As Thomas (1988) explained, the relationship between the productive capacity of the environment and potential changes in the micro and macro climate are not well understood. Climate is often the most critical factor determining the sustainability of agricultural systems and it constitutes a ‘complex’, such as consists of a set of variables that behave coherently, essentially as a result of atmospheric physics and dynamics (Sombroek and Gommes, 1996). For agroclimatologists around the world, the new awareness of sustainability among their colleagues has opened up new and exciting opportunities for interaction as never before. Climate resources also directly affect biodiversity of land and marine ecosystems (Laserre, 1992; MacDonald, 1992; Solbrig, 1992; Solbrig et al., 1992; WCMC, 1992; Tilman et al., 1997). This increased awareness of the need for sustainability perspective has also led to changes in research. Of course, this point should also mention that several definitions have been expressed about the sustainability; some of the important definitions related to sustainability are given in Table 1.

Drought is a common phenomenon in rain fed agriculture in the semi-arid and sub-humid regions. Water scarcity during crop growth reduces yield. However, while developing supplementary irrigation plans for water scarce areas, suitability of land area for irrigation with attention to elevation and slope is very important. Therefore, land suitability evaluation was included the assessment of both land potential for selected crop, and water potential of area (FAO, 1996). More than three-quarters of global land surface are unsuitable for crop cultivation, suffering from severe constraints such as cold climate (13%), dry climate (27%), steep topography (12%), or poor soil conditions (40%). In many cases in developing countries, cultivated land is only moderately suitable for crop cultivation as there are multiple constraints present (Fischer et al., 2001). The main objective of land evaluation is the prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize socioeconomic and environmental costs (de la Rosa, 2000). The planning and management of sustainable methods for drought mitigation and production have increased the required level of detail of agro-ecological information and that information needs to be summarized in a conceivable and accessible way (Hoogenboom, 2000; Smith, 2000). The Geographical Information System (GIS) offers a flexible and powerful tool as it can combine large volumes of different kinds of data into new datasets and display these new datasets in the form of informative and accessible thematic maps (Marble et al., 1984; Foote and Lynch, 1996). The elevation of a geographic location is the height above a fixed reference point, which is often compared to mean sea level. Elevation, or geometric height, is mainly used when referring to points on the Earth surface, while altitude or height is used for the points above the surface, such as an aircraft in flight or spacecraft in orbit. A topographical map is the main type of map used to depict elevation, often through use of contour lines. In GIS, Digital Elevation Model (DEM) is commonly used to represent the surface (topography) of a place through a raster (grid) data-set of elevation. Digital Terrain Models (DTMs) are another way to represent the terrain in GIS. The climate of Iran is so extreme because of the geographic location and variable topography. Most of the countries are arid to semi-arid with mean annual precipitation of 240 mm but at the northern flanks of the Alburz Mountains annual precipitation may range from 750 to 2000 mm. In the arid and semi-arid regions of country with a total acreage of 32.5 million ha, yields are low because of limited rainfall (Zeynaddini and Banaei, 2001; Bannayan et al., 2011). Since land productivity depends on climate, topography, and water availability, these form the