land

MDPI

Supplemental Information(Survey data and remote sensing classification methods)

Survey data

A field survey of the study area occurred from July–August 2021, taking the village-level unit as the study unit. Each village committee was contacted to conduct an overall village survey, and this included a total of 160 villages in 9 townships in Yunzhou District. The survey covers the village's land resources, agricultural cultivation, and land transfer, with specific content regarding the degree of education, the per capita income, the workforce, the daylily yield, the dried daylily price, the daylily industrial support policies, the daylily training frequency, and the land transfer scale (see Table S1).

Table S1. Descriptions of driving factors.

Variables	Mean±SE	Descriptions
Dependent variables		
Daylily area	59.9±4.6	The area classified by remote sensing images is counted by village (hm^2)
Iudependent variables		
Corn area	185.4±11.7	The area classified by remote sensing images is counted by village (hm^2)
Degree of education	84.8±10.1	Number of middle and high school students (including university students)
Workforce	675.2±49.1	people
Per capita income	8992.1±224.8	yuan
Daylily yield	9569.1±499.0	kg/hm^2
Dried daylily price	19.4±0.2	$yuan/hm^2$
Frequency of technical training in daylily industry	2.0±0.2	1=1 time in 1 year 2= 2 times in 1 year 0.5=1 time in 2 years...
Industrial support policies	2.4±0.1	Daylily subsidized by area / water conservancy facilities supporting / the government to handle disaster insurance and price insurance / the government contacts migrant workers to pick / the government builds workshops, drying equipment and other facilities: 1 when there is only one item...
Land transfer area	23.1±3.6	hm^2

Remote sensing classification methods

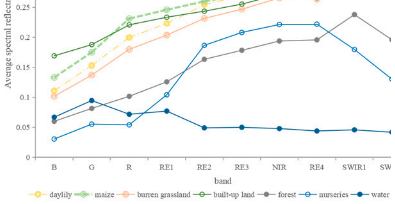
crops	months: April → November
Daylily	Spring seedlings growing period / Budding stage of moss / Anthesis / Autumn seedling growth period / Winter dormant period
Maize	seedling stage / Spike stage / Flowering stage / Harvest period

Figure S1. Phenological calendar of major crops in the study area

1 Optical remote sensing data

The spectral curves of water bodies fluctuated around 0.05 in May, and the NDVI values were consistently below 0 (Figure S2. a, b). Nurseries, as artificial seedling grounds, predominantly cultivate evergreen vegetation in the Yunzhou District. Consequently, in early May, their spectral curves exhibit a unique green vegetation characteristic known as the "two valleys and one peak." In contrast, all other land-use types and crops exhibit spectral curves similar to bare soil, with relatively high NDVI values during their various growth stages, which allows for the differentiation of nurseries. Forested areas in Yunzhou have diverse vegetation types, with less dramatic changes in NDVI values during different periods. The NDVI mean curve for these areas showed minimal variation throughout the season. Grasslands and forests do not exhibit the rapid spectral value decline observed in daylilies and maize. In addition, grasslands have lower NDVI values than forests in May, but higher NDVI values in August (Figure S2. d). Built-up land areas show NDVI values fluctuating around 0.1, and their spectral values in mid-August are entirely dissimilar to other land-use types. By utilizing NDVI values in early May, it is possible to differentiate between water bodies and nurseries. When incorporating spectral values from mid-August, forested, grassland, and built-up land can also be distinguished (Figure S2. c).

This study differentiated between daylilies and maize based on spectral characterization. In early May, when daylilies are just sprouting and maize planting is beginning, the spectral characteristics of the crops are similar to those of bare soil. The spectral curves exhibit a relatively flat trend without distinct "peaks" and "valleys". In June, the spectral curve for daylilies begins to show some of the spectral characteristics of vegetation. In the shortwave infrared wavelength range, there is an increase in absorption due to changes in plant water content, resulting in a decrease in reflectance. Starting from July, both daylily and maize exhibit unique spectral characteristics, which reflect their vegetative growth periods. There is a small reflectance peak near the green band, and two absorption bands in the blue and red bands, which are influenced by chlorophyll. Chlorophyll strongly absorbs blue and red light while reflecting green light. The sharp increase in spectral values in the RE2, RE3, and NIR bands, forming a "steep slope," due to the vegetation leaf cell structure, resulting in high reflectance. In the shortwave infrared band, the reflectance is greatly reduced due to the influence of plant moisture content, leading to a significant increase in absorption. After October, both daylilies and maize have been harvested and gradually wither and turn yellow due to weather conditions. From November to December, the crops on the farmland are in a dormant period, and their spectral characteristics are similar to those of bare soil. Observations of the spectral curves of daylily and corn showed that there were noticeable differences in August and September. In the visible light range, the spectral values of daylily were found to be higher than those of maize. In the red-edge range, the spectral reflectance of maize increases sharply to reach its maximum in the near-infrared range. From the red edge to the near-infrared range, the spectral reflectance of maize remains higher than that of daylily. However, due to the influence of crop moisture content, the reflectance drops significantly, and maize reflectance becomes lower than that of daylily. The spectral curves for November and December showed a consistent overall trend, with the maize reflectance being consistently higher than that of daylily. The differences in these features of the optical remote sensing images for crop classification were ultimately selected for comparison in August, September, and November (Figure S2. e, f).



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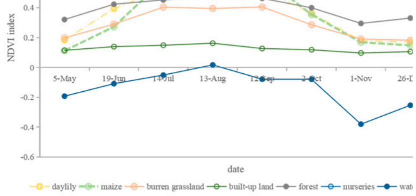

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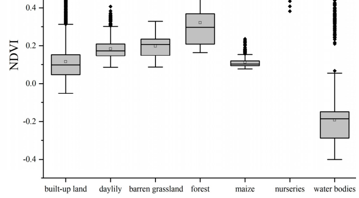

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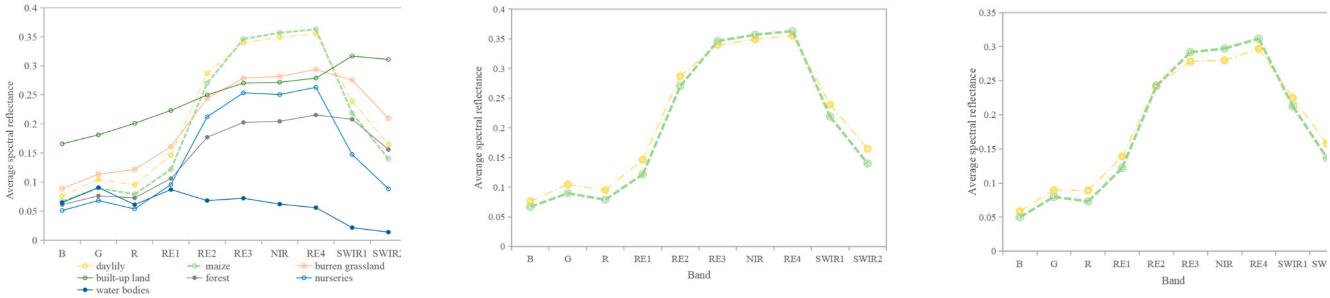


(d) (e) (f)

Figure S2. Crop spectral curves (a)Spectral curve on 5 May, (b)NDVI mean curve, (c)NDVI box plot, (d)Spectral curve on 13 August, (e)Spectral curves of corn and daylily on 13 August, (f)Spectral curves of corn and daylily on 12 September.

2 Vegetation indexes

The Sentinel-2 multispectral satellite encompasses a range from visible to shortwave infrared wavelengths, allowing for the calculation of various vegetation indexes. In this study, various vegetation indexes were selected to distinguish between two similar crops on cultivated land: daylily and maize. These vegetation indexes include soil-adjusted indexes, such as the Optimized Soil-Adjusted Vegetation Index (OSAVI); red-edge vegetation indices, such as the Inverted Red-Edge Chlorophyll Index (IRECI); chlorophyll content vegetation indexes, such as the MERIS terrestrial chlorophyll index (MTCI); the Plant Senescence Reflectance Index (PSRI); and traditional near-infrared vegetation indexes, such as the Normalized Difference Vegetation Index (NDVI).

The OSAVI is an improvement over NDVI as it takes soil factors into account. During the early stages of vegetative growth when the vegetation density is low, OSAVI is better at mitigating the soil influence and reflecting the chlorophyll content.

$$\mathrm{OSAVI}=(1+0.16)*(\mathrm{NIR}-\mathrm{RED})/(\mathrm{NIR}+\mathrm{RED}+0.16) \quad (5)$$

The IRECI is highly correlated with the chlorophyll content of the plant canopy and the leaf area index. It can quantitatively characterize the chlorophyll content of plants and serve as a good indicator of plant growth conditions [43-46]. In this study, the mean value of the IRECI in early May was selected as one of the data inputs.

$$\mathrm{IRECI}=(\mathrm{NIR}-\mathrm{RED}) / (\mathrm{RE1}/\mathrm{RE2}) \quad (6)$$

MTCI is known for its good accuracy and stability in estimating chlorophyll content in maize plants [47].

$$\mathrm{MTCI}=(\mathrm{RE2}-\mathrm{RE1})/(\mathrm{RE1}-\mathrm{RED}) \quad (7)$$

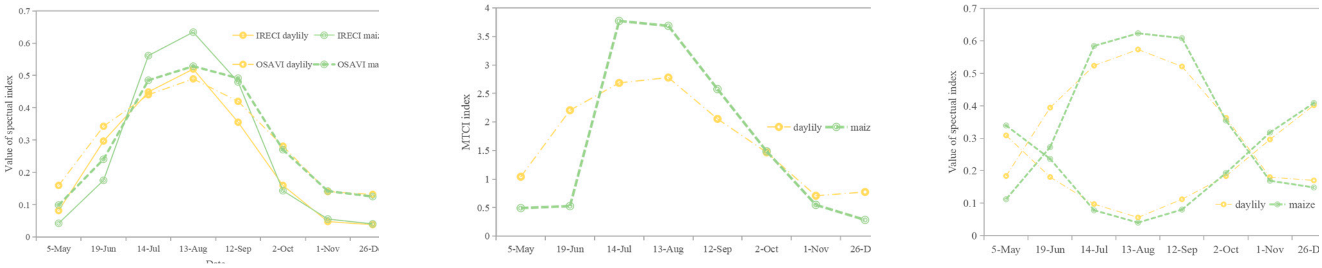
The NDVI is widely used for assessing crop growth and it is a commonly used vegetation index [48].

$$\mathrm{NDVI}=(\mathrm{NIR}-\mathrm{RED})/(\mathrm{NIR}+\mathrm{RED}) \quad (8)$$

The PSRI is utilized to monitor vegetation health, detect physiological stress in plants, and analyze crop production and yield.

$$\mathrm{PSRI}=(\mathrm{RED}-\mathrm{BLUE})/\mathrm{NIR} \quad (9)$$

Except for the NIR wavelength of 783 nm in the IRECI index, all other indexes have NIR wavelengths of 842 nm. The wavelengths for BLUE and RED in all indexes are 490 nm and 665 nm, respectively, while the wavelengths for RE1 and RE2 are 705 nm and 740 nm, respectively.



(a) (b) (c)

Figure S3. Vegetation Index curves (a)OSAVI and IRECI mean curve, (b)MTCI mean curve, (c)NDVI and PSRI mean curve.

The trends in the OSAVI and IRECI spectral means for daylily and maize were found to be consistent. In early May, daylily has already emerged, while maize is just beginning to be planted, and thus the vegetation is very sparse at this time. Using the OSAVI index to remove soil influence results in a more accurate estimation of vegetation chlorophyll content. In May, the OSAVI value for daylily was found to be significantly higher than that for maize, and there were distinct differences in the spectral characteristics of the MTCI index. The OSAVI, IRECI, and MTCI indexes were thus selected for use in May (Figure S3. a, b, c).

Improved Vegetation Index NSP

The overall trends for the NDVI and PSRI indexes were consistent between the daylily and maize. The NDVI values all reached their maximum on August 13th when crop growth was at its peak. However, daylily is typically planted with wider row spacing and often uses wide-narrow row planting. At a spatial resolution of 10 m, the canopy density for daylily is much lower when compared to maize, which is why the NDVI maximum values for daylily were also lower than those for maize. However, daylily is a perennial herbaceous plant, entering its spring seedling growth period in April, and already emerging in early May. In contrast, maize is just beginning to be sown during this period. Therefore, in early May, the NDVI values for daylily are higher than those for maize. Maize grows rapidly after germination, so from June to July, the NDVI slope for maize is much greater than that for daylily, and it reaches its maximum value in August. Maize then essentially stops vegetative growth and enters a phase in which it is focused on reproductive growth. The male and female reproductive organs of maize continue to grow, and the maize cobs increase in size. The maize silks gradually dry up or fall off, leaving behind a mature maize cob. During this stage, NDVI values decrease until the maize fruits are mature and harvested. After the first frost and as the weather turns colder, the NDVI values decrease to their lowest point as the crop residues dry up. Daylily grows much slower than maize, and its height is also significantly lower than that of maize when mature. Therefore, from June to July, the NDVI curve's slope for daylily is lower than that for maize, and it reaches its maximum value in August. By mid-August, daylily is harvested, and farmers often remove weeds to prevent competition for nutrients in the following year. As the weather turns colder, the daylily gradually turns yellow and dries up, and the NDVI values then decrease to their lowest point.

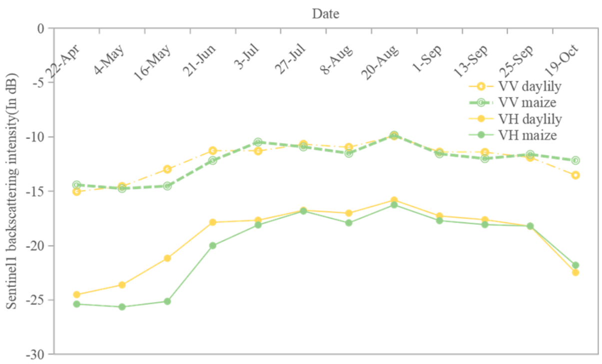
The PSRI is utilized to monitor vegetation health, as it can detect physiological stress in plants and analyze crop production and yield. An increase in PSRI values indicates an increase in vegetation canopy stress, which signifies the onset of vegetation aging and the maturation of plant fruits. From May to August, the PSRI values of both the daylily and maize consistently decrease, reaching their lowest points in August, and during this period, the crops primarily undergo vegetative growth. After August, maize enters the flowering and grain-filling stages, with the fruits gradually maturing. In contrast, as the daylily have passed their harvesting period in August, they begin to age, wither, and turn yellow, leading to an increase in PSRI values. From the figure, it can be observed that the differences between the NDVI and PSRI values were higher for maize when compared to daylily. Therefore, a new and improved vegetation index was proposed to enhance the accuracy when distinguishing between daylily and maize.

$$\mathrm{NSP} = |\mathrm{NDVI} - \mathrm{PSRI}| \tag{10}$$

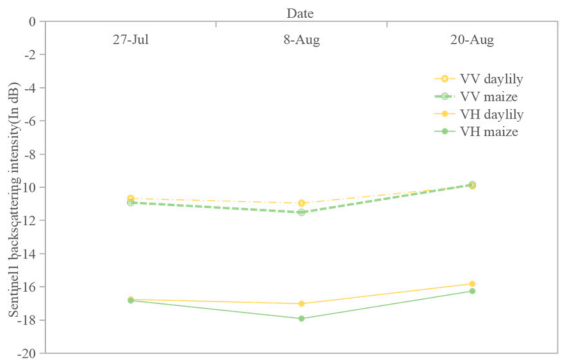
3 SAR data

During the image classification training process, the time series of mean backscattering values for the VV and VH polarizations of the daylily and maize (Figure S4. a) can be observed. As daylilies are perennial herbaceous plants, their growth and germination occur from April to May. During this period, maize has not been planted yet, resulting in relatively low backscattering values for both the VV and VH polarizations, which are all below −13 dB. However, the backscattering curve for daylily shows an upward trend, while the backscattering curve for maize remains relatively stable. In mid-May, maize grows rapidly, leading to a rapid increase in backscattering. In June and July, after the jointing and spiking stages, the backscattering values gradually move to the right and increase steadily. By late August, during the maturity period, the backscattering values reach their highest point, with a maximum value of −9.85 dB (Figure S4. b).

When comparing different polarization modes, the backscattering coefficient trends for VV and VH polarization are generally similar. In VV polarization, the backscattering coefficient for daylily increased from −15.03 dB to −9.91 dB, while for maize, it increased from −14.75 dB to −9.85 dB. The overall change is not significant and fluctuates within the range of −15.03 dB to −9.85 dB. In the VH polarization, the backscattering coefficient for daylily increased from −24.51 dB to −15.81 dB, while for maize, it increased from −25.64 dB to −16.26 dB.



(a)



(b)

Figure S4. Backscatter curves (a)Backscatter curve in whole growing period, (b)Backscatter curve on July to August.

4 Accuracy verification

A confusion matrix was used to calculate the accuracy of the daylily and maize classifications. The matrix utilized statistics on all pixels within the sample area for accuracy assessment and measured the degree of confusion between the categories in the classification map and the actual categories. The overall accuracy (OA) and Kappa coefficient were evaluation metrics for the overall classification performance. While user accuracy (UA) and producer accuracy (PA) were metrics by which to evaluate the classification performance of different crop types. The F1 score is a harmonic mean precision metric based on PA and UA [49].

$$\mathrm{OA} = \frac{\sum_{i=1}^{k} S_{ii}}{n} \tag{11}$$

$$\text{Kappa}=\frac{n\sum_{i=1}^{k}S_{ii}-\sum_{t=1}^{k}(S_{i+}*S_{+i})}{n^2-\sum_{i=1}^{k}(S_{i+}*S_{+i})} \quad (12)$$

$$\text{UA}=\frac{S_{ii}}{S_{i+}} \quad (13)$$

$$\text{PA}=\frac{S_{ii}}{S_{+i}} \quad (14)$$

$$\text{F1}=2*\frac{\text{PA}*\text{UA}}{\text{PA}+\text{UA}} \quad (15)$$

In the equation, k represents the total number of vegetation types; n represents the total number of samples; the diagonal elements S_{ii} represent the number of correctly classified true samples; S_{i+} represents the total number of samples for type i; S_{+i} represents the number of samples classified as class j; S_i and S_j respectively represent the values associated with the element (i, j) in the confusion matrix.