available at www.sciencedirect.com

ScienceDirect

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

Development and validation of canopy reflectance-based crop coefficient for potato

Harikishan Jayanthi [a,1], *Christopher M.U. Neale* [a,*], *James L. Wright* [b,2]

[a] BIE Department, Utah State University, Logan, UT 84322-4105, United States
[b] ARS-USDA, Northwest Irrigation & Soils Research Laboratory, Kimberly, ID 83341, United States

ARTICLE INFO

Article history:
Accepted 19 October 2006
Published on line 29 December 2006

Keywords:
Crop evapotranspiration
Basal crop coefficients
Canopy reflectance-based crop coefficients
SAVI
Neutron probe
Soil water content

ABSTRACT

The present paper describes the development and validation of canopy reflectance-based crop coefficients for potato using canopy reflectance (measured using hand-held radiometers and high resolution multispectral digital imagery), and extensive crop biophysical sampling in selected potato growing fields in and around Kimberly, Idaho, during 1998 and 1999 seasons. Daily crop evapotranspiration was estimated using basal and canopy reflectance-based crop coefficients, and a hydrologic water balance was conducted in the plant root zone. Independent measurements of actual soil moisture measurements were made by neutron probe and gravimetric methods, and used to validate the simulated results. The results validate the reflectance-based crop coefficient method. High resolution multispectral aerial imagery was used to highlight the spatial variability of actual crop water demand in the study fields.

1. Introduction

Crop coefficients (K_c) are used to estimate actual water use of a crop, expressed as a fraction of the potential evaporative demands from a reference evaporating vegetative surface (grass, Doorenboos and Pruitt, 1977; Allen et al., 1998; or alfalfa, Wright, 1982). The manner in which the crop uses the incident solar energy for photosynthesis, uses soil moisture, and shades the underlying soil, forms the basis of canopy-based crop coefficients.

Grattan et al. (1998) and Ojo (2000) developed a simple canopy shading-based crop coefficient from measuring percent cover using a meter stick. Results indicated that the crop coefficients increase as a quadratic function of percent shading for most of the crops that reached full cover. However canopy shading-based crop coefficients do not account for the role that soil plays in modulating the evapotranspiration (ET) requirements of crop. Wright (1982) proposed a dual crop coefficient that splits the total crop coefficient into basal crop and soil evaporation (K_s) fractions. The basal crop coefficient is expressed in percent time between planting and effective full cover (EFC)—a stage when the potential rate of ET for agricultural crops reaches its maximum.

Wright (1982) showed that the crop biophysical characteristics (leaf area index (LAI), plant height, width, percent shading, etc.) at EFC were different for different crops: bean attained EFC at a LAI of 2.6, potato at LAI of 3.5, and sugar beet at LAI of 2.6. Similar results were reported by Tanner and Jury (1976), Stegman et al. (1980), Neale et al. (1989), Bausch (1995), and Ahmed (1997). It is reasonable to conclude that there may

* *Corresponding author*. Tel.: +1 435 770 0297; fax: +1 435 797 1248.
E-mail addresses: jharikishan@yahoo.com (H. Jayanthi), cneale@cc.usu.edu (Christopher M.U. Neale), wright@nwisrl.ars.usda.gov (J.L. Wright).
[1] Tel.: +1 435 764 0908.
[2] Tel.: +1 208 423 5965.
0378-3774/$ – see front matter
doi:10.1016/j.agwat.2006.10.020

not be a single unique LAI threshold that represents EFC because of the differences in canopy architecture and row spacing. Wright (1985) highlighted the need for better means of relating crop coefficients to actual crop development and in principle canopy reflectance-based crop coefficients fulfill that requirement.

Jackson et al. (1980) found similarities between the mean crop coefficients (K_c) for small grain to the ratio of the perpendicular vegetation index (PVI) for wheat to PVI of wheat at full canopy cover. Heilman et al. (1982) investigated the relationship between percent cover and reflectance-based perpendicular vegetation index (PVI) for alfalfa. Neale (1987) transformed the work done by Jackson et al. (1980) relating the crop canopy reflectance to crop coefficients into an operational technique using multispectral inputs for estimating actual crop ET. Neale et al. (1989) derived a canopy reflectance-based crop coefficient by transforming the seasonal normalized difference vegetation index (NDVI) using the percent shading, leaf area measurements, the dates of planting and attainment of EFC.

Neale (1987) and Bausch (1993) found that in using NDVI, the reflectance-based crop coefficient (K_{crf}) varied up to 24% for a range of colored soil backgrounds. Bausch (1995) used the soil adjusted vegetation index (SAVI) (Huete, 1988) to evaluate the performance of the corresponding reflectance crop coefficient as an effective tool for irrigation scheduling for corn. Neale et al. (1996) extended the SAVI-based crop coefficients for cotton to estimate corresponding crop ET.

Ahmed (1997) used hand-held radiometer data, together with airborne multispectral videography, in developing SAVI-based crop coefficients for a composite crop pattern in an irrigated canal command area. Aerial multispectral videography was used to estimate the actual irrigation schedule in a large irrigated tract consisting of alfalfa, barley, and wheat (based on corresponding SAVI-based spectral crop coefficients, meteorological inputs and soil parameters in a GIS environment). The estimated composite crop water demand in the irrigation district compared well with the measured canal deliveries into the command area (Ahmed, 1997; Neale et al., 2005).

D'Urso (2001) used satellite data-based canopy reflectance approach to estimate surface albedo, leaf area index, and height of crop. Meteorological data, tertiary canal topology, geometric and hydraulic characteristics of the conveyance system, soil hydrology, land use, remotely sensed crop coefficient imagery, and irrigation scheduling options were organized in a GIS environment. A water balance was conducted for Gromola district, Italy, and the satellite-based estimated water demands in the irrigation district were compared with the measured irrigation water releases during the 1994 season.

The concept of transforming the soil adjusted vegetation index (SAVI) into a reflectance-based crop coefficient (K_{crf}) is observed to be an effective substitute for the traditional K_{cb} as it is (i) more sensitive to actual crop growth patterns in the field, (ii) sensitive to periods of slow and/or rapid growth induced by climatic conditions, (iii) more representative of actual plant growth if affected by moisture stress/insect damage, (iv) sensitive to plant growth differences influenced by soil factors, and (v) readily applicable to newer varieties of crops developed during the last decade.

The state-of-art with respect to the development of reflectance-based crop coefficients and its subsequent method for estimating crop ET is currently restricted to alfalfa, grain crops, and cotton. The corresponding database is deficient in case of tubers, roots, and vegetable crops as the corresponding reflectance data is absent. Potato, sugar beet, bean, and a wide variety of vegetable crops are cultivated in considerable areas in northwestern United States. Potato in Idaho, Oregon, and Washington accounts for more than 80% of the irrigated areas and more than 35% of the national irrigated area (Wright and Stark, 1990). Furthermore, almost all of the potato acreage in Idaho occupying about 168,000 ha (about 415,000 acres) is considered irrigated (Brad King, USDA ARS, Kimberly, personal communication) which amounts to 34% of the entire fall harvested acreage in United States (Stark and Love, 2003). Potato is very sensitive to water stress, and in view of high economic returns on the relatively large production investment involved, extreme care is taken to maintain optimal soil moisture in the root zone through efficient irrigation. This underlines the need to develop spectral crop coefficients, and validate its use, in cases of major non-grain and vegetable crops.

This paper describes the development and validation of canopy reflectance-based (representing the actual crop growth and development) crop coefficient for potato. Validation of the above was accomplished by comparing the simulated soil moisture in the root zone (using basal and reflectance-based crop coefficients to estimate crop ET) with the actual soil moisture values measured by neutron probe.

2. Methods, materials and study area

2.1. Overview of the methods

The experimental determination of crop coefficients, and their validation, is normally conducted with the help of concurrent precise lysimeteric measurements. In the present study, due to the lack of lysimeter ET data, the experimental data (leaf area, ground cover, phenological dates and crop water use) collected in the development of basal crop coefficients by Wright (1982) were taken as reference, and used in the development and validation of reflectance-based crop coefficients. With a view to replicate the microclimate, soil, and crop growth conditions corresponding to the development of basal crop coefficients in the 1970s (Wright, 1982), study fields were selected in and around Kimberly, Idaho. Multiple replications of plant sampling were conducted to account for influences due to varietal and soil differences. Table 1 lists the fields selected, crop types and varieties, and key phenological events observed during the 1998 and 1999 seasons. It also includes the crop phenology details for which basal crop coefficients were developed by Wright (1982). The row spacing for potato was 92 cm (36 in.) in all the case studies.

Experimental data collection consisted of (i) canopy reflectance data over representative rows and furrows (observation transects), and bare-soil reflectance in each field, (ii) reflectance measurements over a calibrated barium sulfate standard reference panel with known bi-directional reflectance properties, (iii) canopy shading using LICOR Quantum