33 Prediction of Winter Wheat Yield Loss Caused by Dry-hot Wind Based on Remote Sensing

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Abstract—In this paper, firstly, the simulation experiment of dry-hot wind in milk-ripe stage of winter wheat was implemented. Apply MODIS data to simulate commonly used vegetation index, Simultaneous measurement of LAI, chlorophyll, leaf water potential and 1000-grain weight data was carried out and the yield was measured at the harvest stage to establish a model for evaluating the yield loss of NDVI. Take the two typical dry-hot wind years in 2013 and 2017 as an example, Then a regression model was established among $MODIS_{NDVI}$ variation and three meteorological factors including temperature, humidity and wind speed and perpendicular drought index (PDI) calculated by the MODIS images before dry-hot wind occurred, Finally, NDVI was used to integrate two models to establish the prediction and evaluation model of the dry-hot wind disaster. The results showed that there was a high correlation between $NDVI_{MODIS}$ and leaf water potential and 1000-grain weight, which were 0.9585 and 0.9911, The comparison between the estimated wheat yield and the actual yield using the established assessment model for dry-hot wind disasters shows that in the process of severe dry-hot wind, the prediction model of dry-hot wind disaster loss in winter wheat established in this paper has a high degree of reliability.

Key word: Winter wheat, dry-hot wind, MODIS, correlation analysis, multiple regression

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Introduction

Dry-hot wind is a high-temperature and low-humidity disastrous weather condition with certain wind forces and may occur during wheat flowering and grouting in the wheat-growing area in North China. As one of the main growing bases of wheat in China, Henan is frequented by dry-hot wind（Zhao, Zhao and Guo,2012）. The disaster normally takes place 20 days after wheat blossoming and last until the dough ripening stage and thus has considerable impacts on the thousand grain weight and output of wheat (Reeves, Cassaday,2002; Dhonde, Kute, Kanawad, 2000; Upreti, Malik, 2003).

Because of the advantages of synchronicity and high time-validity of satellite remote sensing monitoring(Pei, Ao, 2008), It has been widely used in the monitoring and assessment of agricultural meteorological disasters such as drought, flood and frost, using remote sensing technology to monitor the degree of disaster of large area dry-hot wind and mastering crop disaster of the spatial distribution of the situation, to facilitate the timely adoption of effective countermeasures to improve the capacity of major grain producing areas for disaster prevention and mitigation(Liu, Zhang, Yan, 2003; Xu, Deng, 2011; Li, Li and Song, 2010), in order to ensure national and provincial grain production has played an important role. However, there are limited domestic and overseas researches on the use of satellite telemetric measures for monitoring and assessment of dry-hot wind disasters (Huang, Xiao and Lou, 2002). Prior researches mainly include the analysis of the temporal and spatial distribution, period and other features of dry-hot wind in the winter wheat growing area in 35 years by Shi Yinshan and others in the small wave analysis (Torrence, Compo, 1998).

In this paper using regression analysis and other statistical methods, We focused on the temporal variation characteristics of dry-hot wind and the relation between dry-hot wind and 1000-grain weight. Research on the relations between the harms of dry-hot wind and the vegetation index with research on the feasibility of MODIS data for monitoring of the extent of harms of winter wheat dry-hot wind through spectrum simulation(Liu, Zhang and Ma, 2014); The establishment of NDVI, RVI, ARVI and EVI indexes through the use of domestic meteorological satellite FY3/MERSI data by Li Ying (Li, Wei and Liu, 2014) and others in order to research on the adaptability and sensitivity of different vegetation indexes applied for monitoring and assessment of dry-hot wind. The research programs show that NDVI is most sensitive to dry-hot wind disasters among all vegetation indexes. However, previous studies have not systematically conducted dry-hot wind monitoring based on NDVI, and the research on the correlation between NDVI vegetation index and key meteorological elements is still incomplete. Research has a in-depth analysis of the correlation of the NDVI variation and RVI variation arising from mild and severe dry-hot wind processes to the daily highest temperature, 14:00pm ground wind speed of 10m and humidity and establishes a mono-factor and multi-factor regressive forecast model between vegetation index variation and disaster-causing atmospheric elements with an aim to provide more data supports to telemetric monitoring of dry-hot wind disasters and provide the theoretical base to prevent and alleviate the dry-hot wind disasters.

1. Research Area and Data Sources

1.1 Research Area

Henan Province is between 31°23'-36°22'N and 110°21'-116°39'E with a total area of 167,000 km2, a land area of 118.89 million mu and a land area of 1.21 mu of every people. It is an agricultural big province. Crop planting structure is relatively stable, mainly for the two-crop pattern of winter wheat - summer maize - winter wheat, Winter wheat planting area as shown (Figure.1). Terrain complex, rich vegetation, this paper to study the planting area of winter wheat.

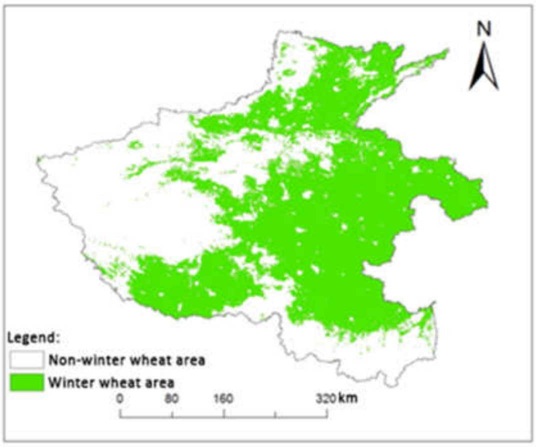


Figure. 1 Henan Province winter wheat planting area

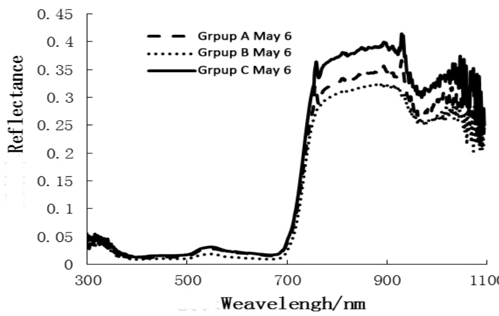
1.2 Data Sources

The data used in this paper are four kinds of data: remote sensing data, spectral data, agronomic parameters and meteorological factors. Remote sensing data used for the United States EOS MODIS data, Includes 250m resolution MOD09GQ, MYD09GQ and 500m resolution MOD09GA day reflectivity products; Spectral data using SVC GER1500 field portable spectrometer to collect spectral information of winter wheat; The agronomic parameters included the relative chlorophyll and leaf water potential, The winter wheat in each plot was determined by SPAD502 chlorophyll meter and PSYPRO dew point water potential meter; Meteorological data from the meteorological stations located in the province measured the site.

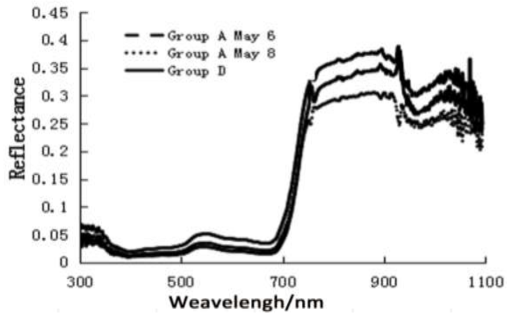
2. Process and Result Analysis

2.1The Dry-hot Wind Simulatio Experiment

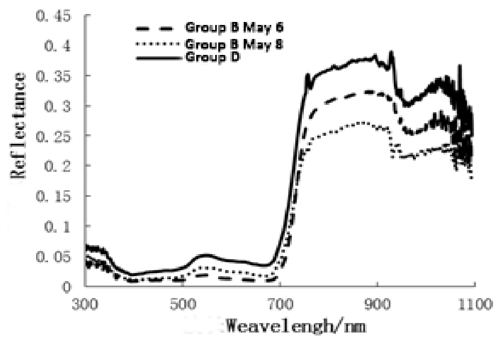
In this paper, firstly, the simulation experiment of dry-hot wind in milk-ripe stage of winter wheat was implemented(Wang, Zheng and Miao,2015). The ground spectral curves of winter wheat canopy before and after dry-hot wind conducted in different degrees by using artificial climate chambers were measured and simulated as EOS/MODIS channel data(Liu, Zhang and etc, 2012)and LAI, chlorophyll, leaf water potential, 1000-grain weight data were synchronously measured. Then, the yield data was also obtained in the harvest period. The spectral response characteristics of winter wheat in each experimental groups before and after the dry-hot wind process showed that the experimental process of dry-hot wind had a great influence on the spectral reflectivity of the canopy of winter wheat. Dry-hot wind after the experiment, 760 ~ 940nm near-infrared band of dry-hot wind effects reflect the most sensitive, each group of winter wheat canopy reflectance in near-infrared wave band has generally been declining, embodies the dry-hot wind disaster damage to the crop leaf cell structure. The experimental results shown(Figure.2).



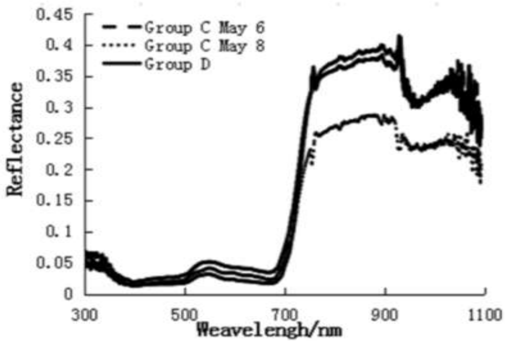
(a) Spectral reflectance of winter wheat varieties before the experiment



(b) Spectral reflectance of A group



(c) Spectral reflectance of B group



(d) Spectral reflectance of C group

Figure.2 (a-d) The spectral reflectance of winter wheat in each experimental group before and after the dry-hot wind experiment

The results of the experimental showed that the chlorophyll content and the leaf water potential of crop growth state decreased significantly after severe dry-hot wind process. This result shows spectral reflectance increase of green band, “red shift” of green peak, decrease of reflectivity of near-infrared band, "blue shift" of red edge and decrease of red edge slope.

2.2 Build a Model and Result Analysis

Through experiment analysis, the wide-band NDVI was selected as the spectral index sensitizing to the change of agronomic parameters of wheat(Table.1). Then the relationship between NDVI variation and agronomic parameters(Table.2 and Table.3)and the evaluation model of wheat yield loss based on NDVI variation were established successively. After that, Henan Province was selected as the study area, and MODIS images and meteorological data from more than one hundred meteorological stations in two typical dry-hot wind years (2013 and 2017) was used, then a regression model was established among MODIS NDVI variation and three meteorological factors including temperature, humidity and wind speed and perpendicular drought index (PDI) calculated by the MODIS images before dry-hot wind occurred. Finally, above two models were combined based on the connection variable (NDVI), and then a new prediction model（Formula3） for winter wheat yield loss caused by dry-hot wind was produced by using the established prediction model(Figure.3), which was verified by ground observation data, and RMSE was 203.77 kg/hm^2. It can visually and clearly show the prediction of loss of wheat dry-hot wind in 2013 and 2017.Effectively saving a lot of manpower and financial resources.

From the sensitivity analysis of four hyperspectral vegetation indices to dry-hot wind disasters, it was found that the absolute values of S_i absolute value from A group to C group showed a gradual upward trend, indicating that the sensitivity of various hyperspectral vegetation indices to dry-hot wind disasters gradually decreases with the severity of dry-hot wind disasters Increased, reflecting the group A to C group of winter wheat gradually increased the degree of disaster.

Table.1 The sensitivity of vegetation index to dry-hot wind disasters

High spectral vegetation index	Formula	S_i			
		Group A	Group B	Group C	Average
$NDVI_{MODIS}$	$(\rho_{859}-\rho_{645})/(\rho_{859}+\rho_{645})$	-0.052	-0.078	-0.093	-0.075
RVI_{MODIS}	ρ_{859}/ρ_{645}	-0.352	-0.567	-0.507	-0.475
$ARVI_{MODIS}$	$[\rho_{859}-(2\rho_{645}-\rho_{469})]/[\rho_{859}+(2\rho_{645}-\rho_{469})]$	-0.066	-0.114	-0.135	-0.105
EVI_{MODIS}	$2.5(\rho_{859}-\rho_{645})/(1+\rho_{859}+6\rho_{645}-7.5\rho_{469})$	-0.115	-0.172	-0.262	-0.183

(S_i is the sensitivity of vegetation index to dry-hot wind disasters.)

Table.2 Correlation model between decline of Hyperspectral Vegetation Index and decline of agronomic parameters

High spectral vegetation index	Agronomy parameter					
	SPAD		Leaf water potential		Grain weight	
	Fitting the model	R^2	Fitting the model	R^2	Fitting the model	R^2

Continued Table.2

$NDVI_{MODIS}$	y=0.0121x-0.0445	0.3394	y=0.0714x-0.0538	0.9585	y=0.0622x+0.9915	0.9911
RVI_{MODIS}	y=-0.0031x-0.4829	0.0008	y=0.2568x-0.4007	0.4307	y=0.2464x+3.7489	0.5411
$ARVI_{MODIS}$	y=0.0182x-0.0595	0.2627	y=0.1199x-0.07	0.9188	y=0.1054x+1.702	0.9685
EVI_{MODIS}	y=0.0585x-0.0379	0.61	y=0.2627x-0.1069	0.9952	y=0.2218x+3.619	0.968

(where x is the agronomic parameter, y is the vegetation index)

Table.3 Major agronomic parameters of winter wheat in different experiment groups with severe dry-hot wind

Agronomic parameters	**Test group**			
	Group A	**Group B**	**Group C**	**Group D**
SPAD change amount	-2.2025	-1.656	-3.586	1.971
Leaf water potential Changes（MPa）	-0.017	-0.271	-0.582	0.175
Grain weight（g）	30.73	30.37	30.07	47.53
Yield（kg/ha）	5273.684	4470	4285.714	6571.667
Yield reduction（%）	19.75%	31.98%	34.79%	—

The table.2 showed that there was a strong correlation between the Hyperspectral Vegetation Index ($NDVI_{MODIS}$, EVI_{MODIS} and $ARVI_{MODIS}$) with the leaf water potential and 1000-grain weight in agronomic parameters after severe dry-hot wind process. However, the dry-hot wind transit would lead to the change of crop agronomic parameters, These indices can better monitor the crop damage and forecast the decline of 1000-grain weight based on the variation before and after the dry-hot wind process, so as to realize the prediction of the crop yield reduction caused by the dry-hot wind disaster.

Comparing the agronomic parameters of the wheat samples from each group, it can be seen that the degree of disaster of winter wheat from A to C is gradually increasing. Combining the changes of various parameters in table.3. It can be seen that the dry-hot wind disaster can cause the relative chlorophyll content of crops to decline obviously, Lower, and with the increase of the degree of dry-hot wind aggravate its change is more significant. Yield reduction analysis found that winter wheat filling during the severe dry-hot wind will have a serious impact on winter wheat yield.

NDVI as the connecting variable, integrate NDVI yield loss assessment model and multiple regression model(Liu, Ma, and Zhang etc, 2004), the establishment of the final prediction of dry-hot wind disaster assessment model, the process is as follows：

$$y = -24939 de_{NDVI} + 36.968 \quad R^2 = 0.9604 \quad (1)$$

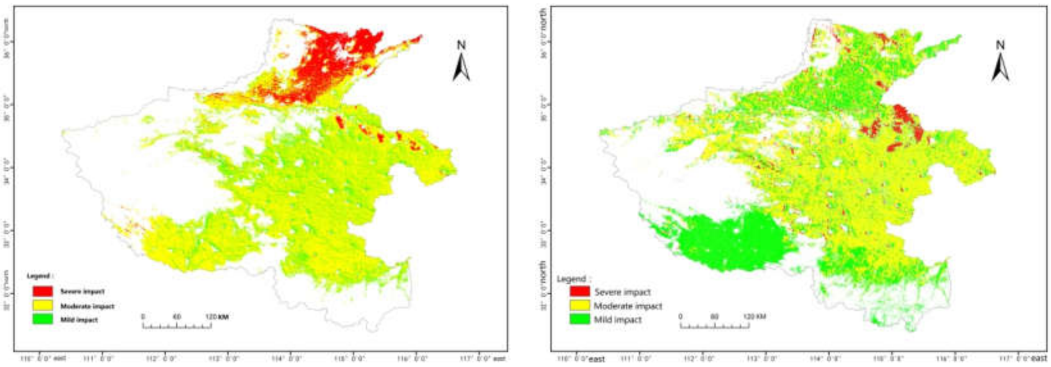
In formula (1): where de_NDVI is NDVI changes before and after dry-hot wind. y is single yield of Wheat(kg/ha). The equation was tested by 0.01 very significance level.

$$de_{NDVI} = 1.919 - 0.004 * H - 0.003 * V - 0.041 * T - 0.688 * PDI \qquad R^2 = 0.861 \quad (2)$$

In formula(2): where de_NDVI is NDVI changes before and after dry-hot wind, H is humidity at 14:00pm, V is surface 10 meter wind speed, T is daily maximum temperature, PDI is crop vertical drought index before dry-hot wind. The equation was tested by 0.01 very significance level.

Formula (1), (2) can be based on the soil drought remote sensing monitoring index and the multi-meteorological factor's dry-hot wind hazard prediction assessment model.

$$y = -47281 + 99.756 * H + 74.817 * V + 1022.499 * T + 17158.03 * PDI \quad (RMSE = 203.77 kg/hm^2) \tag{3}$$



(a) 2013 dry-hot wind disaster damage assessment map

(b) 2017 dry-hot wind disaster damage assessment map

Figure.3 Dry-hot wind disaster damage prediction evaluation map

3.Conclusion

In this paper, The study found experiments of dry-hot wind control on the ground can effectively simulate the dry-hot wind process in nature and can quantitatively monitor and analyze the crop damage caused by this process. The effects of severe dry-hot wind on the relative chlorophyll content, leaf water potential and other growth parameters of winter wheat increased with the degree of crop damage, and the spectral response was more significant.

In addition, By simulating the MODIS center channel 4 vegetation index(NDVI、RVI、ARVI、EVI),analysis shows：The sensitivity of $NDVI_{MODIS}$ to dry-hot wind disasters aggravated with the degree of dry-hot wind disasters and increased the sensitivity. The sensitivity of ARVI to dry-hot wind disasters was between NDVI and RVI. Through the model analysis of the correlation between the relative chlorophyll content, the leaf water potential and the decline of 1000-grain weight and the decline of vegetation index after the dry-hot wind process, it can be seen that there are significant differences in the coefficient of determination between the different index decline and the vegetation index decline , Mainly due to the different spectral response characteristics of each index and the complex physiological function changes of winter wheat after the disaster.

Finally, The proposed method in this paper considered the difference of yield loss caused by atmospheric drought under different soil moisture. Besides, it is possible to predict the spatial distribution of winter wheat yield loss by using the model in combination with weather forecast values and remote sensing drought index before dry-hot wind occurs, which can provide decision support information of disaster response for the agricultural administrative departments，Reduce the hazards of dry-hot wind.

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