Computers and Electronics in Agriculture 152 (2018) 375–384

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

Evaluation of artificial intelligence models for actual crop evapotranspiration modeling in mulched and non-mulched maize croplands

Dahua Tang[a], Yu Feng[a], Daozhi Gong[a,*], Weiping Hao[a], Ningbo Cui[b]

[a] State Engineering Laboratory of Efficient Water Use of Crops and Disaster Loss Mitigation/MOA Key Laboratory of Dryland Agriculture, Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing, China

[b] State Key Laboratory of Hydraulics and Mountain River Engineering & College of Water Resource and Hydropower, Sichuan University, Chengdu, China

ARTICLE INFO

Keywords:
Maize
Evapotranspiration
Eddy covariance
Support vector machine
Artificial neural network

ABSTRACT

Although many studies have demonstrated the good performances of artificial intelligence (AI) approaches for reference evapotranspiration modeling, the applicability of AI approaches for actual crop evapotranspiration (ET) modeling still remains uncertain, especially in plastic mulched croplands. The objective of the present study was to evaluate the applicability of two different artificial intelligence approaches, including support vector machine (SVM) and artificial neural network optimized by genetic algorithm (GANN), in modeling actual ET in a rainfed maize field under non-mulching (CK) and partial plastic film mulching (MFR). A field experiment was conducted for continuous measurements of ET, meteorological variables, leaf area index (LAI) and plant heights (h_c) under both CK and MFR during maize seasons of 2011–2013. The meteorological data containing minimum, maximum, mean air temperature, minimum, maximum, mean relative humidity, solar radiation, wind speed and crop data including LAI and h_c during maize growing seasons of 2011–2012 were used to trained the SVM and GANN models by using two different input combination, and data of 2013 were used to validate the performances of the models. The results indicated that SVM1 and GANN1 models with meteorological and crop data as input could accurately estimate maize ET, which confirmed the good performances of SVM and GANN models for maize ET estimation. The performances of SVM2 and GANN2 models only with meteorological data as input were relatively poorer than those of SVM1 and GANN1 models, but the estimated results were acceptable when only meteorological data were available. Due to the optimizing of the genetic algorithm, the GANN models performed a slightly better than the SVM models under both CK and MFR, and can be highly recommended to model ET.

1. Introduction

As the only term that appears in both surface energy balance and water balance equation (Xu and Singh, 2005; Feng et al., 2017a), evapotranspiration (ET) is a crucial component in eco-hydrological processes, and plays a vital role in determining crop water requirement (Patil et al., 2016; Feng et al., 2016). In agricultural science especially in arid and semiarid regions, proper estimation of crop ET is important (Kisi et al., 2015).

ET can be measured by experimental techniques. Eddy covariance (EC) systems now is considered as the standard technique (Baldocchi et al., 2001). This method are non-destructive, can continually and directly sample the turbulent boundary layer, the fluxes are averaged over medium sized (50–200 m) areas and the EC systems are automated. However, EC has many disadvantages, such as energy balance closure errors and the need for a relatively large fetch to measure (Lee et al., 2010; Allen et al., 2011; Zhang et al., 2013).

The direct measurement of ET using experimental techniques is time-consuming, expensive and not available in many regions, thus developing mathematical models for estimation of ET is the only alternative. The ET models include the direct single-layer Penman-Monteith (P-M) and Priestly-Taylor (P-T), two-layer Shuttleworth–Wallace (S-W) and the indirect FAO crop coefficient models. Good performances of these models or their calibrated versions for ET estimation in different underlying surfaces were found. Zhang et al. (2008) compared the estimated ET by different with the measured ET by the Bowen ratio-energy balance method in a vineyard, and found the variation of the estimated ET from the three models were similar to that of the measured ET. Gharsallah et al. (2013) compared the direct P-M, S-W, indirect FAO single and dual crop coefficient models to latent

* Corresponding author at: Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing 100081, China.

E-mail address: gongdaozhi@caas.cn (D. Gong).

https://doi.org/10.1016/j.compag.2018.07.029
Received 1 March 2018; Received in revised form 14 June 2018; Accepted 23 July 2018

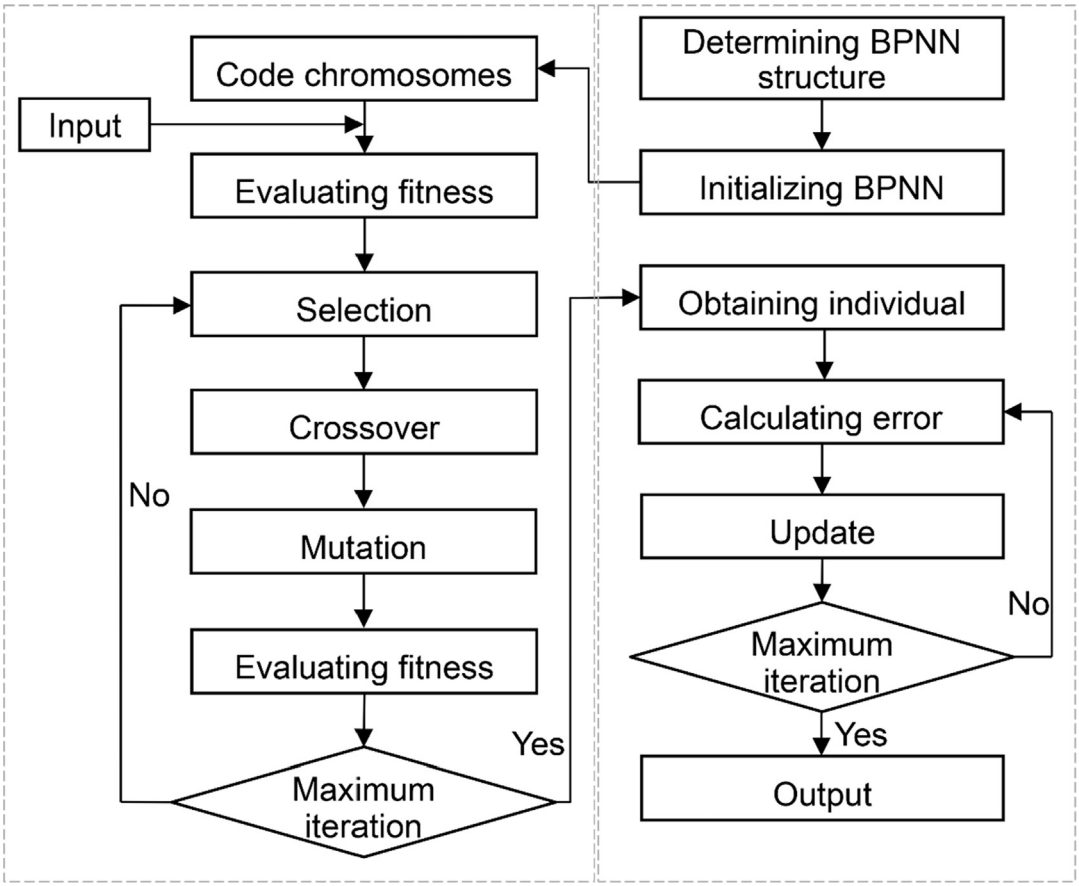

Fig. 1. The flowchart of the coupled GANN model.

Table 1
Summary of input combinations for each AI model under CK and MFR.

Model	Meteorological data				Crop data	
	T	*RH*	*Rs*	U_2	LAI	h_c
SVM1	√	√	√	√	√	√
GANN1	√	√	√	√	√	√
SVM2	√	√	√	√		
GANN2	√	√	√	√		

T is air temperature, including maximum, minimum and mean air temperature; RH is relative humidity, including maximum, minimum and mean relative humidity; R_s is solar radiation; U_2 is wind speed at 2 m height; LAI is leaf area index; h_c is plant height.

heat fluxes measured in 2006 by EC systems in a irrigated maize field in the Padana Plain of Northern Italy, they found P-M and S-W models were more performing. Ding et al. (2013a) developed a modified P-T model incorporating the effect of leaf area, soil moisture, mulching fraction and leaf senescence on ET and parameterized and validated the model by using the measured ET from EC systems in an irrigated maize field with mulching of northwest China, a good agreement was found between ET estimated by the modified P-T model with measurement for both of half-hourly and daily time scale. Nevertheless, many input parameters of direct models cannot be easily obtained, therefore wide application of the direct models is limited (Allen, 2000; Ding et al., 2013b). The indirect models proposed by the Food and Agricultural Organization, including single and dual crop coefficient models, have overcome these deficiencies since the crop coefficient, K_c, has contained all differences between the reference surface and the physiologies, physics and morphologies of crop in question (Allen et al., 1998; Allen, 2000; Ding et al., 2013b). The FAO K_c models, especially the dual K_c model, has been widely used for crop ET estimation (Allen and Pereira, 2009; Er-Raki et al., 2010; Zhang et al., 2013; Zhao et al., 2015; Qiu et al., 2015). However, the straightforward adoption of crop coefficients recommended by FAO-56 can lead to the errors (Zhao et al., 2015), and overestimation of plant transpiration was reported when reference evapotranspiration (ET_0) was high, as water uptake by the plants, even though well-watered, was not sufficient to meet peak hourly demand (Paco et al.,2012; Kool et al., 2014).

As an alternative to conventional methods, in recent years, artificial intelligence (AI) techniques have been successfully applied in hydrology and water resources engineering issues, including ET estimations (Karimi et al., 2017; Kiafar et al., 2017; Feng et al., 2017b; Landeras et al., 2018). Kisi et al. (2015) investigated the ability of four different AI methods, artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS) with grid partition, ANFIS with subtractive clustering and gene expression programming (GEP) in estimating long-term monthly ET_0 by using data from 50 stations in Iran. Shiri et al. (2014) applied ANN, ANFIS, Support Vector Machine (SVM) and GEP techniques for modeling ET_0 considering different data management scenarios in a wide range of weather stations in Iran. Gocic et al. (2015) analyzed the reliability of genetic programming (GP), SVM-firefly algorithm (SVM-FFA), ANN, and SVM–wavelet (SVM–Wavelet) models. Patil et al. (2016) proposed an extreme learning machine (ELM) algorithm to estimate weekly ET_0 for Jodhpur and Pali meteorological weather stations located in the Thar Desert, India. Xing et al. (2016) studied the simplification and universality of the double-factor backpropagation neural networks for estimating ET_0 in South China. Shamshirband et al. (2016) studied the ability to optimize an ANN and ANFIS in ET_0 estimation using the cuckoo search algorithm in Serbia. Shiri (2017) compared empirical, semi-empirical and GEP for estimating ET_0 in hyper-arid regions of Iran. Antonopoulos and