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Water requirements of maize in the middle Heihe River basin, China

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ABSTRACT

As part of an intercomparison study on crop evapotranspiration (ET_c), six methods for estimating ET_c have been applied to maize field in the middle Heihe River basin, China. The ET_c was estimated by the soil water balance and Bowen ratio-energy balance methods while the Priestley–Taylor, Penman, Penman–Monteith and Hargreaves methods were used for estimating the reference evapotranspiration (ET_0). The results showed that the trend of ET_c was very similar, while the differences were significant among the different methods. The variations of ET_c were closely related to the LAI as well as to the meteorological features. The ET_c for the Bowen ratio-energy balance, Penman, Penman–Monteith, soil water balance, Priestley–Taylor and Hargreaves methods totaled 777.75, 693.13, 618.34, 615.67, 560.31 and 552.07 mm, respectively, with the daily mean values for 5.26, 4.68, 4.18, 4.16, 3.79 and 3.73 mm day^{-1}. 1. The Penman–Monteith method provided fairly good estimation of ET_o as compared with the Priestley–Taylor, Penman, Hargreaves methods. By contrast with the Penman–Monteith method, the Bowen ratio-energy balance and Penman methods were 25.8% and 12.0% higher, while the Priestley–Taylor and Hargreaves methods were 9.4% and 10.7% lower, respectively. Therefore, the Hargreaves and Priestley–Taylor methods were the alternative ET_c methods in arid regions of Northwest China.

1. Introduction

The Heihe River Basin is the second largest inland river basin in arid regions of Northwest China and one of the main grain producing regions in China (Chang et al., 2006). Water shortage has become the major obstacle to the plant production which relies thoroughly on irrigation (Kang et al., 2004). In the middle Heihe River basin, in years with a little precipitation, water consumption accounts for 86% of the total water resource available from the Heihe River, and 96% of the water consumption is used for irrigation (Chen et al., 2003). Crop water requirements is supplied mainly by the irrigation, which is essentially governed by ET_c (Smith, 2000; Moges et al., 2003). Moreover, water requirement of crop is needed to quantify the changes in the ET_c due to climate and land surface changes (Choudhury and DiGirolamo, 1998; Hutjes et al., 1998). The quantification of ET_c is critical to the irrigation scheduling and water allocation because the large share of the water budget is typically composed of ET_c in arid regions (Baumgartner and Reichel, 1975). Therefore, it is important that crop water requirement was estimated with the combination of climate, soil and plant factors to distribute water resource and to improve water use efficiency in arid regions of China.

Water shortage has heightened the importance of water resource in agricultural production in arid regions (Payero et al., 2008). Recently, many researchers concentrated on crop water requirements in arid regions (Abdelhadi et al., 2000; Ali et al., 2000; de Azevedo et al., 2003; Jia and Luo, 2006). However, ET_c is still ambiguous because the upper limit to ET_c depends on vegetation type as well as soil water and climatic conditions (Burman and Pochop, 1994). The ET_o was estimated by many methods (Jensen, 1974; Hill et al., 1985), and these methods range from the complex energy balance equations (Allen et al., 1989) to simpler equations which require limited meteorological data (Hargreaves and Samani, 1985). Differences in ET_c are significant among these methods (Shuttleworth, 1991). The Penman–Monteith method had been successfully recommended by FAO to calculate ET_o under different conditions (Bormann et al., 1999; Abdelhadi et al., 2000; Kang et al., 2003; Goyal, 2004), and showed higher accuracy and wider suitability compared with Priestley–Taylor, Hargeaves, Penman, Blaney–Criddle, and other methods (Beyazgül et al., 2000; Kashyap and Panda, 2001; Droogers and Allen, 2002; Rivas and Caselles, 2004). But, the climate data required in the Penman–Monteith method are not always available, especially in developing regions. Therefore, it is necessary to select the most appropriate

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and feasible method of estimating ET_o in the arid regions of Northwest China.

Maize (*Zea mays* L.) is the main irrigated crop in the middle Heihe River basin, and it has high irrigation requirements (Rhoads and Bennett, 1990; Stone et al., 2001). In arid regions, the daily ET_c of maize often exceed 10 mm day^{-1} during the growing period (Howell et al., 1997). Although some works on the ET_c of maize have been documented in worldwide (Rhoads and Bennett, 1990; Howell et al., 1997; Stone et al., 2001; Kang et al., 2000, 2003; Liu et al., 2002; Tan et al., 2002; Li et al., 2003; Watanabe et al., 2004; Utset et al., 2004; Hupet and Vanclooster, 2005), detailed investigation on the ET_c using different methods is lacking for maize in arid regions of Northwest China. However, it is important to determine the irrigation schedule and to improve water use efficiency at irrigated agriculture in arid regions.

Crop water requirements and ET_c at Pingchuan town are the representatives in Heihe River basin. In this paper, as part of an intercomparison study on the ET_c and ET_o using different methods, the water balance and the five meteorological methods for estimating ET_o, including Bowen ratio-energy balance (Mastrorilli et al., 1998), Priestley–Taylor (Priestley and Taylor, 1972), Penman–Monteith (Allen et al., 1994, 1998), Penman (Penman, 1948) and Hargreaves method (Hargreaves and Samani, 1985) have been applied on the maize field. Therefore, the purpose of this study was to: (i) estimate water requirements and ET_c of maize under the flood irrigation method; (ii) select the best method of ET_c appropriate in arid regions of Northwest China; (iii) seek for the optimal irrigation amount for arid regions of Northwest China. These measurements also provide the basis for an analysis of water physiology in maize during the growing period, and the temporal variation in ET_c can be used to improve irrigation scheduling and regional water allocating in arid regions.

2. Materials and measurements

2.1. Study area

The study area is located at Pingchuan town, in the middle Heihe River basin, Gansu province, China (between 39°18′ and 39°24′N, and 19°56′ and 100°10′E) (Fig. 1). It belongs to the representative piedmont valley plain oasis. The climate is continental arid temperate. The annual average precipitation is 116.8 mm (1965–2000), and about 60% of the total precipitation with low rainfall intensity is received during July–September, and only 3% during winter. The potential evaporation is 2365.6 mm $year^{-1}$, and the dryness index is 15.9. The annual average temperature is 7.6 °C, and the lowest and highest temperature are about −27 °C in January and 39.1 °C in July, respectively. There are about 165 frost-free days in a whole year. The growing period ranges from March to October. The shallow, porous and highly permeable soil in the study areas are typically characterized as greyish-brown desert soil, sandy loam and sandy soil, respectively.

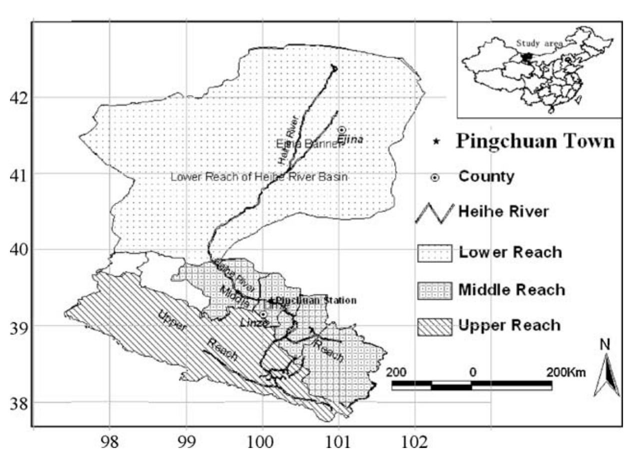

Fig. 1. The map of the Heihe River Basin and location in China.

The study area has an agricultural development history of over 2000 years owing to its flat land, adequate sunlight, and convenient water resource from Qilian Mountains. The plain oasis (the middle Heihe River basin) has then become an important commodity grain base in China. The main crop is maize which generally is sown in the late April and harvested in the middle 10 days of September.

2.2. Meteorology measurements

The meteorological data were used for estimating the components of the energy fluxes on the interface between plant/soil system and the atmosphere from January to December in 2007. The sensors were installed at a tower at Pingchuan town, in Linze Inland River Basin Research Station, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. The location of this tower provided a mean fetch of 500 m in all directions. The tower was installed in experimental area of a maize farm which was surrounded by a large area planted maize. The sensors for wind speed, air temperature and humidity, atmospheric pressure and water vapor were installed at two levels above crop canopy (1 and 2 m). The sensors of net radiation and photosynthetically active radiation were installed at 1 m above crop canopy. Wind velocity was measured with the three-dimensional sonic anemometer. Air temperature was measured with the CS500 probe installed within a radiation shield. Air humidity was measured with the infrared gas analyzer. Atmospheric pressure and water vapor were measured with the infrared gas analyzer. Net radiation was measured with a closed-cell thermopile-style sensor. Another radiometer was also used to measure upward and downward welling short-and longwave radiation to estimate albedo. Three soil heat flux plates were buried at a depth of 2 cm in 1 m × 1 m plots 20 m distance apart near the base of the tower. Rainfall was measured with a tipping bucket rain gauge. The meteorological data were measured at 10 Hz and recorded every 5 min on a CR10X datalogger and then stored 30 min average data. But the data of wind speed and precipitation were stored every 10 min.

2.3. Crop morphological and soil measurements

A field experiment on water requirements of the maize was conducted in a 90 m × 90 m experimental area in a maize farm. In the center of the experimental area, an experimental plot (10 m × 10 m) was selected for crop morphological and soil measurements. The growing period of maize was established from days after sowing (DAS = 1) (April 21, 2007) to harvest (DAS = 148) (September 15, 2007). The crop field observations were started after germination and early growth. The growth cycle of crop was divided into the following four phenological stages: (a) initial stage (April 21 to May 15) from sowing date to about 10% ground cover. (b) Development stage (May 16 to July 4) from 10% ground cover to effective full cover (70∼80%). (c) Mid-season stage (July 5 to August 15) from effective full cover to the start of maturity. (d) Late-season stage (August 16 to September 15) from the start of maturity to harvest.

Leaf area index (LAI), crop height and density were recorded at intervals of about 10 days during the growing period. The LAI was measured with the plant canopy analyzers. The irrigation was measured using a water meter which was installed at the hydrant