Assessing Agricultural Water Productivity in Desert Farming System of Saudi Arabia

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***Abstract*—The primary objective of this study was to assess the water productivity (WP) of the annual (wheat, barley, and corn) and biennial (alfalfa and Rhodes grass) crops cultivated under center-pivot irrigation located over desert areas of the Al-Kharj region in Saudi Arabia. The Surface Energy Balance Algorithm for Land (SEBAL) was applied to Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images to obtain evapotranspiration (ET) for assessing WP and irrigation performance (IP) of crops. Crop productivity (CP) was estimated using Normalized Difference Vegetation Index (NDVI) crop productivity models. The predicted CP ($\mathrm{CP_P}$) for corn varied from 12 690 to 14 060 kg/ha and from 6000 to 7370 kg/ha for wheat. The $\mathrm{CP_P}$ for alfalfa and Rhodes grass was 42 450 and 58 210 (kg/ha/year), respectively. The highest predicted WP was observed in wheat ($0.80{-}2.01\ \mathrm{kg/m^3}$) and the lowest was in alfalfa ($0.38{-}0.46\ \mathrm{kg/m^3}$). The deviation between SEBAL predicted ET ($\mathrm{ET_P}$) and weather station recorded ET ($\mathrm{ET_W}$) was 10%. The performance of the prediction models was assessed against the measured data. The overall mean bias/error of the predictions of CP, ET, and WP was 9.4%, -2.68%, and 9.65%, respectively; the root mean square error (RMSE) was 1996 (kg/ha), 2107 ($\mathrm{m^3/ha}$), and 0.09 ($\mathrm{kg/m^3}$) for CP, ET, and WP, respectively. When CP was converted into variations between the actual and predicted, the variations were 8% to 12% for wheat, 14% to 20% for corn, 17% to 35% for alfalfa, 3% to 38% for Rhodes grass, and 4% for barley.**

***Index Terms*—ASTER image, center-pivot irrigation system, crop productivity, evapotranspiration, water use.**

I. Introduction

AGRICULTURE is the largest consumer of freshwater in the world [1]. In arid and semiarid environments, competition for freshwater has been steadily increasing among agricultural, domestic, and industrial sectors [2]. This competition will further increase with ever growing concerns of climate change and its variability, population growth, economic development, and environmental impacts. The demand for water in the Middle East and North African (MENA) region that was $270\ \mathrm{km^3/year}$ in 2000 is expected to increase to $393\ \mathrm{km^3/year}$ [3] or $460\ \mathrm{km^3/year}$ [4] in 2050.

The rapid dwindling of finite water resources and the steady increase in demand for food are the major obstacles for attaining agricultural sustainability in Saudi Arabia. Agriculture in general and irrigation in particular consume over 80% of the freshwater used in Saudi Arabia. In 2012, freshwater consumption for the agricultural sector in Saudi Arabia was estimated at 86%—an increase of 6% between 2008 and 2012 [5]. Water used for irrigation is pumped from deep aquifers (up to 1000 m) to feed center-pivot irrigation systems at enormous economic and environmental costs. This situation creates an urgent need for attaining agricultural sustainability, but it is extremely difficult to maintain equilibrium between water and food securities. This critical equilibrium emphasizes the Kingdom's need for strategic technologies and methods to drastically reduce the current depletion rate of groundwater resources and optimize water consumption without reducing agricultural production. This can only be achieved through the efficient use of irrigation water. Therefore, increasing water productivity (WP) in the agricultural sector is crucial for water conservation efforts that can serve other competitive and critical needs such as domestic, industrial, environmental, and recreational purposes.

WP is determined from biological/economic yield of crops and the quantity of water used to produce that yield. It is one of the key indicators for evaluating the efficiency of water use in agriculture. Any attempt to improve water use efficiency in irrigated agriculture must be based on reliable estimates of seasonal/total evapotranspiration (ET), which has a major impact on water management. ET varies regionally and seasonally according to weather conditions [6]. Understanding the variations in ET is essential for the management of water resources, particularly in hyper-arid regions of Saudi Arabia, where crop water demand exceeds precipitation by several folds and requires irrigation from groundwater resources to meet the deficit. ET values are not only useful for developing WP maps at field and regional scales, but are also useful for precision irrigation purposes.

Satellite-based remote sensing is a robust, economic, and efficient tool for estimating ET, WP, and the assessment of irrigation performance (IP). Monitoring the temporal changes of the key parameters used in these estimates through employing

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