The applicability of A Modified Palmer Drought Severity Index on Agricultural Drought Evaluation in the North China

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Abstract. Agricultural irrigation is an important factor affecting the development of agricultural drought, which is not showed in the Palmer Drought Severity Index (PDSI). In this work, the water balance model in PDSI has been modified by adding irrigation items, which improves the accuracy of the calculation results of the model and shortens the calculation time step. The modified Palmer Drought Severity Index (M_PDSI) is constructed by using daily weather data and irrigation data from 1985-2012 in the study area. Weekly indices cumulated in each growth stage are used for the implementation of crop models by a linear multiple regression model. The crop yield models are evaluated to determine a more appropriate agricultural drought index between M_PDSI and PDSI by comparing the predicted yields to the observed yields. By comparing the development of agricultural drought, it can be seen that the M_PDSI can improve the sensitivity to the dynamic change of soil wet and dry in short-term, and the development process of drought is more in line with the actual situation; by comparing the fitting test results of the predicted yields, it can be seen that, the M_PDSI ranks better than the PDSI in all four goodness-of-fit measures, M_PDSI is proved to be more suitable than PDSI for evaluating agricultural drought.

1 Introduction

The frequency and severity of droughts have increased over the past decade, causing heavy crop losses and posing a potentially grave threat to grain security, leading agriculture experts warn. According to the statistical results of the Chinese Academy of Agricultural Sciences, during the 59 years from 1951 to 2009, the average annual crop damage area in China increased by more than 4.67 million ha per decade. The annual average loss of food due to disasters increased by more than 500,000 ton per decade. Crop losses caused by drought account for 60% of total natural disaster losses.

Drought severity indicators are a measure of the causes and extent of drought. In 1965, W. C. Palmer proposed the concept of Climatically Appropriate for Existing Condition(CAFEC) Precipitation. Throught reflecting the dry and wet conditions of the area with the difference between the actual precipitation and considering the impact of the previous weather conditions on the later stage, a systematic method for analyzing the severity of the drought and determining the duration of the drought is established, which is called the Palmer Drought Severity Index(PDSI)[1]. PDSI has strict systemicity, which takes into account factors such as water evapotranspiration, runoff, soil moisture exchange, and the impact of pre-precipitation and water supply and demand on the later stage. The drought index derived from the principle of water balance has a clearer and clearer physical meaning, and can describe the characteristics of drought more reasonably, and has better time-space comparison. To date, PDSI has enjoyed a good reputation internationally, and the United States, Australia, Canada, South Africa and other countries have tested the applicability of its methods. Moreover, China's meteorological, agricultural, water conservancy and government decision-making departments also use the index to monitor and analyze the drought situation.

PDSI has been widely used and has been further revised. In 2004, Wells revised the climate traits and drought persistence factors, and established a more adaptive time-space adaptive Palmer Drought Index (SC-PDSI) [2]; Kingtse used measured evapotranspiration values, runoff values, and the soil moisture value replaces the calculated value, simplifies the soil moisture model, and establishes M_PDSI [3]. In China, An Shunqing et al [4-5] revised the evapotranspiration model and soil constant values to establish a Palmer drought index suitable for China's climate characteristics.

Some researchers measured agricultural drought with PDSI directly [6-8]. Nevertheless, it is believed that its limitations should be recognized. The occurrence of an agricultural drought is the result of a combination of many factors and the drought process is complex and changeful; there are many different indexes from different point of view. PDSI, which contains a clear physical mechanism to give full consideration to precipitation, evapotranspiration, runoff and soil

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properties, such as water conditions, can describe the intensity, range and duration of the drought, and it is used widely to assess drought. the index is too large a time scale and the cycle is too long, which is more suitable for long-term drought monitoring and evaluation. The monitored dry and wet change cycle however, is too long to reflect the provisional crop water status and thus cannot be directly applied to agricultural drought monitoring. Furthermore, there are many natural factors affecting agricultural drought, such as precipitation, temperature, soil moisture, groundwater table and so on. Agricultural irrigation, a non-negligible human factor, is also a significant factor that might be a marked influence on agricultural drought, as it significantly affects the dynamic of soil moisture. This cannot be satisfactorily reflected by the PDSI. It is necessary to consider the influence of irrigation to formulate an accurate assessment of agricultural drought [9-11].

North China is densely populated and economically developed, and it is the primary area in the region for producing crops such as winter wheat and summer maize. Nevertheless, a continental monsoon climate in the area results in lesser rainfall amounts. Drought has become an urgent issue as its high frequency is caused by insufficient precipitation, especially in spring, when winter wheat grows rapidly. Therefore, agricultural irrigation has become a necessary means to ensure the normal growth and development of crops, and to achieve stable grain production. The effects of irrigation on farmland soil moisture condition should be taken into account. In this work, a typical agricultural region in the North China, Beijing-Tianjin-Hebei region is selected as a case study. The water balance model in the PDSI is modified by including irrigation in the calculation of soil water content. Meanwhile, the time step is shortened from one month to one week in order to build a Palmer drought severity index that is adapted to the monitoring and assessment of agricultural drought. And compare farmland soil moisture and agricultural drought results. Not only that, but to better illustrate the applicability of M_PDSI in agricultural drought assessment, the M_PDSI and PDSI are used to develop a set of winter wheat and summer corn yield models. By comparing the performance of two drought index to determine which is more appropriate for measuring agricultural drought. The performance of the two drought indices are evaluated using four goodness-of-fit measures.

2 Study area

The study area is located in the middle of the North China (Fig. 1). It belongs to a transition region between a humid climate and arid climate with four distinct seasons: hot, rainy summers and cold, dry winters. The average temperature varies from 4°C to 14°C and the annual precipitation varies from 385mm to 770 mm. The annual potential evapotranspiration is about 1000mm, which is much larger than the annual average precipitation. The rainfall in summer is heavy, about 2/3 of which falls during June–September. The region has a long history of agricultural reclamation and is an important grain producing area in China. The main crops are winter wheat and summer corn. The winter wheat and summer corn are planted in two forms. In general, wheat is sown in early October and harvested in early June. The corn was planted in mid-June and harvested in late September of that year. The whole growth period of wheat is more than 250 days, and irrigation was conducted 4-5 times in the growing period. The whole growth period of corn is about 100 days, and irrigation was conducted 2-3 times in the growing period, and the water consumption of corn is larger. The spring is in the critical period of winter wheat growth, the precipitation is less than 100 mm, which only accounts for merely 20% of the total annual precipitation, far less than the water requirement for winter wheat growing. For that reason, irrigation is highly necessary for making crops grow and producing high yields.

Figure 1. The location and topography of the study area

3 Materials and methods

3.1 Materials

For the selected crops(Winter wheat and summer corn) and for the soil-atmosphere units considered (Shijiazhuang, Luancheng, Raoyang, Xingtai, Nangong) the following data were available: a) The daily time series of meteorological data (precipitation, temperature, wind speed, air humidity, solar radiation) from 25 meteorological stations during 1985-2012 were used in this study. The data was provided by the China Meteorological Science Data Sharing Service Network; b) the soil data mainly includes soil texture, saturated water content, field water holding capacity, and wilting coefficient; c) 2007-2012 measured data of soil moisture content of soil layers in the depth range of 0-100 cm of Yicheng Experimental Station in Shijiazhuang City, Hebei Province is used; d) Irrigation data for the study area from 1985 to 2012. The data adopted herein was obtained from the Statistical Yearbook of the three provinces (Beijing, Tianjin and Hebei); E) Winter wheat and summer corn yield data were available for 21 years (1992–2012) for Shijiazhuang and Luancheng, 14 years for Xingtai and Nangong (1999–2012), 18 years for Raoyang (1996–2012). Crop yield data obtained from the Statistical Yearbook of Hebei Province.

3.2 Methods

3.2.1 The Modified Palmer Drought Severity Index

Palmer's method begins with a water balance equation. In this work, irrigation is taken into account, and the time step is shorten to one week to increase sensitivity to short-term wet and dry changes. The modified water balance equation is expressed as follows.

$$\hat{Q} = \hat{ET} + \hat{RO} + \hat{R} - \hat{L} \quad (1)$$

$\hat{Q}$ is the CAFEC (Climatically Appropriate For Existing Conditions) water supply, including precipitation and artificial irrigation.

PDSI uses the Thornthwaite's method to calculate the amount of evapotranspiration. The factor considered by this methodis only temperature, and it is assumed that when T ≤ 0°C, PE = 0, and this is quite different from the measured value, and the effect deviation is calculated. Therefore, this time, the Penman-Monteith equation was used to calculate the evapotranspiration.

PDSI is calculated using the monthly step size, and the distribution of precipitation is uneven during the month. The soil moisture at the end of the month cannot reflect the dry and wet state at different times during the month. In order to accurately reflect the changes of soil moisture, and improve the sensitivity of the wet and dry change in the short-term, this paper uses the week as the time step in calculation.

A two-layer bucket-type model was applied to carry out the hydrological accounting in the PDSI computation method. Palmer assumes that when the rainfall is greater than the potential evapotranspiration, the water supply is sufficient, the soil water evaporates at the potential evapotranspiration rate, and the remaining water enters the soil; when the rainfall is less than the potential evapotranspiration, the rainfall provides insufficient water to meet the evapotranspiration The amount of water required, the water in the soil evaporates and loses water, and the amount of water that is emitted is equal to the sum of rainfall and soil water loss. Now, irrigation is added into the water supply, and assume that when the sum of rainfall and irrigation, that is, the water supply, is greater than the potential evapotranspiration, the actual evapotranspiration is equal to the potential evapotranspiration. It is equal to the sum of rainfall and soil water loss. Therefore,

$$ET = \begin{cases} PE & PE \le P+I \\ P+L & PE > P+I \end{cases} \quad (2)$$

Where I is the amount of irrigation, PE is the potential evapotranspiration, and P is the amount of rainfall.

Similarly, it is assumed that the water supply is less than PE, the water supply is insufficient to maintain soil evaporation and the water loss. Moisture is first lost from the upper layer at the rate of potential evapotranspiration. Until the surface layer of available water is completely consumed, the water begins to escape from the bottom soil, and the loss of the bottom soil moisture is assumed to be affected by the initial bottom soil moisture. Potential evapotranspiration and available moisture capacity (AWC) of the entire soil layer has a common impact. The amount of water loss is equal to the sum of the water loss of the surface and lower layers of soil

$$L = \begin{cases} 0 & P+I > PE \\ L_s + L_u & P+I < PE \end{cases} \quad (3)$$

Water loss from the surface layer

$$L_s = PE - P - I \text{ or } S_s \quad (4)$$

The result is the minimum of the two

Water loss from the underlying layer

$$L_u = (PE - P - I - L_s) \cdot S_u / AWC \quad (5)$$

Where PL represents the amount of water that may be lost; S_s, S_u represent the initial water content of the surface and underlying layers of the soil, respectively. AWC represents the combined available moisture capacity in both soil layers.

It is assumed that only if the water supply is greater than the potential evapotranspiration

$$R = AWC - (S_s + S_u) \quad (6)$$

Runoff is assumed to occur if Q is larger than PE and both layers reach field capacity.

$$RO = P + I - ET - R \quad P + I > PE \quad (7)$$

The climatic coefficients of each hydrological sub-item are evapotranspiration coefficient, recharge coefficient, runoff coefficient and loss coefficient, which are the ratio of the average value of each component to the average possible value.

$$\begin{aligned} \alpha &= \overline{ET} / \overline{PE} \\ \beta &= \overline{R} / \overline{PR} \\ \gamma &= \overline{PR} / \overline{PRO} \\ \delta &= \overline{L} / \overline{PL} \\ 0 &\le \alpha, \gamma, \beta, \delta \le 1 \end{aligned} \quad (8)$$

Where the symbol "-" indicates that the value is averaged value in calculation.

The difference between the "CAFEC" precipitation and the actual precipitation P is the water anomaly $d = P - \hat{P}$

The modified PDSI calculations need to be modified accordingly. The water anomaly value is the sum of rainfall and irrigation, and the difference between the climate and the appropriate water supply.

$$d = P + I - (\alpha \cdot PE + \gamma \cdot PRO + \beta \cdot PR - \delta \cdot PL) \quad (9)$$

On that basis, the difference d was converted into indices of moisture anomaly z, which was defined as

$$z = k \cdot d \quad (10)$$

Where k is the climatic characteristic that can be estimated as

$$k = \frac{\overline{PE} + \overline{R}}{\overline{P} + \overline{I} + \overline{L}} \quad (11)$$

An empirical formula for determining drought severity was given by the equation

$$X_i = 0.72 X_{i-1} + z_i / 22.1 \quad (12)$$

Where X_i is the M_PDSI for the ith week and X_{i-1} is previous week's M_PDSI.

Eqs.(10)-(12) are the final expression of M_PDSI in the study area.

3.2.2 The Relative Soil Moisture Drought Index

The water content of the crop root layer soil is the main indicator of agricultural drought at the decision point. The Relative Soil Moisture Drought Index (RSM)[12] is one of the indicators for characterizing soil drought and can directly reflect the increase or decrease of available water. Therefore, RSM uses the measured soil moisture data to divide the drought level, which can more accurately determine the actual degree of agricultural drought. The work uses the RSM to test and compare the M_PDSI.

As the crop grows and develops, the root system of the crop grows and deepens, and the root layer is continuously thickened. Therefore, different soil depths are taken during the growth stage of the crop: the depth of the soil layer is 20 cm in the early stage of crop sowing and growth, and 50 cm in the middle and late stages of crop growth. The so-called pre-growth period refers to the vegetative growth period of the crop, and the period before the growth of the winter wheat refers to the period before the return to the green, usually from the beginning of October to the end of February; the pre-growth period of the corn refers to the seedling stage and the three-leaf stage (joint stage). Previously, it usually ends between mid-June and mid-July. RSM is very suitable for northern China and natural grassland pastoral areas with dry crops such as corn and wheat as the main seeding types.

The relative humidity of the soil is calculated as follows:

$$RSM = a \cdot (\sum_{i=1}^{n} \frac{w_i}{w_{FCi}} \cdot 100\%)/n \qquad (13)$$

RSM represents the average soil relative humidity (%) of all soil layers; w_i represents the volumetric water content of the i-th layer of soil (mm);w_{FCi} represents the soil water holding capacity of the i-th layer (mm); n represents the measured value of soil water content Number; a indicates the adjustment factor of the crop development stage. The seedling stage is 0.9, the water critical period is 1.1, and the rest development period is 1. The water critical period refers to the period when the crop is most sensitive to moisture, that is, the growth period in which water has the greatest impact on crop yield. The critical period of winter wheat is from booting-heading stage, which is usually from mid-April to the end of May. The critical period of summer corn is booting-milky stage, which is from the beginning of August to the beginning of September in every year generally.

It is worth noting that since soil available water is greatly affected by soil properties, it depends on the specific conditions of soil properties in different regions. RSM also considers the different soil conservation properties of different textures, and appropriately adjusts the scope of drought classification, so that the evaluation indicators are versatile and comparable under different circumstances. The drought classifications of the PDSI and RSM are shown in Table 1.

Tab.1 The correspondence between the drought classifications of the two indices

Classification	RSM (%)			PDSI
	Sandy Soil	Loamy Soil	Clayey Soil	
Extreme Wet	*RSM*≥95	*RSM*≥100	*RSM*≥105	X≥4.00
Severe Wet	85≤*RSM*<95	90≤*RSM*<100	95≤*RSM*<105	3.00≤X<3.99
Moderate Wet	75≤*RSM*<85	80≤*RSM*<90	85≤*RSM*<95	2.00≤X<2.99
Mild Wet	65≤*RSM*<75	70≤*RSM*<80	75≤*RSM*<85	1.00≤X<1.99
Normal	55<*RSM*>65	60<*RSM*<70	65<*RSM*<75	-0.99<X<0.99
Mild Dry	45<*RSM*≤55	50<*RSM*≤60	55<*RSM*≤65	-1.99<X≤-1.00
Moderate Dry	35<*RSM*≤45	40<*RSM*≤50	45<*RSM*≤55	-2.99<X≤-2.00
Severe Dry	25<*RSM*≤35	30<*RSM*≤40	35<*RSM*≤45	-3.99<X≤-3.00
Extreme Dry	*RSM*≤25	*RSM*≤30	*RSM*≤35	X≤-4.00

3.2.3 Models based on the drought indices for the predictive assessment of the grain yield

The two drought index (M_PDSI, PDSI) variables are used to develop a set of winter wheat and summer corn yield models in 5stations(Shijiazhuang, Luancheng, Raoyang, Xingtai, Nangong) (5stations × 2 drought indices × 2 crops=20 crop yield models). Each model is derived using a linear multiple regression model fit to the data, where the independent variable is a growth stage drought index and the dependent variable is the crop yield for that linear multiple regression is used to determine the crop yield models [13]:

$$Ya = a + b \cdot T + \sum_{k=1}^{L} (\alpha_k \cdot \sum_{i=1}^{n} X_{ki}) \qquad (14)$$

Where *Ya* is the estimated crop yield; a is a constant; b is the linear trend of crop yield; *T* is the ordinal number of year(*T*=1,2,…); X_k obtained by the sum of the weekly values of the index in growth stage *k*.; n is the number of weeks in one growth stage; *L* is the number of crop growth stages which determine crop yield. The study found that crop yield is largely determined by moisture stress during the elongation to soft dough stages[14], which usually occur during March to June for winter wheat and July to September for summer corn in north China.

The crop yield models are evaluated to determine the most appropriate agricultural drought index by using two goodness-of-fit measures: The root mean square error (RMSE), and the Nash–Sutcliffe efficiency coefficient (E_{NS}). This approach provides an objective means of evaluating the drought indices that is consistent with our definition of agricultural drought and that has precedence in the literature[15-16].

4 Results and Discussion

4.1. Drought evaluation

The RSM needs the measured soil moisture data to evaluate the agricultural drought, which can objectively reflect the actual situation of agricultural drought, which also can be used as a reference to compare the evaluation results of the above two indicators. By comparing the trend of M_PDSI and PDSI values of Yucheng Station from 2007 to 2012 (Fig. 3), the trend of M_PDSI in time series is close to that of RSM, and the PDSI value before correction isn't consistent with the trend of RSM sequence. According to the correspondence between the RSM and PDSI dry and wet levels, the correlation coefficients of the weekly M_PDSI, PDSI and RSM in 2007-2012 are compared, as shown in Fig. 4. M_PDSI is more correlated with RSM values (r = 0.66), indicating that M_PDSI is more accurate than PDSI for assessing agricultural drought.

The record of the agricultural meteorological disasters in Hebei Province also confirmed that M_PDSI is more accurate than PDSI in evaluating agricultural drought. According to the data of the agricultural meteorological disasters in Hebei Province in April 2011, the relative humidity of 20cm soil in some areas of Shijiazhuang, Hengshui and Xingtai was below 60%, and there was mild or moderate drought. In May, most of the central part of Hebei Province had precipitation above 30mm, which effectively increased soil moisture and eased the drought. The M_PDSI and RSM values changed from the original negative value to a positive value, indicating the occurrence and mitigation process of the drought, while the PDSI described the drought gradually increasing. From July to August 2011, the relative humidity of 20cm soil in crops in most areas of central and southern Hebei Province was above 60%, and the moisture was suitable and there was no drought. The M_PDSI value indicates that the Yucheng area is in a drought-free or slightly wet state, while the PDSI shows an extreme drought level. Since March to April in 2012, the long-term rainfall in Yucheng area is less than 20mm, and the evapotranspiration is large. The crops are in a state of drought. With two irrigations on May 31 and June 21, the total water amount reached 200mm, the drought quickly cleared and turned to wet, while PDSI showed extreme drought. According to the data of the agricultural meteorological disasters in Hebei Province from July to September 2012, due to the abundant precipitation in the past three months, the soil moisture conditions in the southeastern part of Shijiazhuang and Xingtai are better, and the relative humidity of 20cm soil is mostly in 70-90%. The light and water in the ten years are coordinated, which is conducive to the growth and development of autumn crops. However, due to the influence of the wet state in the early stage, the soil in the southeastern part of Shijiazhuang and the eastern part of Xingtai has excessive moisture. The M_PDSI and RSM values also indicate that the farmland is in an extremely humid state during this period of time, while the PDSI shows that the farmland drought has subsided to normal. It can be seen that the PSDI is not reflected in the above process due to the influence of the dry and wet conditions in the early stage, and the corrected PDSI fluctuation is obvious, indicating that it is very sensitive to soil moisture anomaly, which can quickly reflect the short-term soil dry and wet state changes, M_PDSI evaluation. The effect of agricultural drought is satisfactory.

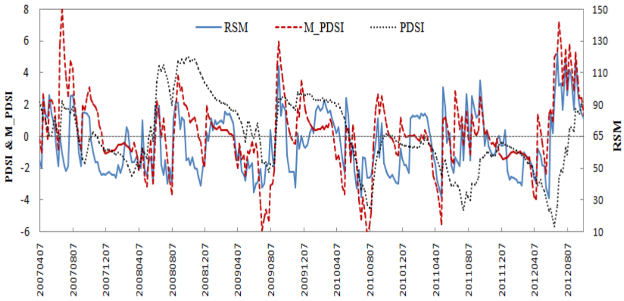
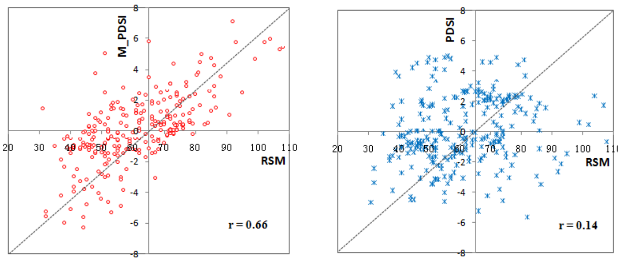


Figure 2. Time series plot of the PDSI , M_PDSI and RSM at Ruancheng from Apr 2007 to Oct 2012



(a) (b)

Figure 3.(a) Distribution of the correlation coefficient between the M_PDSI and RSM. (b) Distribution of the correlation coefficient between the PDSI and RSM. Values below 0.4 are statistically insignificant. The correlation coefficient (r) is also shown,respectively.

4.2 Model evaluation

Using the yield models for Shijiazhuang based on 1992-2001 data, yield estimates are calculated for 2002-2012 period and the models for other stations are obtained by a similar procedure. The root mean square error (RMSE) and the Nash–Sutcliffe efficiency coefficient (E_{NS}) are given in the Table 2a for winter wheat and Table 2b for summer corn. The M_PDSI rank better than PDSI in the two goodness-of-fit measures. The M_PDSI correlates brtter with the yield, it agrees almost more closely with the observed data (E_{NS} = 0.67 for summer corn, but winter wheat excepted), and it has the least amount of error (RMSE values of 442.3 kg/ha for winter wheat, 395.7 kg/ha for summer corn, respectively). M_PDSI is proved to be more suitable than the PDSI for measuring agricultural drought.

Tab.2 Mean model performance statistics for 5 stations
a) Winter wheat

Index	Site	Series for model	Series for estimation	RMSE (kg/ha)	E_{NS}
M_PDSI	Shijiazhuang	1992-2001	2002-2012	557.1	0.38
	Luancheng	1992-2001	2002-2012	558.7	0.36
	Raoyang	1996-2004	2005-2012	325.0	0.60
	Xingtai	1999-2005	2006-2012	348.8	0.61
	Nangong	1999-2005	2006-2012	421.9	0.55
	Mean			**442.3**	**0.5**
PDSI	Shijiazhuang	1992-2001	2002-2012	703.1	0.33
	Luancheng	1992-2001	2002-2012	1254.7	0.36
	Raoyang	1996-2004	2005-2012	266.0	0.65
	Xingtai	1999-2005	2006-2012	269.0	0.75
	Nangong	1999-2005	2006-2012	423.0	0.55
	Mean			**583.2**	**0.53**

b) Summer corn

Index	Site	Series for model	Series for estimation	RMSE (kg/ha)	E_{NS}
M_PDSI	Shijiazhuang	1992-2001	2002-2012	375.3	0.45
	Luancheng	1992-2001	2002-2012	754.2	0.44
	Raoyang	1996-2004	2005-2012	439.1	0.76
	Xingtai	1999-2005	2006-2012	208.9	0.90
	Nangong	1999-2005	2006-2012	200.9	0.81
	Mean			**395.7**	**0.67**
PDSI	Shijiazhuang	1992-2001	2002-2012	484.9	0.49
	Luancheng	1992-2001	2002-2012	1058.6	0.38
	Raoyang	1996-2004	2005-2012	442.4	0.78
	Xingtai	1999-2005	2006-2012	266.2	0.87
	Nangong	1999-2005	2006-2012	672.6	0.35
	Mean			**584.9**	**0.57**

5 Conclusions

Agricultural irrigation is an important factor affecting the development of agricultural drought. To accurately assess agricultural drought, the work presented a modified Palmer drought severity index to monitor and assess of agricultural drought in the study area. The agricultural irrigation processe was considered for calculating soil moisture to improve the accuracy of the calculation.This study analyzed the accuracy of the original and modifed PDSI by comparing the time series of the two PDSIs and the predicted yields to the observed yields. The results are as follows:

(1) By comparing with the drought evaluation results of the two indices report, the M_PDSI is more sensitive to the dynamic changes of soil wet and dry in short-term farmland, which can accurately describe the start and stop time and intensity of agricultural drought, and improve the accuracy of agricultural drought assessment and the timeliness of agricultural drought monitoring are greatly improved. And the drought M_PDSI reported is basically consistent with the historical records, while the PDSI has failed to detect the real processes in several months.

(2) The M_PDSI and the PDSI are used to develop a set of winter wheat and summer corn yield models, each model is derived using a linear multiple regression model fit to the data. The models are evaluated to determine which is more appropriate for measuring agricultural drought by using two goodness-of-fit measures(RMSE, E_{NS}). The results show that the M_PDSI ranked better than PDSI in almost all four goodness-of-fit measures, M_PDSI is proved to be more suitable than the PDSI for evaluating agricultural drought.

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