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STUDY ON MODEL FOR REMOTE SENSING ESTIMATION OF MAIZE YIELD

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ABSTRACT: Through analysis of perpendicular vegetation index (PVI) from combination of visible and near-infrared spectrums reflecting the feature of crop reflectance, we come to the conclusion that the index can better indicate crop instantaneous photosynthesis whereas people generally regard it as the representation of crop leaf area index(LAI). Exploration of crop photosynthesis within a day and its period of duration leads to production of photosynthetic vegetation index (PST) that can reflect the whole crop accumulated photosynthesis, which means the total biomass produced by crop, moreover the method simulating PST is put forward by employment of multi-temporal spectrum parameters. On the basis of the achievements mentioned above, a new comprehensive model for remote sensing estimation of maize yield is established, which can comprehensively show major physiological actions of maize and the course of its yield formation, organically integrate various effective ways of crop yield estimation. It lays a solid foundation for carrying out remote sensing estimation of maize yield on a large scale.
KEY WORDS: perpendicular vegetation index, photosynthetic vegetation index, comprehensive estimation yield model, remote sensing estimation of maize yield

Acquisition of crop output information is vital for national politics and economy, especially for China with a large population, limited cultivated land and frequent natural disasters, in which remote sensing estimation of crop output plays an active role. Model of forecasting maize yield is a very important part. However the method of forecasting maize yield, which can both conform to scientific principle of remote sensing estimation of crop output and be easily performed, is rare, even though enormous achievements have been obtained. Thus it's urgently expected to seek a rational and practical forecasting model.

I. MODEL OF FORECASTING MAIZE YIELD BY REMOTE SENSING

Maize produces biomass in nutritious growth stage, breeds seeds and transports biomass into the seeds in reproductive growth stage. We can derive a formula from the description (Feng *et al*., 1991):

Output = (Photosynthetic output − Respiratory loss) * Economic coefficient

Where (Photosynthetic output− Respiratory loss) is the amount of net photosynthetic substance produced by crop during its whole life period, economic coefficient means the ratio between seed and net biomass, which describes how much of net biomass is transmitted and converted into seed. If this biological course can be reflected in forecasting model, remote sensing estimation of maize yield will have a solid scientific foundation. Visible reflectance can indicate chlorophyll content, near-infrared reflectance relates with crop cell structure. We can get PVI (Perpendicular Vegetation Index) through combination of the two reflectances. Much research work showed that there is a good relation between PVI and LAI (Leaf Area Index) (Xu *et al*., 1991). Through field experiment and theoretical analysis we found relation between PVI and amount of chlorophyll taking part in photosynthesis is much closer than one between PVI and LAI (Fig. 1). That means PVI can reflect Instantaneous photosynthesis of maize (Liu *et al*., 1993). Daily change of photosynthetic intensity is parabolic in shape (Jing *et al*., 1995) (Fig. 2).

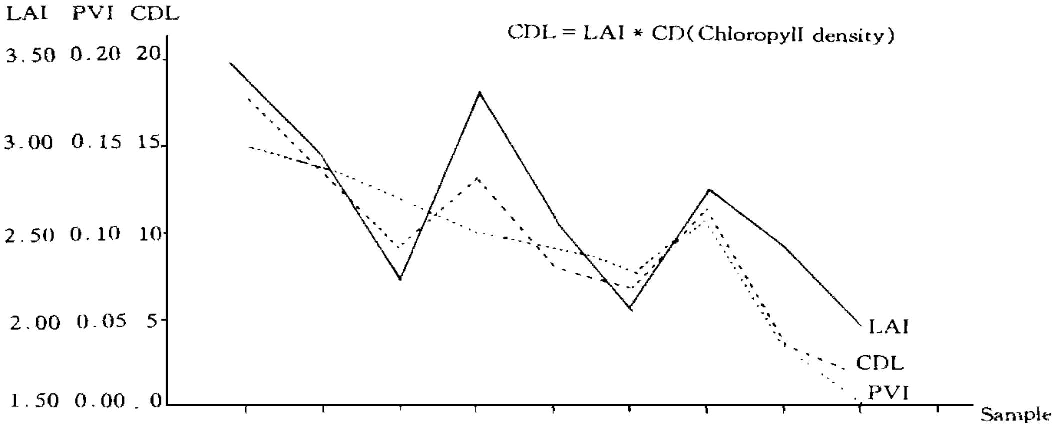

Fig. 1 Relationship between LAI, CDL and PVI

Sunlight is the essential condition of photosynthetic activity, so sunshine hour becomes an important parameter. Supposed that all PVIs during maize lifetime can be acquired, we can form a coordinate system with sunshine hour as abscissa and PVI as ordinate. The area of these polygons represents amount of biomass produced by maize. So a new vegetation index is put forward, Photosynthetic Vegetation Index——PST (Perpendicular Vegetation Index, Sunshine, Time) (Liu *et al*., 1993),

$$\mathrm{PST} = \int \mathrm{PVI}\, \mathrm{d}T$$

which can present accumulated photosynthetic product. Here the biomass produced in cloudy and rainy days is relatively little and left out, because maize is fond of stronger solar illumina-

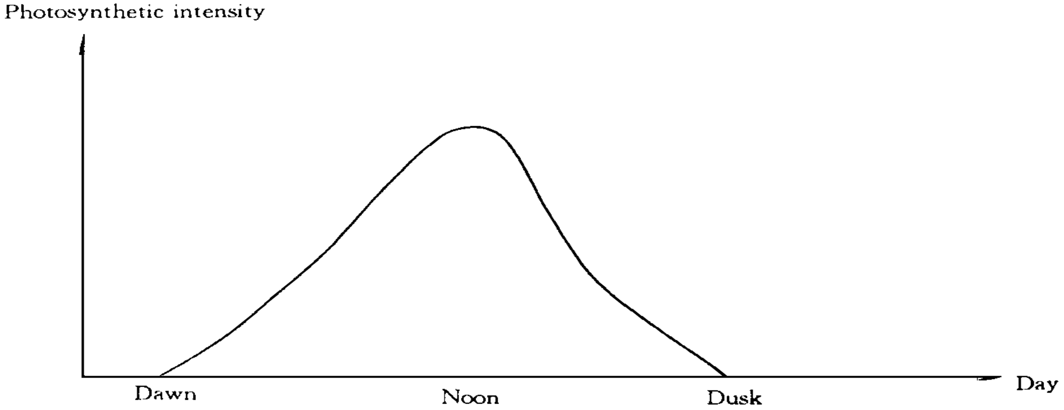

Fig. 2 Change of photosynthesis during one day

tion and sensitive to sunshine hour as C_4 plant (Li *et al.*, 1992). Actually number of acquired PVI data is limited, these data are connected with lines or fit them with some kinds of curve to approximate ideal PST (Fig. 3), of course the cloud and rainy days damage the perfect curve to some extent.

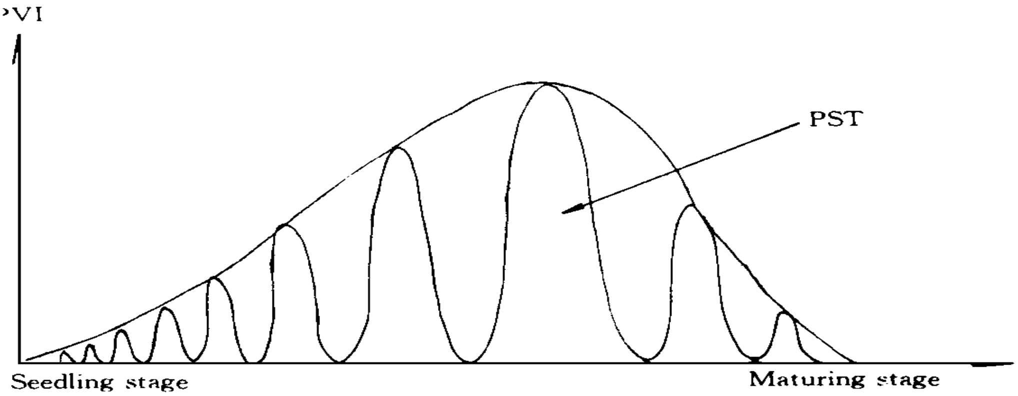

Fig. 3 Sketch map of photosynthetic vegetation index——PST

Daily temperature difference can be used as a forecasting factor for it is testified to have a good bearing on consumed biomass by maize respiration. The difference between leaf temperature and environmental one——SDD (Stress, Degree, Day) is a dictator of maize transpiration and physiological activities (Zhang, 1990). The accumulated SDD can be used as a forecasting factor to present volume of maize seeds and amount of transported biomass. Meteorological conditions in key phases sometimes play a decisive role in formation of maize yield (Li *et al.*, 1992). They also can be introduced into forecasting model.

Visible and near-infrared image data of NOAA AVHRR and sunshine hour data can be handled into the forecasting factor——PST. Medium and far-infrared image data can be retrieved into leaf temperature, which forms forecasting factor——SDD together with environmental temperature.

We took Lishu County of Jilin Province as an experimental region for its various types of maize growing environment and high percentage of maize land.

The comprehensive model for remote sensing forecasting of maize yield established on unit for forecasting maize yield (Liu, 1993) results from the combination of all of these forecasting factors with sampling data of maize per unit yield. All of these can be summed up as follows (Fig. 4):

$$Y = \alpha_r * f_r(\text{PST}, \text{SDD}) + \alpha_m * (f_t(t) + f_m(x_i))$$

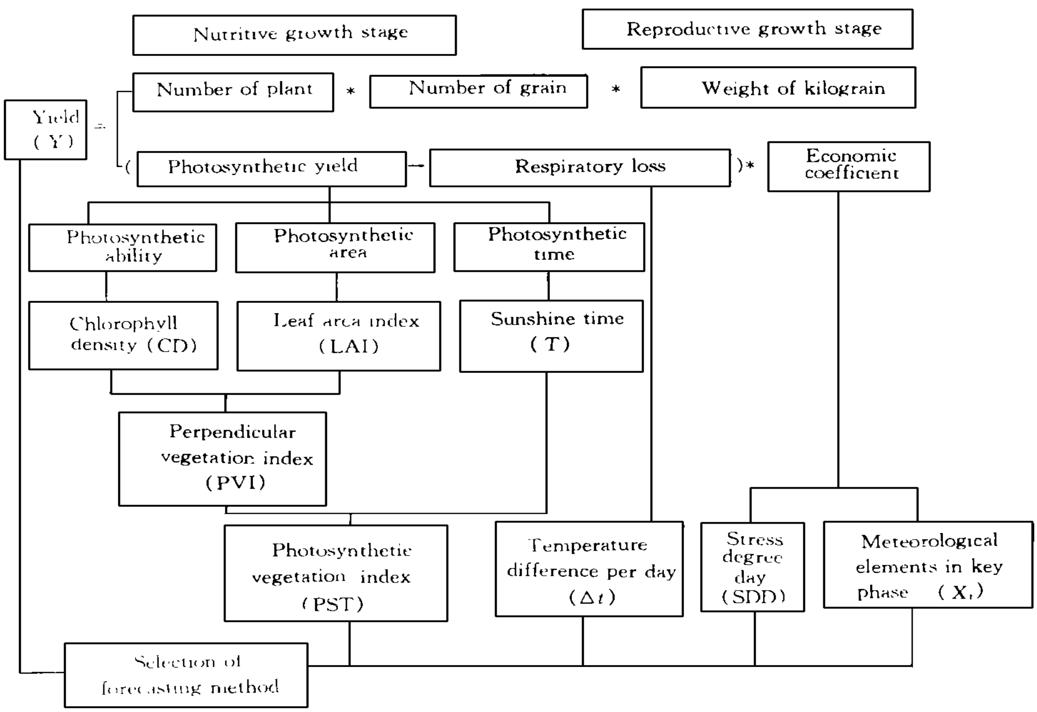

Fig. 4 Principle of forecasting model for remote sensing estimation of maize yield

where α_r, α_m are respectively the fitting rates of remote sensing model and meteorological one, f_r refers to model of Grey System, $f_t(t)$ is nonlinear simulation of maize yield series, $f_m(x_i)$ is regressive polynomial with meteorological elements —— x_i as forecasting factors.

II. APPLICATION OF FORECASTING MODEL

We collected the AVHRR image data from 1989 to 1993. Even though cloudy and rainy days greatly lessened the number of available image data, at least three images in one year are available. Through calibration of radiation and geometric correction, they are matched with maize estimation unit. If there are scattering clouds floating over estimation region, they will be removed. Then the two channels are composed into PVI images. Average PVIs of the units for forecasting maize yield are calculated. We used slanted parabola to fit the values (Fig. 5):

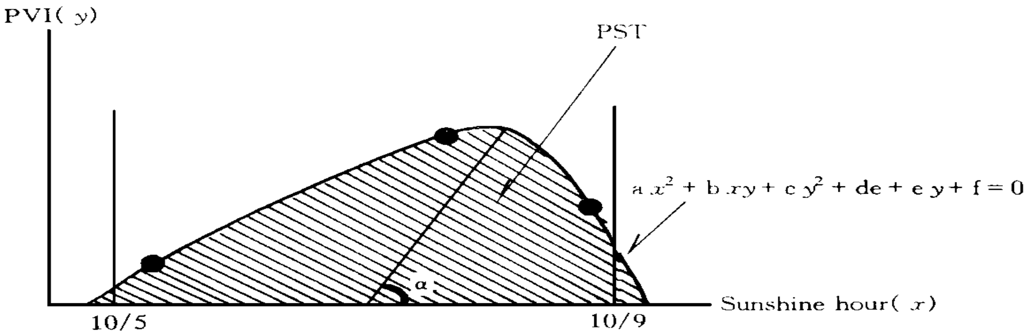

Fig. 5 PST simulation

(α is the slanting angle of the fitting parabola)

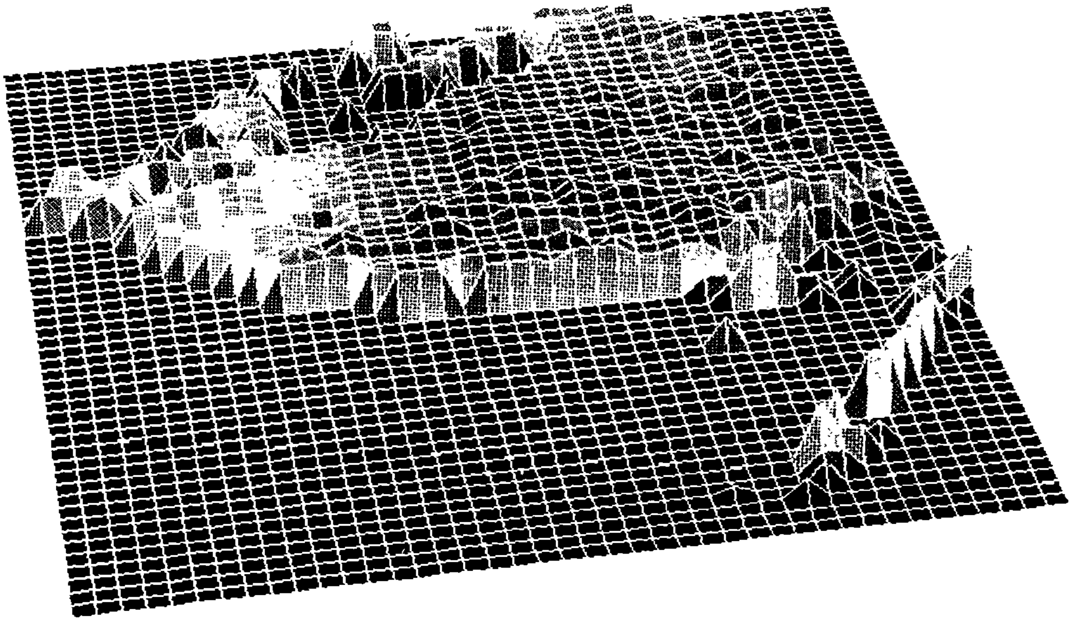

Fig. 6 Spatial distribution of maize yield in Lishu County

The area of shady shape is PST. After the work for calculating PST values of all years and of all units is done, we use the method of Grey System to establish forecasting model of maize yield. The forecasting factor (SDD) is not included in the model for its irregular undulation caused by technological problems, but we make up for it by introducing meteorological model. The fitting rates of two kinds of models are taken as proportion to integrate them into comprehensive model for remote sensing estimation of maize yield, which possesses high precision(T).

Table 1 Predicting results of three models in Lishu County

Unit	Actual yield (kg/ha)	Remote sensing		Meteorological model		Comprehensive model	
		yield (kg/ha)	precision (%)	yield (kg/ha)	precision (%)	yield (kg/ha)	precision (%)
11	7335	6015	82	6600	90	6315	86
12	6660	5535	83	6195	93	6195	93
13	6975	5505	79	6555	97	6210	89
14	6930	5205	75	6030	87	5610	81
21	7515	7440	99	7365	97	7440	99
22	7020	6675	95	6810	96	6945	99
23	7200	6915	96	7050	97	7125	99
24	7050	6915	98	6480	92	6840	97
31	8340	7920	95	7335	88	7590	91
32	7950	7470	. 94	6915	87	7230	91
33	8250	7755	94	7095	86	7425	90
34	7545	7170	95	6795	90	7020	93

III. ESTIMATION OF MAIZE GROWING AREA

TM image data on August 26 1993 are applied to estimate maize growing area for maize is in the mature stage at that time, and the leaf area index and chlorophyll density of maize are the biggest. It is easier to extract maize information. Various types of maize growing environment within Lishu County lead to spatial diversity of maize growth and different spectra. In order to reduce the affection of identical objects with different spectra, TM image is divided into three parts through overlaying climatic map. Then some conventional methods in digital image processing are adopted to extract maize information respectively in the three parts and estimate maize growing area . We also get the maize areas of every unit for forecasting maize yield. It is easy to calculate the total maize output of Lishu County. The result is shown in Table 2.

Table 2 Estimating results of maize growing area and output

Unit	Growing area(ha)	Maize output(ton)
11	12069	76214
12	18049	111815
13	18843	117018
14	18794	105434
21	17933	133720
22	36778	255426
23	27712	197445
24	13900	95073
31	8630	60948
32	4818	34835
33	8673	64394
34	7592	53297

IV. CONCLUSION

Through all-round analysis of biological course of maize yield formation, and from the practical need, the forecasting factor——PST is advanced; a comprehensive model is established and applied into maize yield prediction. These will contribute to practice of remote sensing estimation of maize yield on a large scale. Estimation of the maize output of Jilin Province in recent years just follows the basic idea, the more contents will be discussed in detail in other papers.

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