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Identification and Research of Winter Wheat in Loess Plateau Based on Multi-Temporal Vegetation Index Model

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Abstract: The key factor affecting the planting monitoring of winter wheat is the interference of crops at the same time, which will cause the problem of data inconsistency between the winter wheat planting area obtained by remote sensing technology and the cultivated land planting area statistics. Therefore, accurate and efficient rapid acquisition of cultivated land planting monitoring information is of great significance for ensuring food and agriculture security, grain yield estimation, and area estimation in the study area. At present, there are few studies on winter wheat cultivated land area extraction in the Loess Plateau by using the construction of multitemporal vegetation index synthesis model, the change characteristics of winter wheat index, and the separability of cultivated land image information. We use Sentinel-2 data to study through a multitemporal vegetation index synthesis model. In this research, we estimated the planting area of winter wheat cultivated land extracted by the vegetation index model from 2020 to 2021, and studied the correlation between the multitemporal index model and winter wheat on the Loess Plateau. The separability of multitemporal normalized vegetation index model for winter wheat and concurrent crops was also discussed. The result shows that: (1) By using the multitemporal NDVI model composed of overwintering stage, jointing stage, and Milk-Ripening stage, the accuracy of the total cultivated area of winter wheat reached 96.80%, the overall accuracy was about 94.26%, and the Kappa coefficient was 0.89, which ensured the consistency between the cultivated area of winter wheat and the actual total planted area in the Loess Plateau and the accuracy of winter wheat remote sensing monitoring. (2) The results of multitemporal NDVI vegetation index model extraction of winter wheat planting area showed that the NDVI values of winter wheat were clearly different under different terrain in the same growing period and susceptible to the interference of crops in the same period. We found that the multitemporal NDVI index model could effectively reduce the interference of rapeseed and forestland growing at the same time on the planting area of winter wheat, and enhance the separability of winter wheat planting area. Overall, based on Sentinel-2 data and using the multi-period NDVI index synthesis model, we accurately obtained the area of planting area, which proved that the model can be effectively applied

to winter wheat in the Loess Plateau, and provided data support for the remote sensing planting monitoring of winter wheat in the local area.

1. Introduction

The security of agricultural grain is the foundation of the country[1], and winter wheat is an important food crop in China[2]. Gansu Province is located in China's rain-fed agricultural region[3], and is a major grain-producing province in China. The monitoring of winter wheat cultivation in Gansu is the basis for accurate and efficient estimation of grain yield. In addition, mastering the spatial distribution of winter wheat in the Loess Plateau of Gansu Province can provide data support for the formulation of local food and agriculture policies. The traditional winter wheat planting monitoring needs to be obtained by means of artificial field investigation, which not only consumes a lot of manpower and material resources but also fails to update relevant information in a timely and efficient manner[4]. With the development of medium-high resolution remote sensing satellite technology, the development of technology related to the rapid extraction of winter wheat planting information using multitemporal remote sensing data has optimized the work process. Therefore, the use of multitemporal remote sensing data is of great significance to the monitoring of winter wheat cultivation in mountainous areas of the Loess Plateau in Gansu[5].

With the development of remote sensing monitoring technology, optical remote sensing satellites as data sources have been widely used in many fields of cultivated land information extraction[6,7]. Landsat8 satellite data is widely used in cultivated land monitoring due to its high spatial resolution and the reentry cycle is only 16 days. Some studies have pointed out that the high-resolution feature information obtained by Landsat8 SR and other multisource data sets can effectively extract cultivated land information, and the accuracy rate of cultivated land identification is as high as 0.970[8]. GF remote sensing satellite takes advantage of its high resolution to reduce the mixing ratio of pixels, so it is widely used in the research of fine extraction of cultivated land monitoring[9]. Compared with the former, Sentry 2 satellite provided by ESA since 2017 has advantages such as high spatial resolution and a short repetition period. In monitoring winter wheat planting in the North China Plain, the overall accuracy of winter wheat extraction by using long time series vegetation index image reached 95.1%, and the Kappa coefficient was about 0.948. It has been proved that Sentinel-2 has a high accuracy in crop-cultivated land information extraction[5].

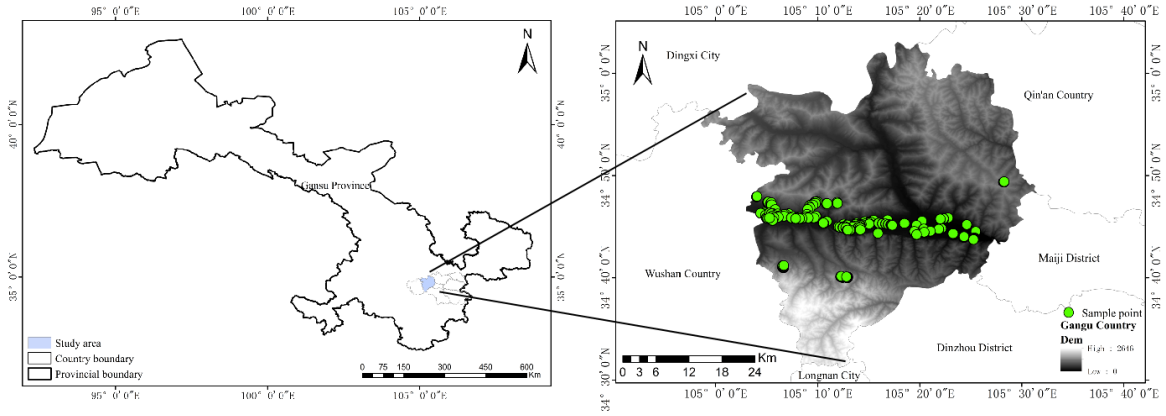
The monitoring of cultivated land information is mainly based on a classification algorithm. As more algorithms are proposed and the technology is improved, appropriate algorithms can improve the efficiency and accuracy of crop identification[6]. Some studies have shown that the extraction accuracy of winter wheat area in the North China Plain can reach 97.0% under the classification method based on multisource remote sensing satellites combined with different feature indices[10,11]. In the south of our country, the accuracy of winter wheat extraction has been increased to 90.6% by using the multifeature analysis rule of sequential data[12]. With the deepening of Sentinel-2 data monitoring research on cultivated land, some studies have pointed out that the extraction accuracy of five different classification algorithms is compared by combining Sentinel-2 data, spectral characteristics, exponential characteristics, and other information, and the results show that the best accuracy of extraction results using RF algorithm is up to 99.6%, effectively optimizing the extraction results[13]. In recent years, the technology of crop extraction by multitemporal image fusion has been gradually applied in cultivated land monitoring research, and high-precision cultivated land information has been obtained[14-16]. The overall accuracy of

winter wheat extraction by NDVI vegetation index is about 87.1%[17,18], but there are few types of research on winter wheat extraction by the multitemporal vegetation index model.

The study area in this paper is located in the southeastern part of Gansu Province, located in the Loess Plateau region, with the terrain gradually rising from north to south, and the forest land mainly concentrated in the southern part of Gangu County. Affected by the "same foreign body spectrum" and "same object different spectrum" of vegetation in the same period of the study area, the cultivation area of winter wheat cannot be accurately extracted by a single phase image[19]. In view of this, Sentinel-2 data was used in this paper to study the monitoring methods of winter wheat in Gangu County from 2020 to 2021 based on the multitemporal vegetation index model. It was revealed that the multitemporal vegetation index model could effectively reflect the growth changes of winter wheat in the northwest Loess Plateau and provide data support for local agricultural production. It is clear that using multitemporal data set and multi-feature information can effectively monitor the cultivated area of winter wheat. Therefore, the study on the recognition method of winter wheat in the Loess Plateau provides a reference for the recognition and extraction of winter wheat in northwest China, which has certain research value.

2. Overview and Data Analysis of the Study Area

2.1. Research Area



a.Administrative boundaries of the study area b.Spatial distribution of samples

Figure 1: Geographic location and sample points of Gangu County.

Table 1: Phenological period time of Gangu County.

Month	1			2			3			4			5			6			7			8			9			10			11			12		
Variety	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Winter wheat	Overwintering period						Rejuve-nate period			Jointing and grouting stage						Maturity and maturity												Sow-ing date			Tillering stage with long leaves			Overwinteri-ng period		
Rape	Overwintering period			Mossing stage						Flowering stage						Mat-ure peri-od														Sowing date			Long leaf stage			Overwi-ntering period		

The study area is located in Gangu County of Tianshui City belonging to Gansu Province (104°58 '~105°31'E, 34°31 '~35°03'N) (Figure 1), a total area of 1572.6 square kilometers, is located in the northwest winter wheat district of our country, local average annual precipitation is low, crop planting maturity is one year in our country's typical rain-cultivated agricultural area. Located in the Loess Plateau mountainous area, planting winter wheat has a long history, planting crops of winter wheat and rape, mainly as a large area of winter wheat planting county, Tianshui

City. In 2021, the cultivated area of winter wheat in Gangu County is 331,000 mu[20]. The growing period of winter wheat is sown in late October and harvested in July of the following year. The phenology period of winter wheat is shown in Table 1.

2.2. Research Data

Sentinel-2 (Sentinel-2) satellite data is provided by A (Sentinel-2A) and B (Sentinel-2B) binary complementary, with a reentry period of 5 days. The study area in this paper is covered by two field images numbered SVD and SWD. The image data are from S2MSI-2A products provided by ESA. The 2A level data are BOA orthographic corrected images. The Sentinel-2 satellite image has 13 bands, including three spatial resolutions of 10m, 20m, and 60m, respectively. The data set of this study is from November 2020 to July 2021, with one cloud less than 30% in each month.

DEM elevation data of 12.5 m resolution in Gangu County, Tianshui City, was used to extract elevation data images and reduce the interference caused by "foreign bodies of the same spectrum" on winter wheat extraction.

Vegetation index (VI) can effectively represent the feature information of remote sensing images of vegetation through spectral and band characteristics of vegetation and is the key to the rapid identification of winter wheat in the Loess Plateau of Gansu province. In this paper, bands related to winter wheat (green band, red band, and near-infrared band) in spectral characteristics are selected, as shown in Table 2.

Table 2: Sentinel-2 band parameters involved in this study

Band	Central wavelength/μm	Spatial resolution/m
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 8 – NIR	0.842	10

3. Research Method

This study includes long-time series data set preparation, synthetic model construction and crop feature recognition, machine learning, RF model extraction, accuracy evaluation, and crop feature separability discussion. Firstly, the threshold method is used to extract the region below 2036 m from DEM data, and the machine learning RF algorithm is used to analyze the separability of the extraction results of the study area of the NDVI synthesis model in February (overwintering period), April (jointing period) and June (milk ripening period) in 2021. Finally, according to the research results, the separability of different characteristic information for winter wheat recognition was discussed.

In order to explore the influencing factors of image features of remote sensing satellite data on the recognition and monitoring of winter wheat in the northwest Loess Plateau, this study combined vegetation index characteristics, spectral curve characteristics, phenology characteristics, and long-time series vegetation index curve characteristics to build a multitemporal NDVI index synthesis model combined with false color image identification and extraction of winter wheat cultivated land.

Cultivated land monitoring in the mountainous area of the Loess Plateau based on the Sentinel-2 multitemporal vegetation index model mainly involves three parts. One is to extract images below a certain height by using DEM data of Gangu County; the other is to construct multitemporal NDVI images and distinguish different map spots; the third is to study the extraction method of winter wheat cultivated land information by using the model. In the process of winter wheat crop extraction in the study area, the single-phase false color remote sensing image has limitations on the

identification of the cultivated area of winter wheat. Therefore, based on the multitemporal NDVI index model, combined with the crop phenology spectrum, long time series, vegetation index curve, spectral curve, and other features of Gangu County, winter wheat cultivated land information was identified.

3.1. Multi-Temporal Index Synthesis Model

The image of the false color combination has high separability to the field characteristics of winter wheat and rapeseed from February to April in Gangu County, but it cannot be extracted effectively due to the interference of the "same object and different spectrum" on winter wheat. In this study, according to the characteristics of the Vegetation Index, the GEE platform was used to draw a long time series graph for the Normalized Difference Vegetation Index (NDVI) of ground objects in the study area, to show the exponential transformation characteristics of different ground objects in the time series index images. In order to further determine the color of the corresponding pattern spot of winter wheat in the synthetic model, the crop change rule of winter wheat in the corresponding growth period was followed, and the ground glass samples were confirmed by comparing them with high-definition images, as shown in Figure 2,3.

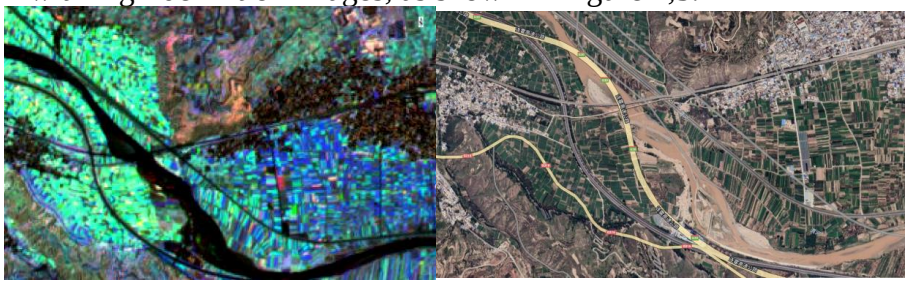


Figure 2: Schematic diagram of winter wheat samples.

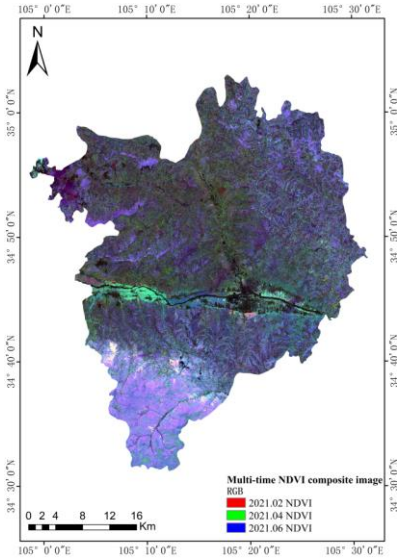


Figure 3: Schematic diagram of vegetation index fusion image.

The normalized Difference Vegetation Index (NDVI) involved in this study can be used to track the growth state of winter wheat and is an index parameter reflecting the spatial distribution density of vegetation[21]. Normalized differential vegetation index formula:

$$NDVI = \frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + \rho_{RED})} \quad (1)$$

Where NDVI is the normalized differential vegetation index, ρNIR and ρRED are the spectral reflectance of near-infrared and red bands, respectively, representing band 8 (842nm) and band 4 (655nm) in Sentry 2 data.

3.2. Phenological and Spectral Curve Characteristics

The phenological period of crops can effectively reflect the periodic growth change rule of crops under the influence of natural environmental conditions. Some studies have pointed out that the normalized differential vegetation index value of crops will change with the passage of the growing period. By comparing the changes in vegetation index in different growing periods with the characteristics of winter wheat, select the most suitable vegetation index to identify winter wheat in the critical period. In this study, five ground object samples including winter wheat, concurrent crops, forest land, water area, and impervious layer were selected to obtain and construct the time series curve of the vegetation index. The study showed that the NDVI time series curve of winter wheat from February to June each year was different from that of other ground object vegetation indexes. Before and after winter, wheat was at the milk ripe stage (low in May each year), and the vegetation index would gradually rise. Since rape in the Loess Plateau mountainous area of northwest China is sown from mid-September every year to mature at the end of May next year, there is no obvious difference between it and winter wheat in the false color spectral image. In the following months, it is interfered with by other crops and woodlands of the same period, so it is impossible to accurately identify winter wheat through a single phase image. Therefore, the overwintering stage, jointing stage, and milking stage (from early February to mid-June) in the growing period of winter wheat in the study area in 2021 are mainly selected as the critical growth period of crop growth for the study and analysis of winter wheat. The Sentinel 2A image dataset was used to construct the long-term change curve of the vegetation growth index (FIG. 4) of various areas in the northwest Loess Plateau.

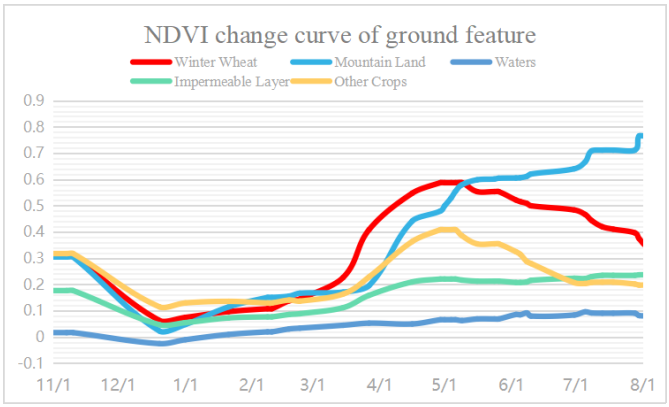


Figure 4: Time series curve of vegetation index of different land use types.

In the process of RF machine classification learning, the spectral characteristics of each band of each feature are visualized, which helps to confirm the separability of the feature. Sentinel-2a remote sensing images in February 2021, April 2021, and June 2021 were selected, respectively, and the spectral curve features of each critical period were extracted based on the judgment of high-definition images, as shown in Figure 5.

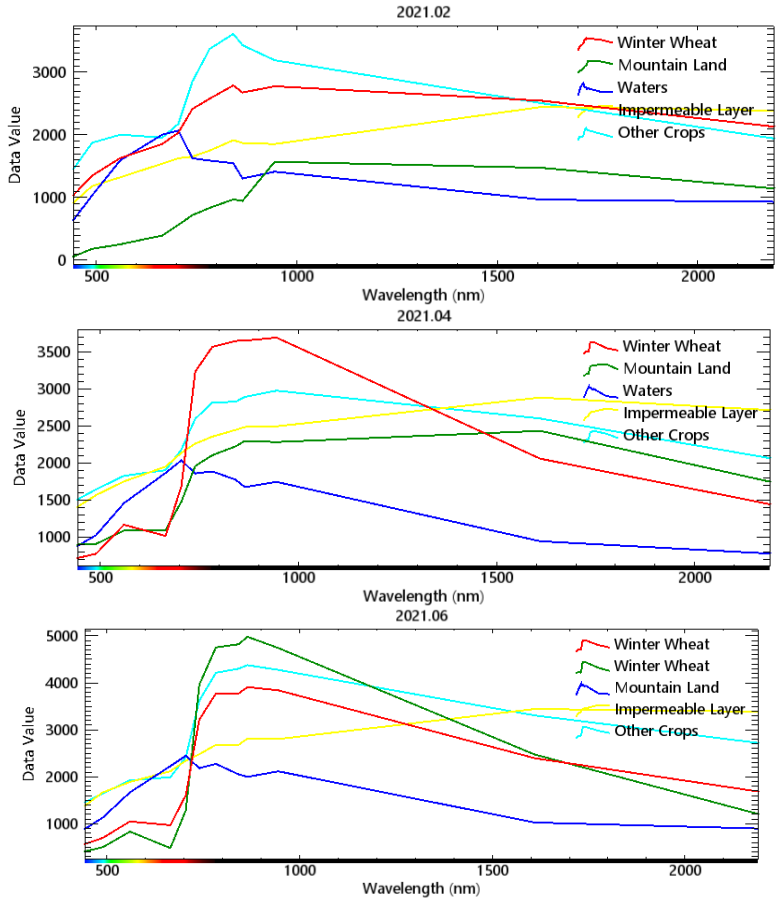


Figure 5: Spectral curve of critical crop growth period.

As can be seen from Figure 5, the spectral values change with the growth period of crops, which can be identified through the selection of the band threshold during crop identification. The analysis of the spectral curve characteristics of winter wheat crops in the study area showed that the spectral curve value of winter wheat in the critical growth period increased significantly in the 8th band (842nm), and the value was in the range of 2500-3000 in February, and in April and June, the value would be in the range of 3500-4000. The fourth band (665nm) has been on a downward trend from 1,800 in February to 1,000 in April and June. According to this characteristic, when samples are selected, the corresponding date and corresponding band value are consistent with this characteristic. It can effectively improve the sample selection accuracy.

3.3. Texture Feature

According to the texture features of remote sensing satellite images, the surface properties of ground objects and the distribution of gray values in the spatial domain can be more directly presented. The texture feature of the image is a structured form of expression. In Sentinel-2 remote sensing images, false color images constructed by a red band, green band, and near-infrared band can be used to effectively distinguish vegetation, crops, and other ground objects in the critical period of winter wheat.

4. Results and Analysis

To explore a method to quickly extract the cultivated area of winter wheat in the Loess Plateau of Gansu province, four types of characteristics including vegetation index, spectral curve, phenological characteristics, and long time series vegetation index curve were studied, and compared in this paper, and the random forest (RF) algorithm was combined to conduct the identification and classification experiments. The separability of different characteristic conditions and the multitemporal vegetation index synthesis model was analyzed by experimental results.

4.1. Extraction Results of Planting Area with Different Vegetation Indices

In this study, data from 2020 to 2021 were extracted and studied. Sentinel-2 high-resolution multispectral satellite data was used to conduct visual interpretation of winter wheat information, and the synthesis model was obtained by the multiphase vegetation index synthesis method. 184 samples were selected in Gangu County based on rules (FIG. 1).

According to the classification results of the multiphase vegetation index model by the RF algorithm (Table 3), the declared area of winter wheat cultivated land in 2021 is about 331,000mu.

Table 3: Extraction results of synthetic winter wheat from three images of different vegetation indexes.

Index Type	Producer's Accuracy/%	User precision/%	OA/%	Kappa Coefficient	Extraction area (10000 mu)
NDVI	91.70	94.10	94.26	0.89	32.041

The extraction results showed that after several sample modifications, the multitemporal NDVI model had a high separability for winter wheat extraction. The overall identification accuracy of winter wheat in the study area was 94.26%, the extraction accuracy of the cultivated area of winter wheat was about 320,410 mu, and the extraction accuracy of winter wheat area was about 96.80%.

4.2. Accuracy Verification

In the quantitative evaluation of winter wheat cultivated land information extraction results, the area of winter wheat cultivated land was tested according to the data of winter wheat cultivated land area in the statistical yearbook, and a certain number of winter wheat map spots were randomly selected to confirm the accuracy of winter wheat retrieval results using the imagery data of Earth map and World Imagery Wayback. A confusion matrix will be used to analyze the errors. According to the above study, it can be seen that the cultivated area of winter wheat extracted by the multitemporal vegetation index model constructed by multiperiod NDVI is more accurate, and the results of map spot extraction are more accurate. However, there are still a few map spots identified as the ground objects extracted by wrong identification after comparing with the historical image data. Some verification results omitted are shown in Table 4.

Table 4: Number of sample points and correct classification in Gangu County from 2020 to 2021

Sentinel-2 visual interpretation	Winter wheat	Non-winter wheat	total	Accuracy
Winter wheat	153	14	167	91.6%
Non-winter wheat	29	4	33	87.9%
Total	182	18	200	

160 winter wheat samples and 40 non-winter wheat samples were selected, 160 sample points were correct, and 18 sample points were wrong. The classification accuracy was 95.0%. The error of analysis and extraction is mainly due to the fact that Sentinel-2 data has a resolution of 10m, and there are mixed pixels in the boundary zone of the winter wheat region, leading to some differences in the selection of samples. In addition, in the labeling process of selecting winter wheat samples manually, the inaccurate labeling of samples also has a certain impact on the results.

4.3. Discuss

Under the influence of the local natural environment in Gansu, the supervised classification algorithm or NDVI Weighted index (WNDVI) classification algorithm is mostly used in winter wheat extraction studies in the Loess Plateau area of Gansu province[5], and few studies are carried out by multitemporal vegetation index synthesis model. Appropriate features of the multitemporal vegetation index synthesis model can affect the effect and accuracy of crop extraction. The feature information of ground objects mainly involved in this model includes spectral features, image texture features, spatial relationship features, and vegetation index time series curve features, which are used to extract and analyze crop information. Among them, the spectral features of classification features are the most important feature for crop extraction. Moreover, the extraction accuracy of crops can be improved by combining the other three characteristics[15]. In this study, the extraction accuracy of winter wheat was studied under the multitemporal vegetation index model, and it was found that due to the influence of "homospectral foreign bodies", the area of winter wheat could not be accurately extracted by single-phase image after overwintering. Therefore, it is necessary to construct image models suitable for winter wheat in the critical period for classification based on the characteristics of spectral curve changes and exponential changes under the long time series data set, to improve the crop identification accuracy.

In this study, the Sentinel-2 image data with 10m spatial resolution was used to construct the temporal index model, and the supervised classification (support vector machine) algorithm was used to obtain the overall classification accuracy of NDVI of 94.26% (Kappa=0.89), respectively. By comparing the multitemporal vegetation index model with the HD historical image, it can be found that the model constructed by the NDVI index has a better extraction effect on winter wheat, with a producer accuracy of 94.10%. However, it is still affected by part of the forest land, so it is necessary to add DEM data to determine the threshold to improve the extraction accuracy.

200 sample points were randomly sampled from the multitemporal NDVI index model extraction results, and the classification accuracy of winter wheat was 95.0%, which met the extraction requirements of the winter wheat planting area. In the critical period of winter wheat growth, the image is relatively complete, which can be widely used in vegetation identification and extraction research. In terms of the practicality of the model, this model can be suitable for planting monitoring of winter wheat yield area. In general, the multitemporal NDVI index synthesis model can satisfy the monitoring of winter wheat planting in the Loess Plateau of Gansu Province.

In the study, due to the limitation of the optical satellite resolution, there is a phenomenon of objects mixing in the terrestrial boundary in the image synthesized by the multiphase vegetation index, which leads to the repeated screening of winter wheat samples in the initial stage of sample selection to extract winter wheat samples as much as possible and avoid the wrong extraction of ground objects. In this study, by fixing the single-phase vegetation index threshold of winter wheat, the characteristics of vegetation index in a threshold interval of each growth period of winter wheat were utilized to screen samples dominated by winter wheat in mixed pixels, and DEM data was used to screen the extraction area below a certain altitude, to reduce the interference of woodland

and other ground objects on winter wheat extraction. Based on the above sample selection rules, the cultivated area of winter wheat can be accurately extracted.

5. Conclusion

In this paper, based on Sentinel-2 time series data set from 2020 to 2021 in Gangu County, vegetation index spectral curve, crop phenology, and long time series vegetation index curve were extracted based on the ENVI5 platform, and their feature rules were input into the multiperiod vegetation index model. Finally, the RF classification algorithm was used to extract the cultivated land information of winter wheat and obtain the cultivated land area of the study area. This paper draws the following conclusions:

(1) Using the multitemporal NDVI model synthesized at an overwintering stage, joint stage, and milk ripening stage, the accuracy of the total cultivated area of winter wheat reached 96.80%, the overall accuracy was about 94.26%, and the Kappa coefficient was 0.89, which ensured the consistency between the cultivated area of winter wheat and the actual total planted area in the Loess Plateau and the accuracy of winter wheat remote sensing monitoring.

(2) According to the extraction results of winter wheat planting area by the multitemporal NDVI vegetation index model, the NDVI values of winter wheat under different terrain in the same growing period are clearly different and susceptible to the interference of crops at the same time, while the multitemporal NDVI index model can effectively reduce the interference of rape and forest growing at the same time on the planting area of the winter wheat cultivated land. Enhance the separability of winter wheat planting area.

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