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Crop Yield Function and Evapotranspiration Comparison for Crops near Hatch, New Mexico, USA

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Abstract: The state engineer in New Mexico continually evaluates the water rights of many of the water users in the state. Recently, the state has evaluated the water rights of water users in the Hatch, NM area. To determine water users' water rights and claims, this study used crop yield data to determine water requirements using crop yield functions. Average annual crop yields were collected for alfalfa, silage corn, grain sorghum, onions, and chile. These yields were entered into yield functions to estimate the amount of water or evapotranspiration (ET) that is required to produce these crops. This study compared the ET values from the yield functions to ET values that were determined using 10 years of temperature data for the area. The results indicated that the estimates of crop water requirements based on crop yield functions are comparable to those based on crop ET values. This comparison only accounts for part of the water requirement because additional water is needed due to irrigation inefficiency. Water losses in the irrigation process require that additional water is needed to produce the crop yields for this area.

Key Words: Crop water requirements, Crop yield function, Evapotranspiration, Hatch, NM

1. Introduction

Water is an important and often scarce resource which is the key for the sustainability of agriculture in arid regions including New Mexico. However, water resources in this region are declining at an alarming rate because of drought that has persisted for the majority of years since 1994 (Gutzler, 2013). The majority of water consumption in the arid southwest is utilized by irrigated agriculture. More than 28 percent of New Mexico's cropland is under irrigated agriculture[A]. Accurate estimations of crop water requirements are important to enhance optimization and efficiency of applied water and subsequently determine irrigation water requirements and scheduling.

Irrigation application requirements for crops are important criteria for water rights negotiation (Blaney *et al*., 1938; Schaible and Aillery, 2012). For example, water users in the Hatch, New Mexico area recently underwent a water use evaluation by hydrologists from the New Mexico Office of the State Engineer. Farmers were required to account for the amount of water that they need and use to grow crops in their area. They were required to report their crop yields so that they could validate crop water needs using a crop yield function.

Researchers at New Mexico State University later compared the yield data water requirements to ET data. The ET values were determined from an analysis of temperature data for the area. It should be noted that the ET data and the yield function data only account for the water that is required for the crop production. It does not consider irrigation efficiencies.

Sammis and Mexal (1999) discussed irrigation in New Mexico and stated that the majority of irrigation is surface applied. This means that up to 50% of the water that is diverted to a field is lost to carriage loss, runoff, deep percolation, or some other loss that cannot be accounted for. The Hatch New Mexico area is located in Dona Ana County of New Mexico (32°N, 107°W). The major crops grown in the area include chile, onions, pecans, alfalfa, grain sorghum, and silage corn. Nearly all of this irrigation is accomplished with flood irrigation practices.

There are two sources of water for this area. A portion of this water supply comes from the Elephant Butte and Cabillo reservoirs via the Rio Grande and Elephant Butte Irrigation District canal system. The other source of water comes from groundwater wells.

Considering that New Mexico has been in a drought for nearly 20 years, researchers and water users are questioning the long term viability of the water supply (Barnes, 2011; Schaible and Aillery, 2012). Many ask about the sustainability of the irrigation practices in the area. This is one of the reasons why the State Engineer has been validating crop water needs.

1.1. Crop production functions

Crop production functions indicate how varying amounts

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of water influence crop yields (Liu *et al*., 2002). Production functions are simplified relationships that can be used to determine crop water requirements for a given crop yield (Hanks, 1974). Yield functions are used for "irrigation system design and management, agronomic and economic development, feasibility studies and the benefits of irrigation water compared with other water uses" (Hanks, 1974).

Yield functions are calibrated for the particular area where the crop is grown (Sammis, 1981). In this study, the relationship that was used for alfalfa was developed from New Mexico State University research data. Smeal *et al*. (1992) developed the following crop production function:

$$Y=168.035(ET)-2{,}538.391 \quad (1)$$

Where Y = alfalfa seasonal crop yield (kg ha^{-1}), and ET is crop water use (cm depth). This equation was converted from its original form to accommodate metric units. In addition, this equation is manipulated to solve for required evapotranspiration depth when a crop yield is entered into the equation. For example equation 1 would take the following form:

$$ET=\frac{Y+2{,}538.391}{168.035} \quad (2)$$

For this analysis, it is assumed that a total of seven cuttings of alfalfa are harvested in the growing season. It is also assumed that the first crop is grown for 54 days before it is cut. The next six crops are harvested every 28 days. These are common time periods for alfalfa in this area.

Kallsen *et al*. (1983) developed a crop yield function for silage corn that is grown in New Mexico. This function is:

$$Y=238.9(ET)-7309 \quad (3)$$

Where Y = silage corn seasonal crop yield (kg ha^{-1}), and ET is crop water use (cm). Corn is usually planted in the Hatch area in late April or early May. The crop usually grows for about 110 days before it is harvested for silage.

Al-Jamal *et al*. (2000) presented an onion crop water production function:

$$Y=1{,}224.2(ET)-35{,}300.0 \quad (4)$$

Where Y = onion seasonal crop yield (kg ha^{-1}), and ET is crop water use (cm). Onions are planted in Hatch in February and in late September. The February crop grows for about 165 days before it is harvested while the fall crop grows for about 210 days.

Wierenga (1983) developed a crop yield function for green chile that is grown in southern New Mexico. This function is:

$$Y=0.5168(ET)-12.1 \quad (5)$$

Where Y = green chile seasonal crop yield (tonne ha^{-1}), and ET is crop water use (cm). The crop is usually planted in the middle of April in New Mexico and it grows for about 150 days before it is harvested.

Yield function data are limited in availability for forage sorghum. Saeed and El-Nadi (1998) published some research on sorghum forage crops. This research does not present a yield function, but it does have graphs from which water requirements can be determined. In the Hatch area, sorghum crops are planted in early May and grow for about 90 days before harvest.

2. Methods

Recent investigations in the Hatch area used crop production to determine the irrigation water requirements for average crop yields. Average yield data were collected and used to estimate the amount of water required. In order to validate these data, temperature data for 10 years (2001 to 2010) were collected to estimate crop evapotranspiration. The Hargreaves equation was used to determine the average reference ET for these 10 years and subsequently the individual crop ET was computed.

2.1. Hargreaves ET equation

For this study, an estimate of crop ET water use was required for the entire growing season. This allowed for a comparison to the water use that was estimated from the crop water yield functions. When all of the weather data are available, the Penman-Monteith equation is recommended to estimate crop ET (Hargreaves and Merkley, 2010). However, only air temperatures were available for this area so the Hargreaves equation was used to estimate ET.

$$ET_o = 0.0023R_A(T+17.8)\sqrt{TR} \quad (6)$$

Where ET_o = reference evapotranspiration; R_A = extraterrestrial solar radiation; T = the mean temperature; TR = the average daily temperature range. Hargreaves and Merkley (2010) explain that this equation does not work as well for daily ET estimation but it provides a good estimate of ET for longer periods of time. Considering that the crop water use is estimated for the growing season, this equation will accomplish the goal of this research. The extraterrestrial radiation has to be estimated for the above equation using a relationship found in Hargreaves and Merkley (2010).

The crop coefficient (K_c) values and the growth stages that are used to convert reference ET_o to crop ET_c estimations are found in Hargreaves and Merkley (2010). This text presents a range of K_c values for the various growth stages. The values at the higher end of these growth stages were selected because of the intense sunlight that is regularly received in New Mexico.

Table 1. Summary of the water requirements to produce the crops for the Hatch, New Mexico area and the expected ET_c for these crops.

Crop	Average Yield (kg ha^{-1})	Yield Function Depth (cm)	Hargreaves ET_c (cm)	Diff. (cm)
Alfalfa	19,712	132.7	140.8	-8.1
Silage Corn	9,072	68.6	74.5	-5.9
Onions	67,200	83.7	91.4	-7.7
Chile	35,840	92.8	93.5	-0.7
Sorghum	11,200	46.6	52	-5.4

3. Results

The crop yield functions are normally used to determine the amount of water that is required to produce the recorded crop yields. In this study the crop yield is already known and the yield functions are manipulated to determine the required seasonal water depth for the reported crop yield. A relatively good agreement is observed between seasonal water depth that is estimated from Hargreaves *ET* equation and the seasonal water use that is estimated by the yield functions for alfalfa, silage corn, onions, green chile, and grain sorghum.

As these data were evaluated, the Hargreaves seasonal ET_c totals could be varied by 2 to 4 centimeters simply by slightly changing the K_c values. While this may have allowed for a closer correlation of yield function values and ETc values, the K_c values that are reported by Hargreaves and Merkley (2010), were used to be consistent with using of the Hargreaves equation.

4. Discussion

When the yield functions are used to determine the amount of water that would be required to produce the average crop yields, these values corresponded closely to the crop ET values determined from the temperature data and the Hargreaves equation. This indicates that the producers in the area are harvesting the reported crop yields.

Table 1 shows that there are differences ranging from 0.7 cm to 8.1 cm. These differences are expected for a number of reasons. First there are errors in the yield function and Hargreaves equations. The yield functions are linear equations that were determined from a set of data that were collected for the specific crops. These functions are a best fit for the entire set of data and do not reflect the year to year variation that may be realized by the specific crop. As mentioned earlier, the Kc value can also slightly change the results. While it is believed that the K_c value is representative of the crops in the area, there could be slight differences.

Because there is an agreement does not mean that the irrigation for this area is sustainable. These numbers do not indicate the irrigation efficiency. They only indicate the amount of water that is required to produce crop yields. When efficiency is considered, more water is required for the same crop yield. Considering the drought that New Mexico has experienced for the last several years, a sustainable irrigation project needs to increase the irrigation efficiency to provide enough water to irrigate in the present season and in future years.

Irrigation management involves applying judicious amounts of water at the optimum time. Irrigation methods can vary significantly in efficiency. For example, frequent flood irrigation avoids most water stress to plants and enhances crop yields, but decreases irrigation efficiency (Sammis and Mexal, 1999). Improved yields can be achieved by using micro-irrigation techniques such as surface drip, subsurface drip, and/or micro-spray as well as low pressure sprinkler systems.

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Note

A) U.S. Department of Agriculture. (2011): New Mexico Fact Sheet. Accessed at: http://www.ers.usda.gov/data-products/state-fact-sheets/state-data.aspx#.Uss9KvuOds Ehttp://www.ers.usda.gov/data-products/state-fact-sheets/state-data.aspx#. Uss9KvuOdsE (verified Jan. 06, 2014).

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