
Madrid Multi-Spectral Data

This appendix includes the spectral images per crop type as obtained from the outdoor experiment described in Section 3.4.2 and in Chapter 7. They are shown chronologically per crop type for both seasons. In each measurement, each crop row was measured three times, out of which the best image set, after stitching as described in Section 4.2, was included here. For each set of spectral images, the raw reflectance values, ranging in values from 0 to 2^{16} inherent to the 16-bit encoding, are shown, alongside the calculated vegetation indices (VI's) after automatic translation for optimal overlap. Finally, the heightened contrast obtained from the Gaussian filtering and the mask based on the Otsu threshold as described in Section 4.4 are included as well. Of the final masks of each week and crop the VI means, and the areas and perimeters are summarised graphically per field-half.

Contents of this appendix:

- Original spectral images, unfiltered and filtered images with their respective histograms, and the final vegetation masks. All per week.
 - D.1: Cauliflower
 - D.2: Red Cabbage
 - D.3: Cabbage
- D.4: Means and standard deviations of the VI values, areas (in m^2 per m^2), and perimeters (in pixels) for each VI, crop, field-half, and week both with and without masking as identified in Sections D.1 to D.3.

D.1 Cauliflower

D.1.1 2019 - Week 3

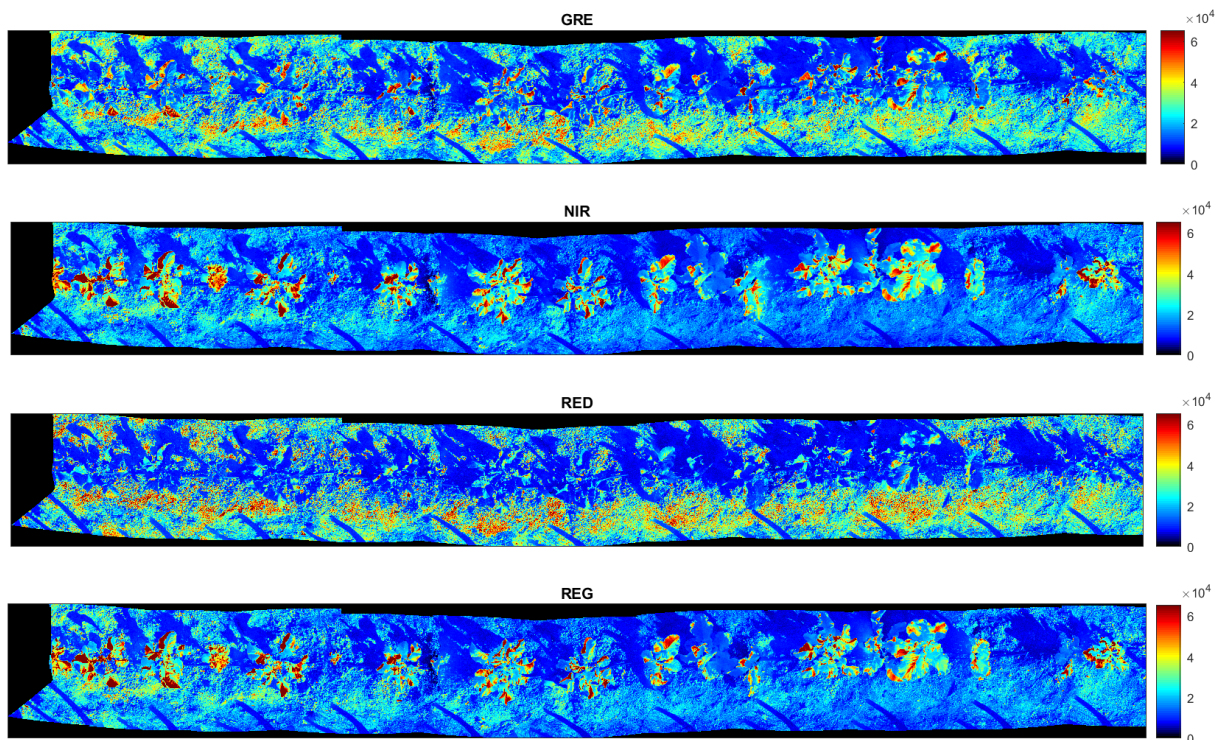


Figure D.1 Original spectral bands of Cauliflower 2019 week 3.

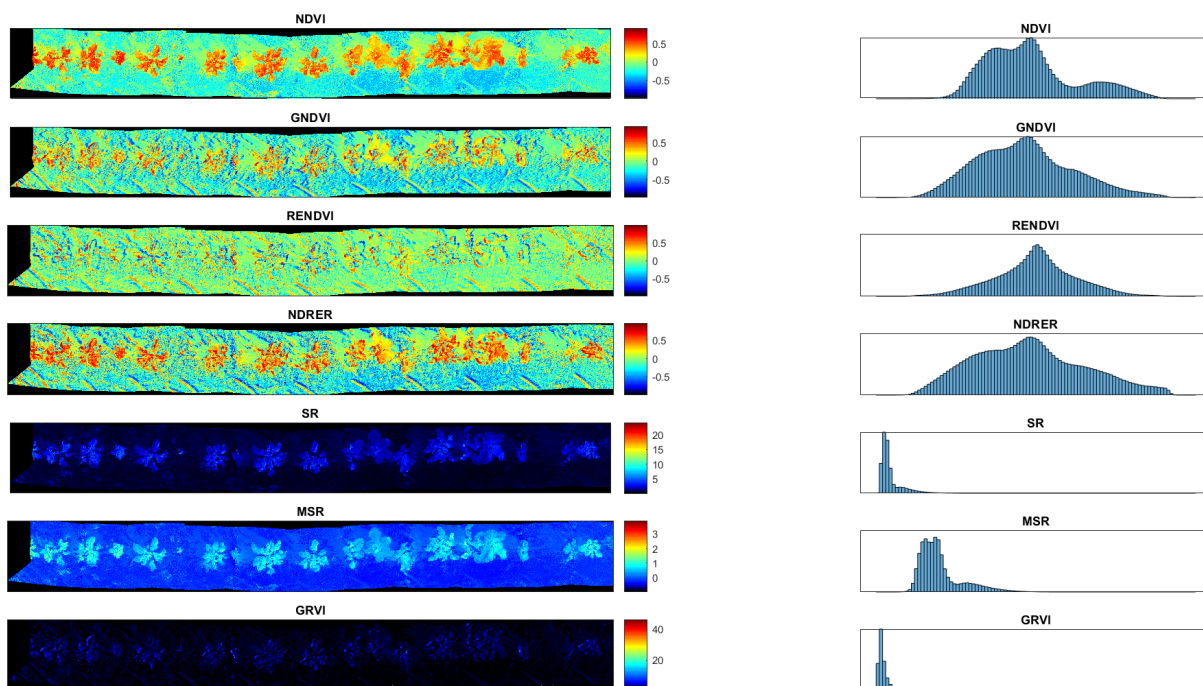


Figure D.2 Unprocessed VIs of Cauliflower 2019 week 3 and their value distributions.

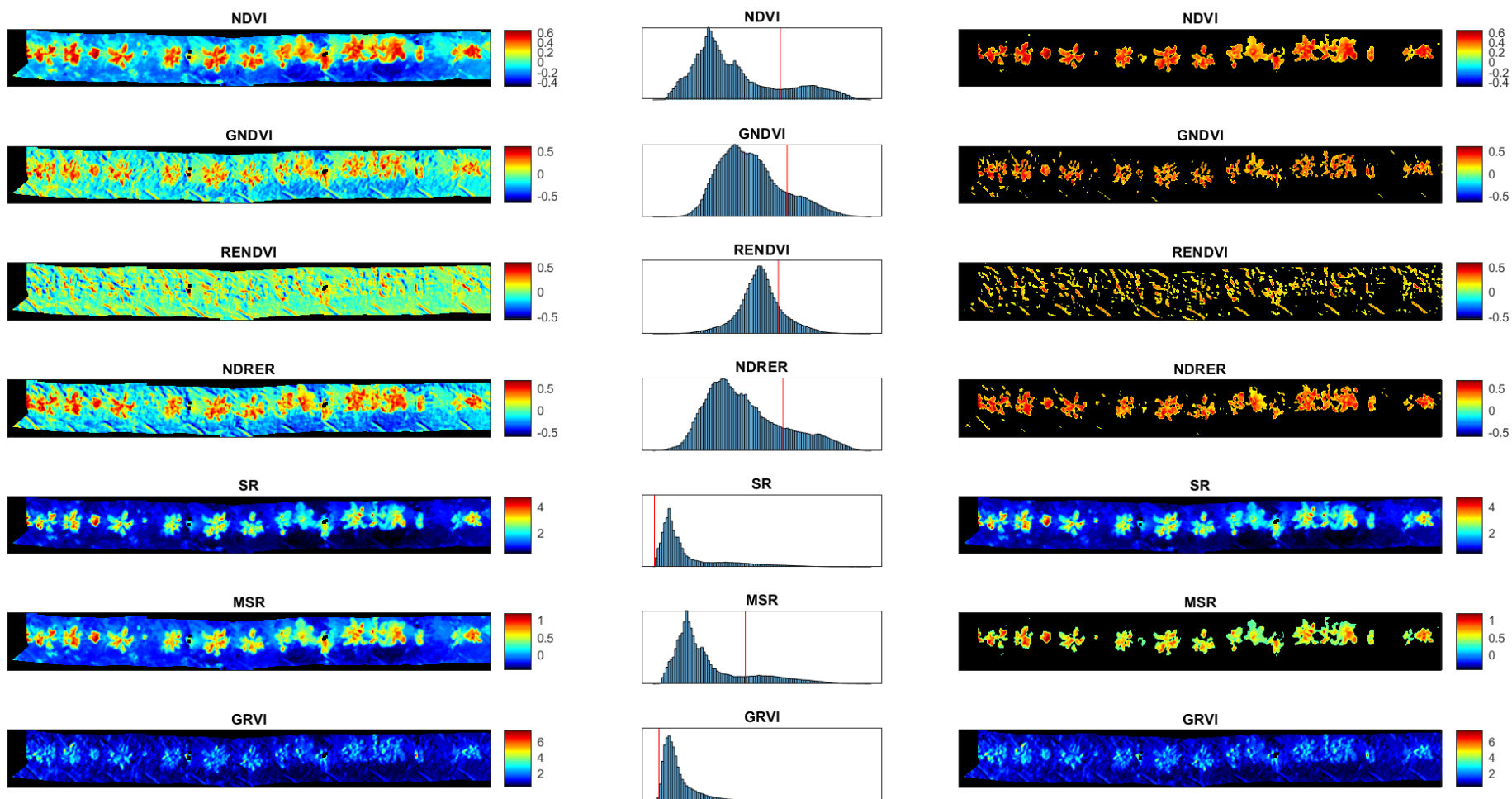


Figure D.3 Gaussian filtered VI's of Cauliflower 2019 week 3 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.1.2 2019 - Week 10

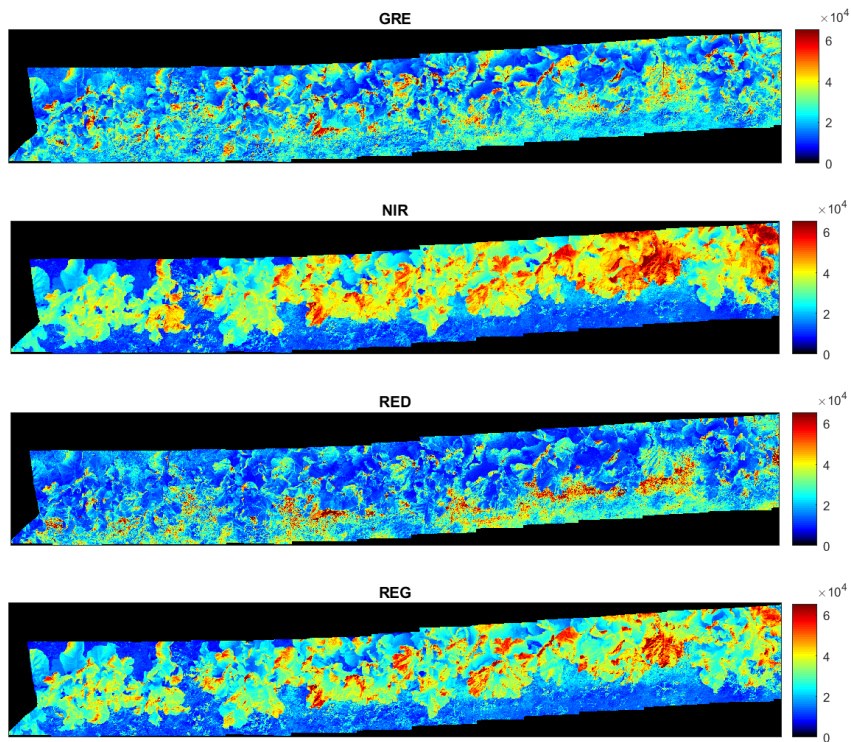


Figure D.4 Original spectral bands of Cauliflower 2019 week 10.

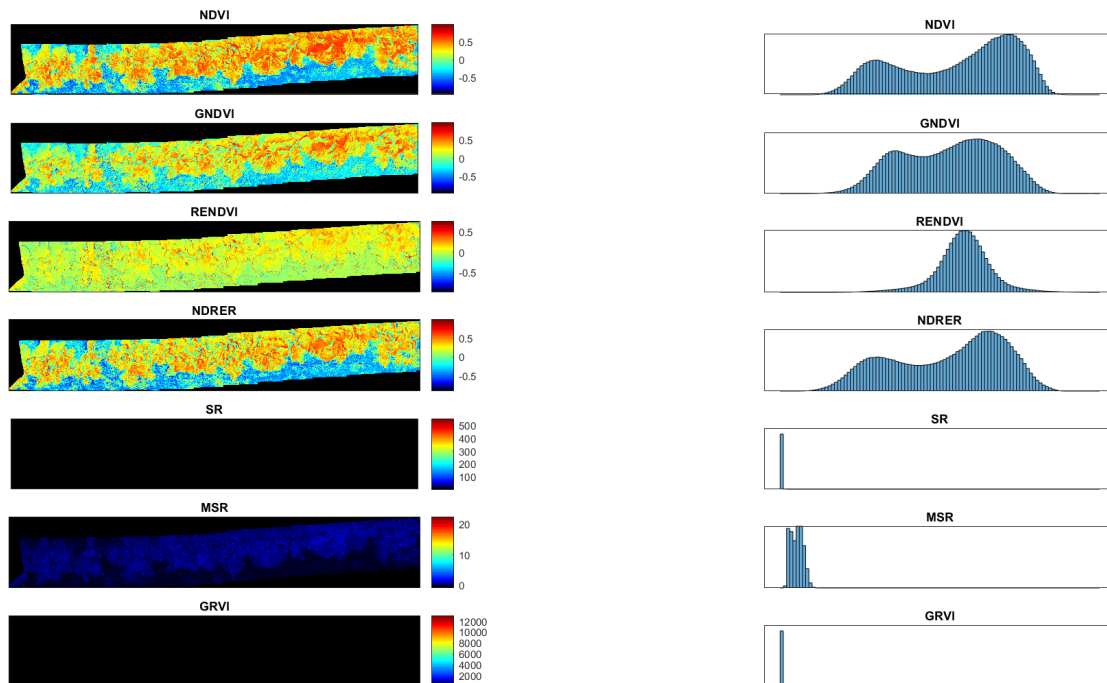


Figure D.5 Unprocessed VI's of Cauliflower 2019 week 10 and their value distributions.

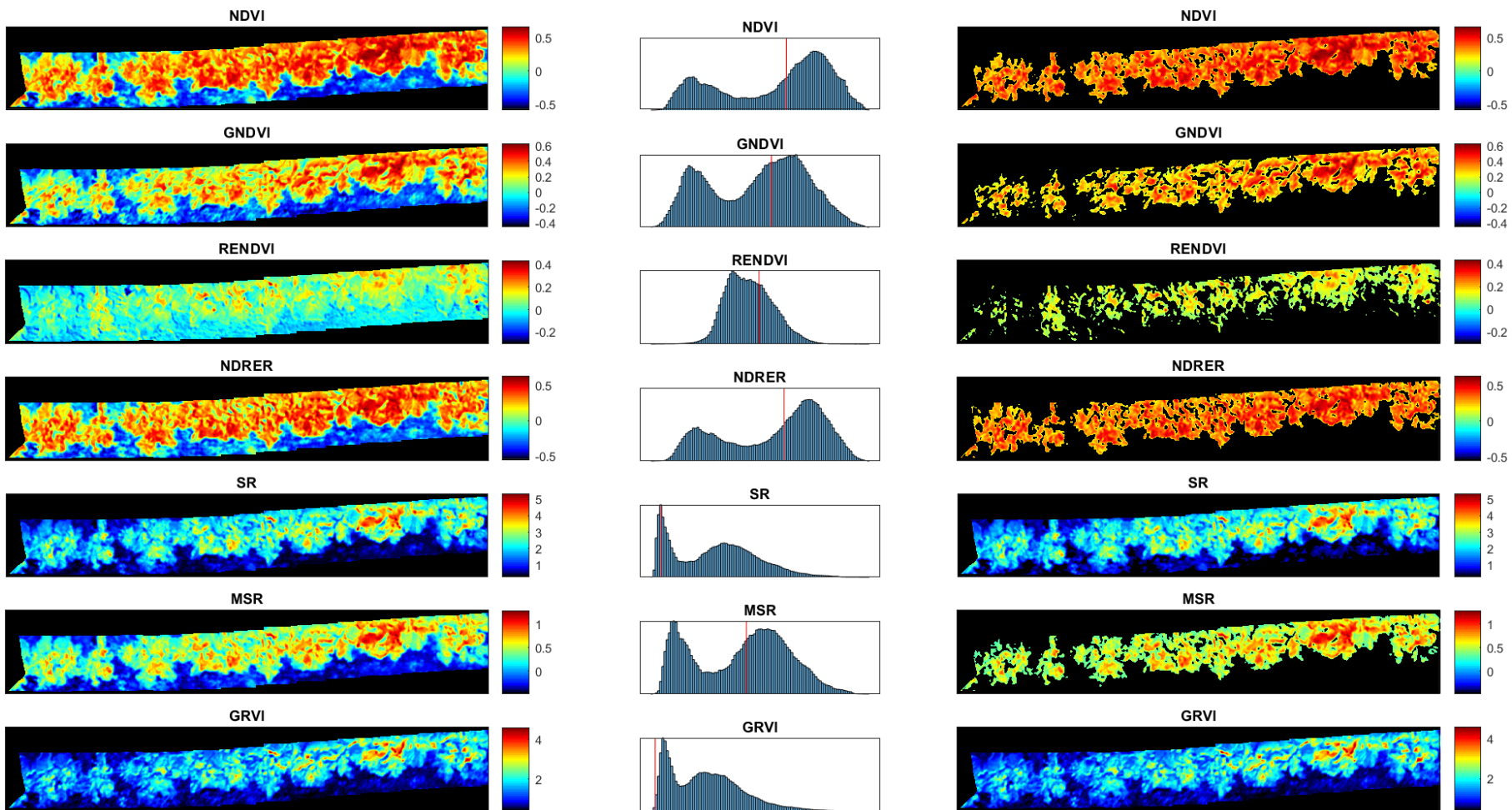


Figure D.6 Gaussian filtered VI's of Cauliflower 2019 week 10 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.1.3 2020 - Week 5

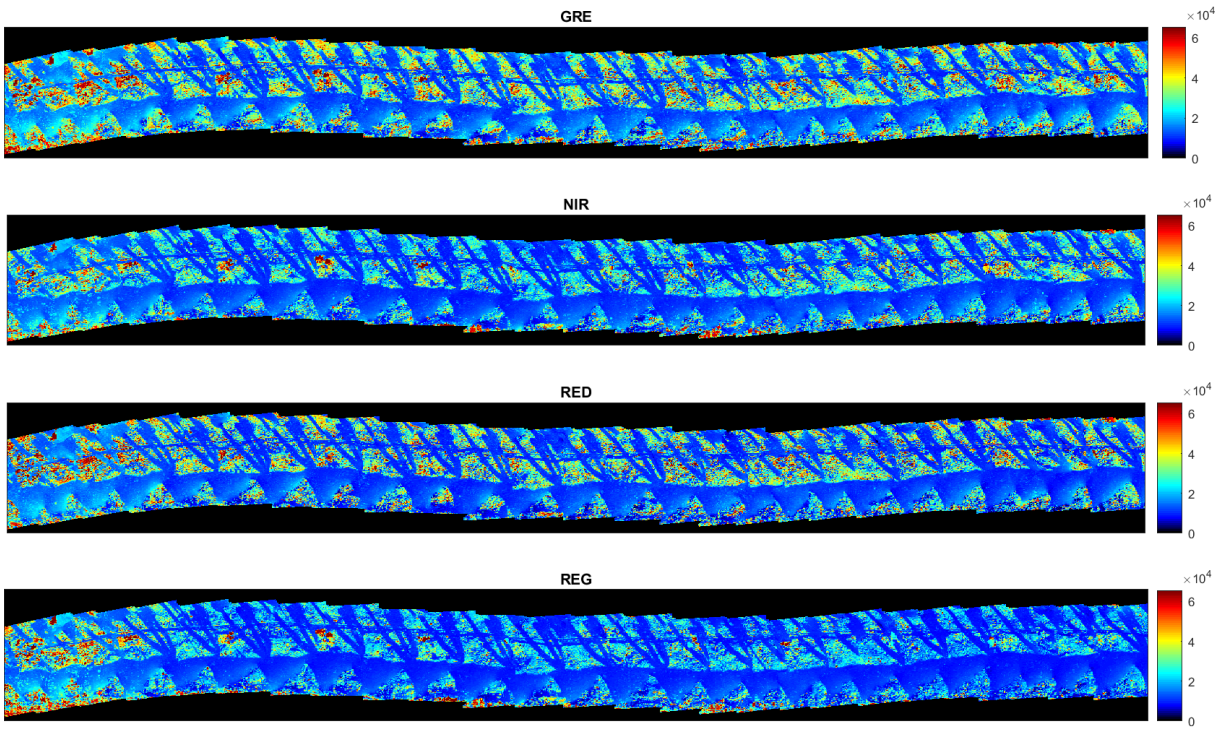


Figure D.7 Original spectral bands of Cauliflower 2020 week 5.

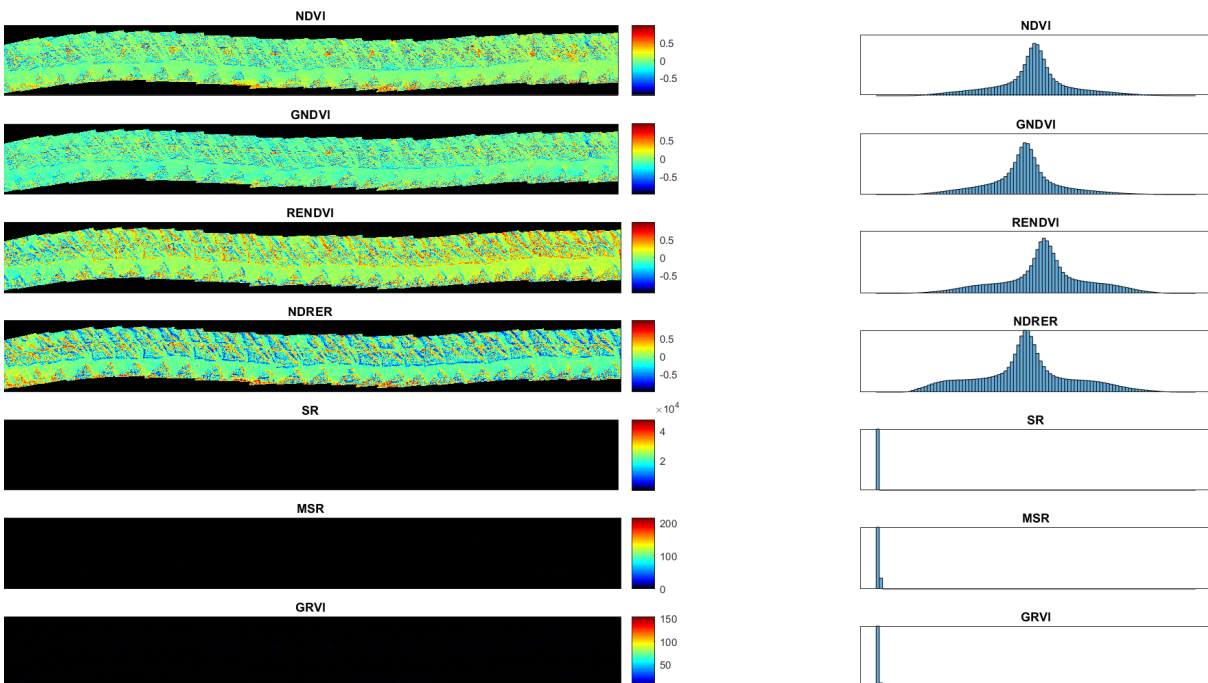


Figure D.8 Unprocessed VIs of Cauliflower 2020 week 5 and their value distributions.

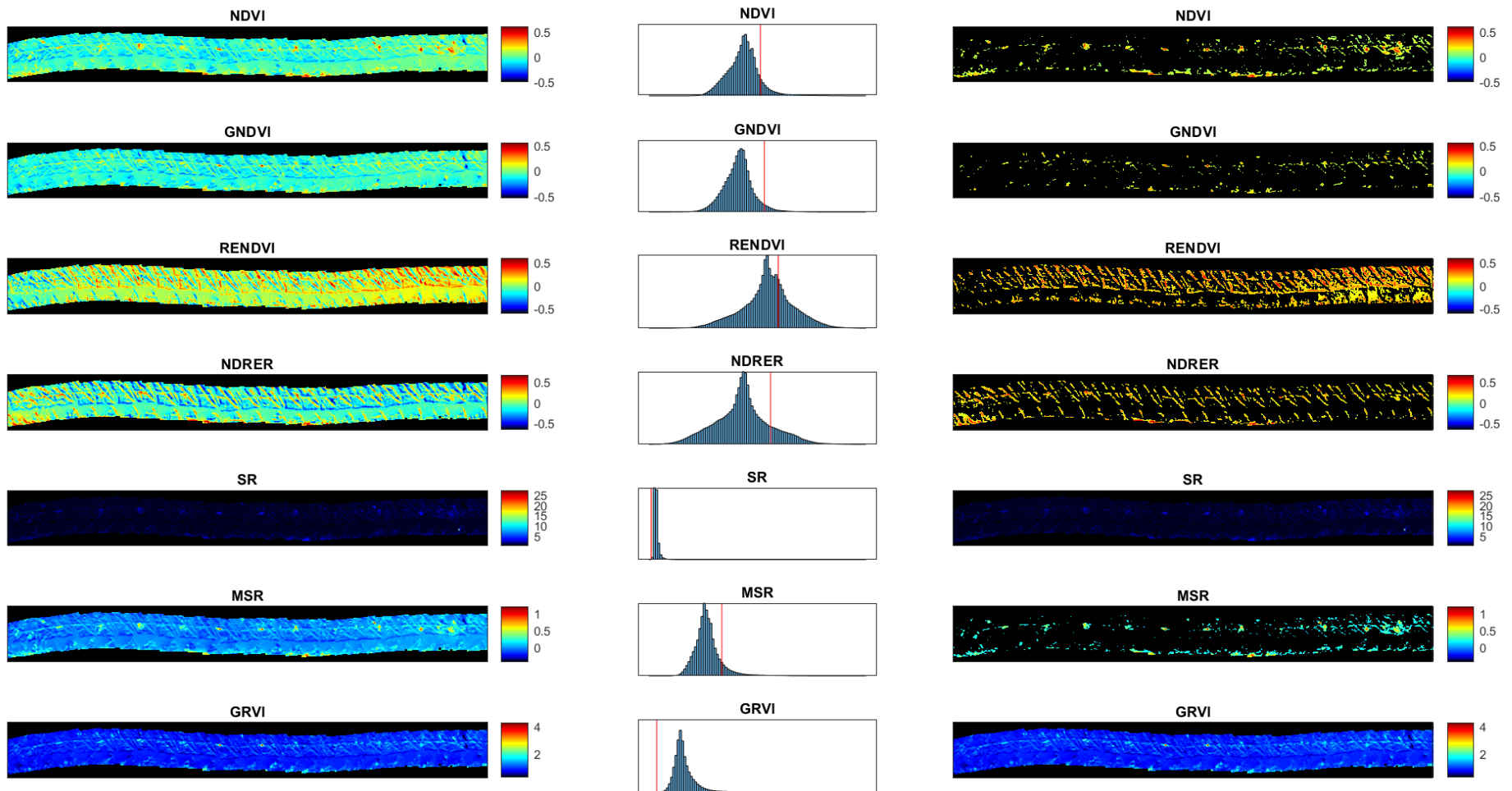


Figure D.9 Gaussian filtered VI's of Cauliflower 2020 week 5 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.1.4 2020 - Week 6

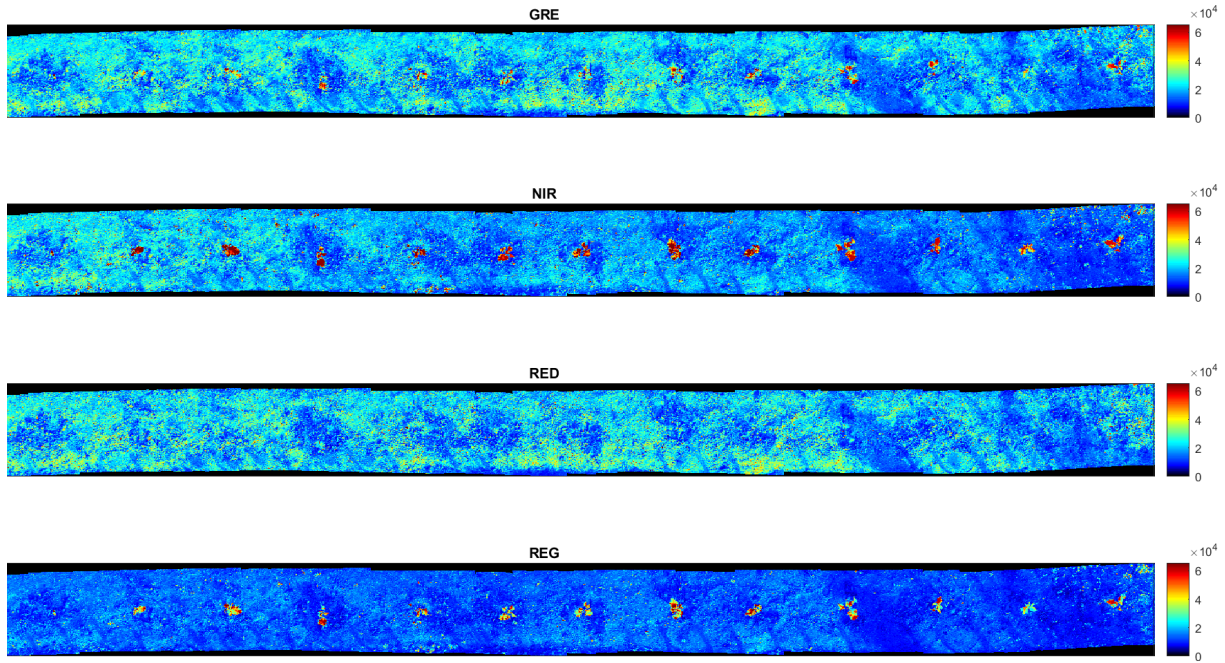


Figure D.10 Original spectral bands of Cauliflower 2020 week 6.

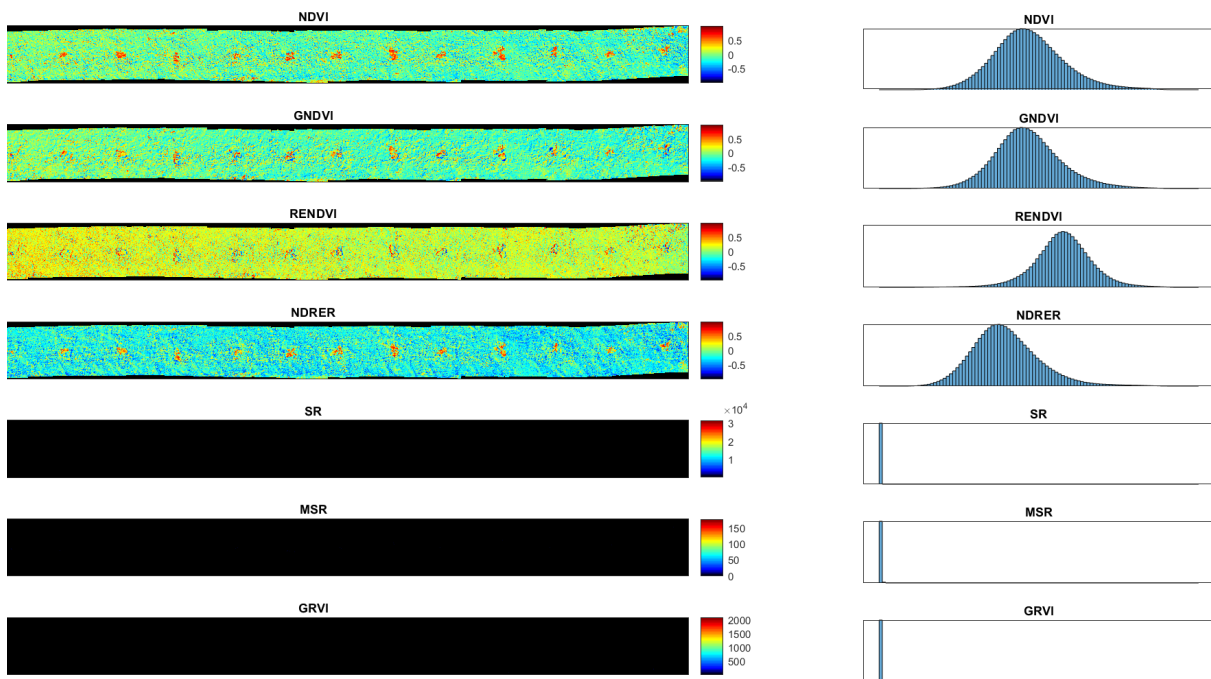


Figure D.11 Unprocessed VI's of Cauliflower 2020 week 6 and their value distributions.

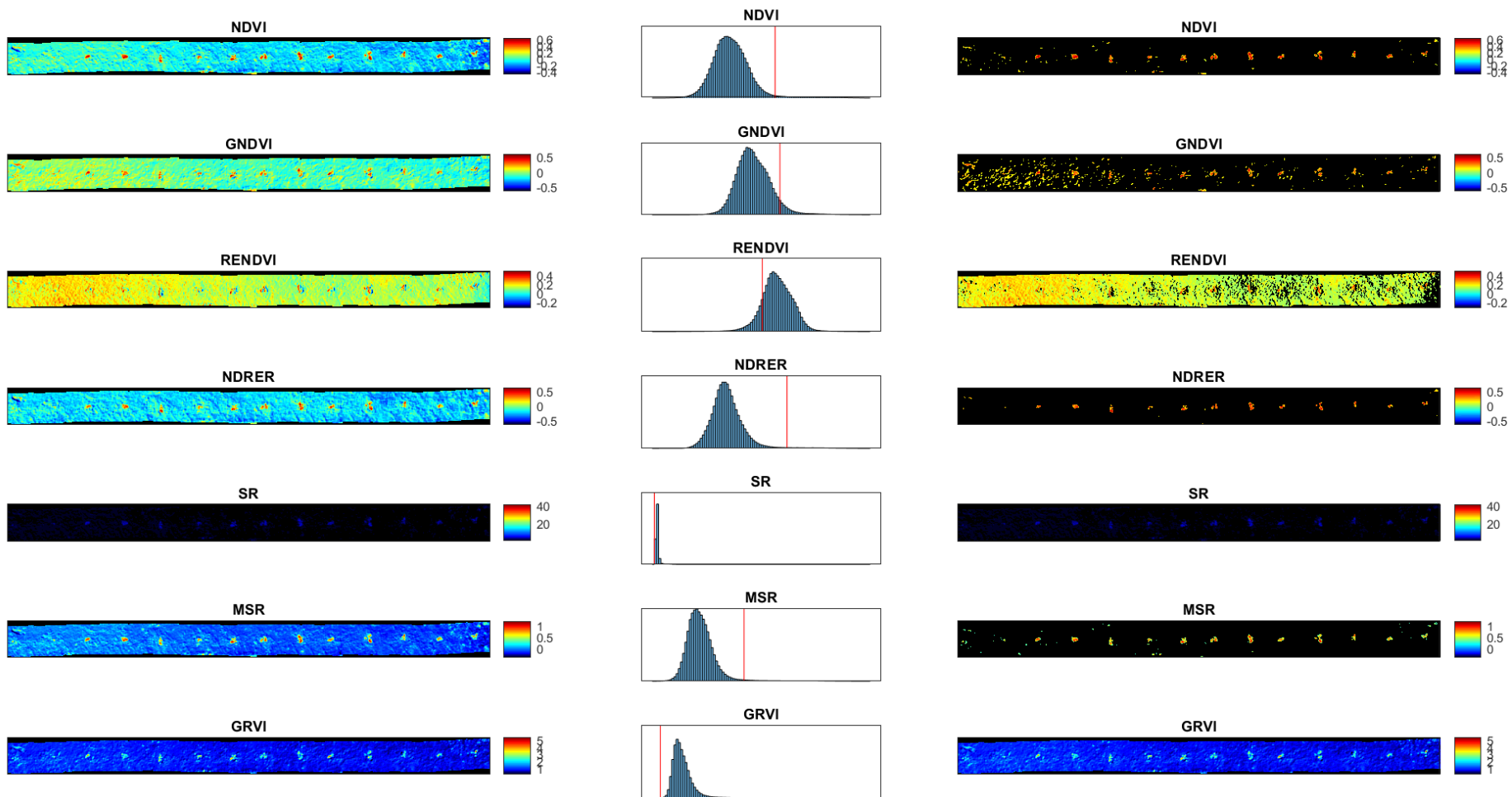


Figure D.12 Gaussian filtered VI's of Cauliflower 2020 week 6 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.1.5 2020 - Week 7

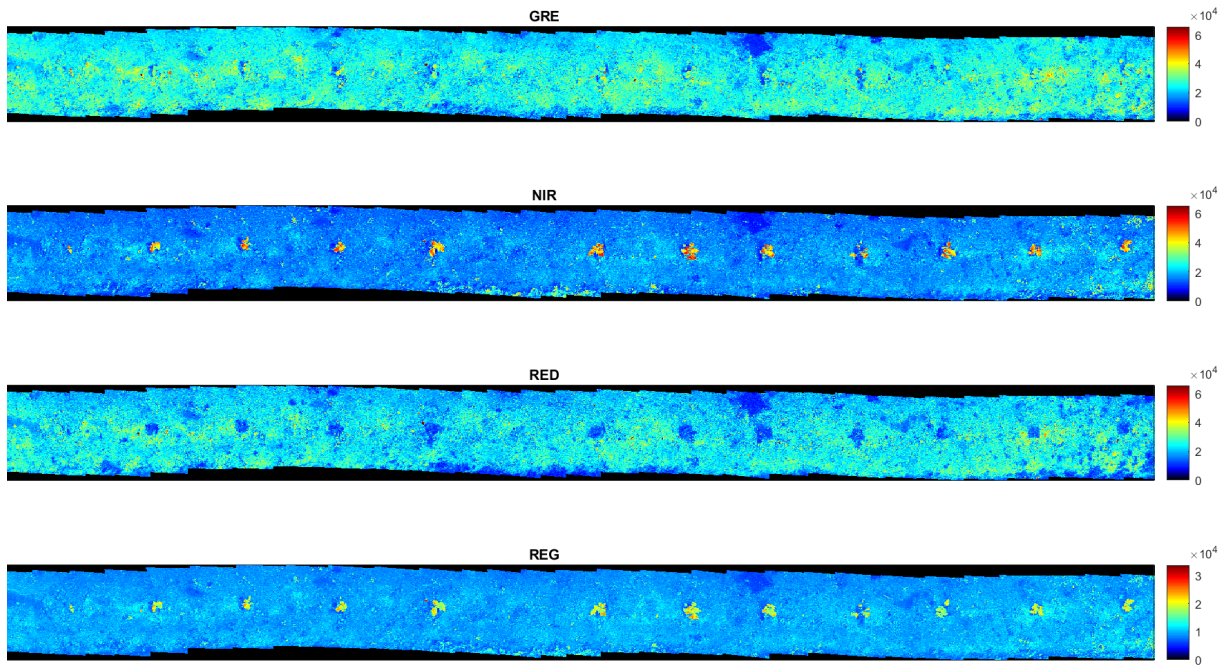


Figure D.13 Original spectral bands of Cauliflower 2020 week 7.

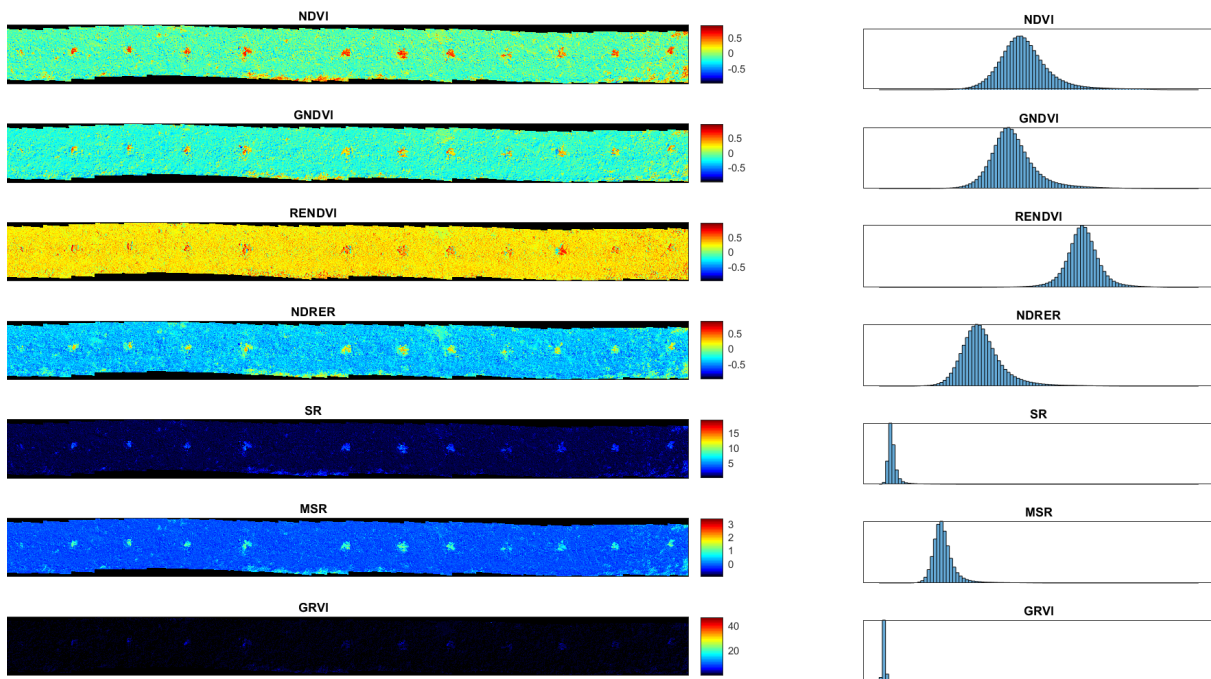


Figure D.14 Unprocessed VIs of Cauliflower 2020 week 7 and their value distributions.

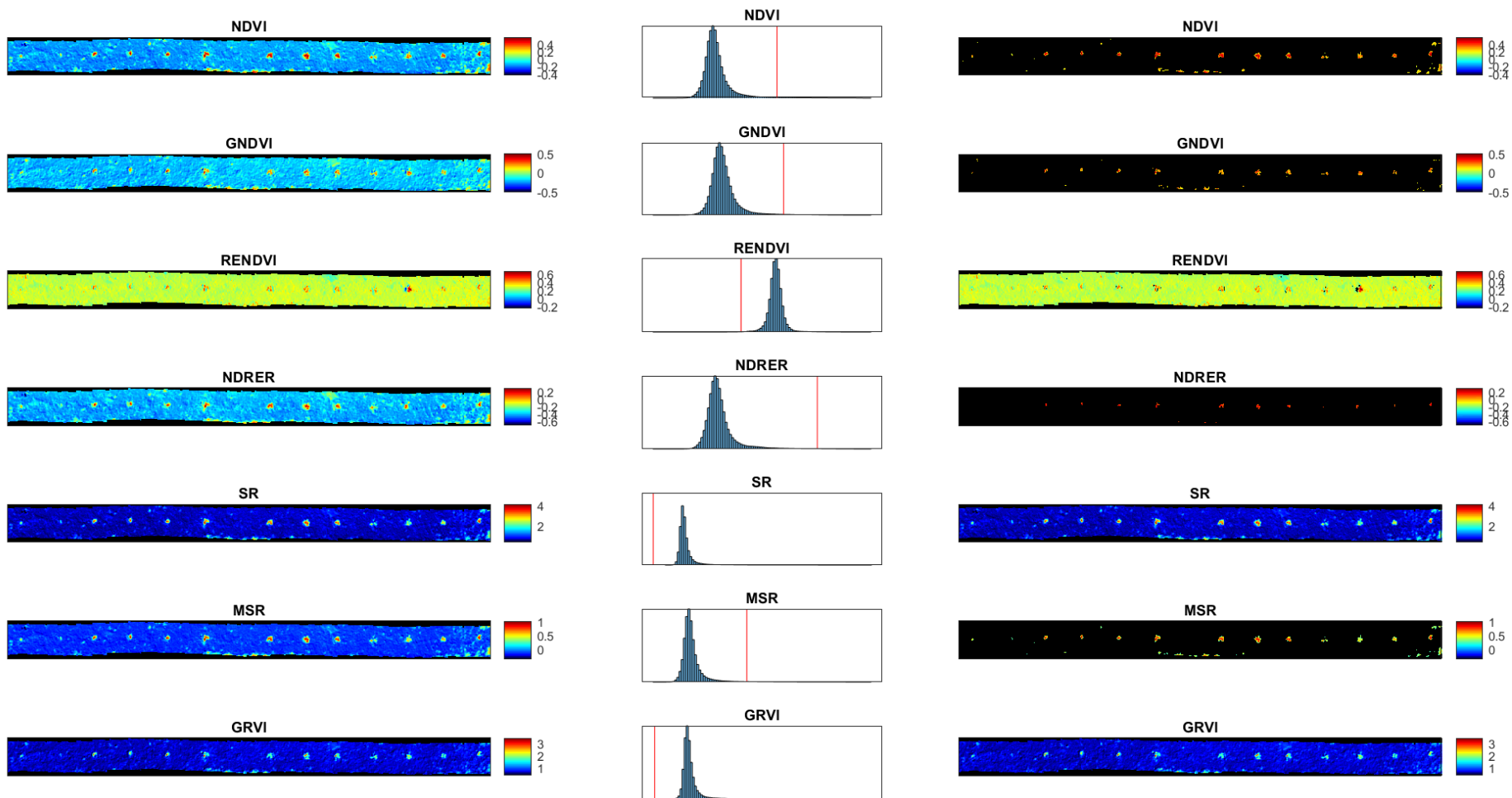


Figure D.15 Gaussian filtered VI's of Cauliflower 2020 week 7 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.2 Red Cabbage

D.2.1 2019 - Week 3

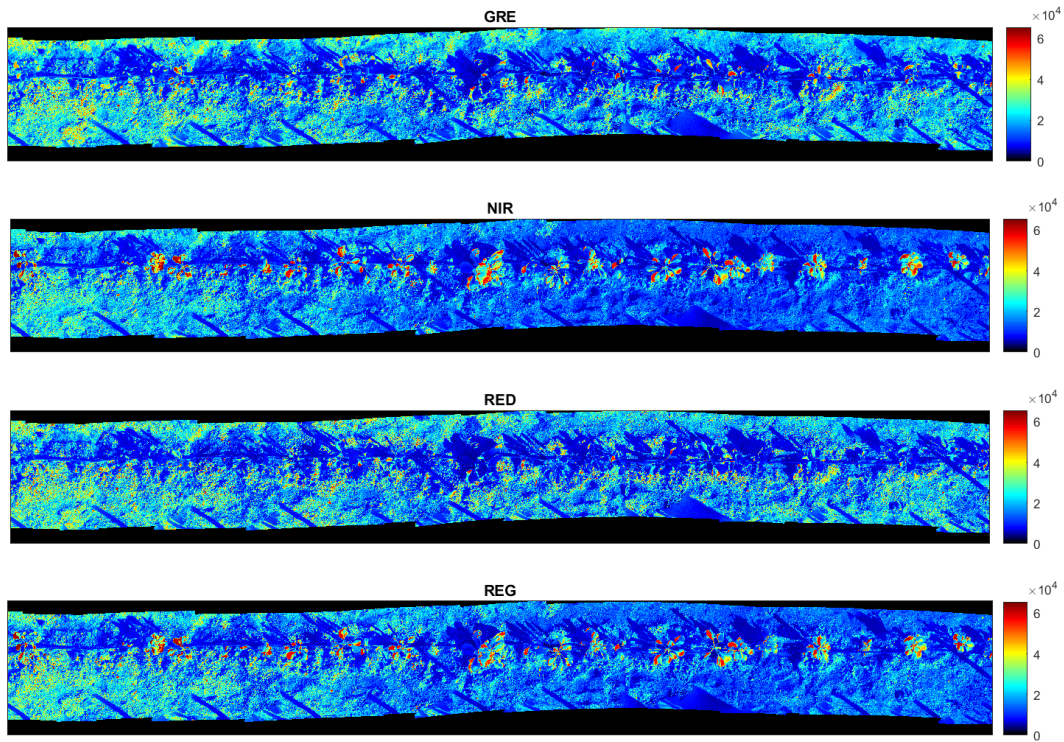


Figure D.16 Original spectral bands of Red Cabbage 2019 week 3.

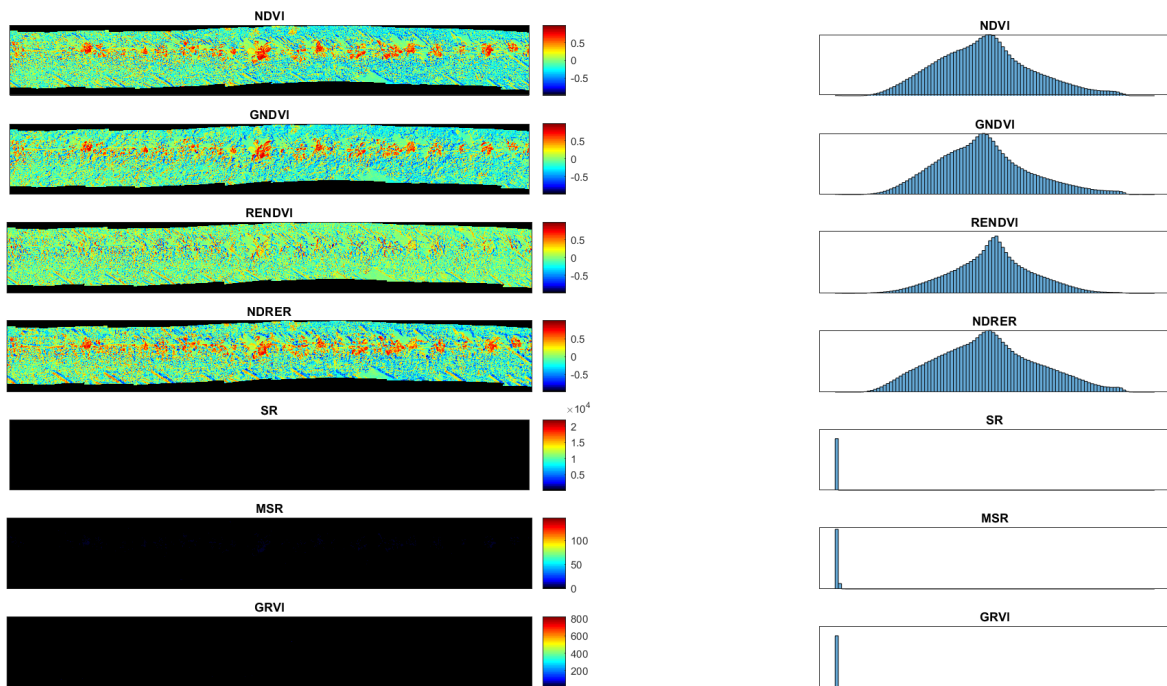


Figure D.17 Unprocessed VI's of Red Cabbage 2019 week 3 and their value distributions.

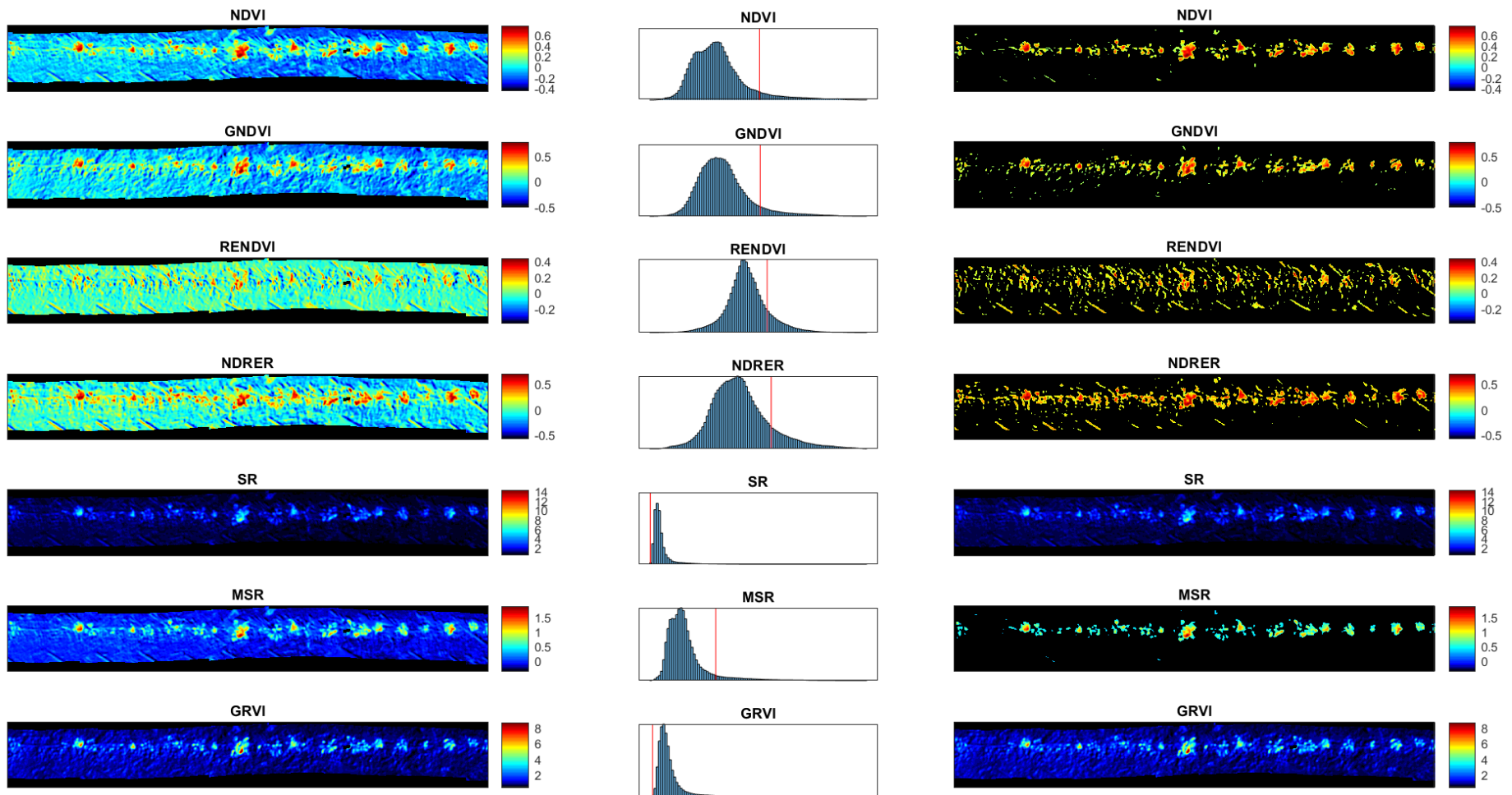


Figure D.18 Gaussian filtered VI's of Red Cabbage 2019 week 3 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.2.2 2019 - Week 9

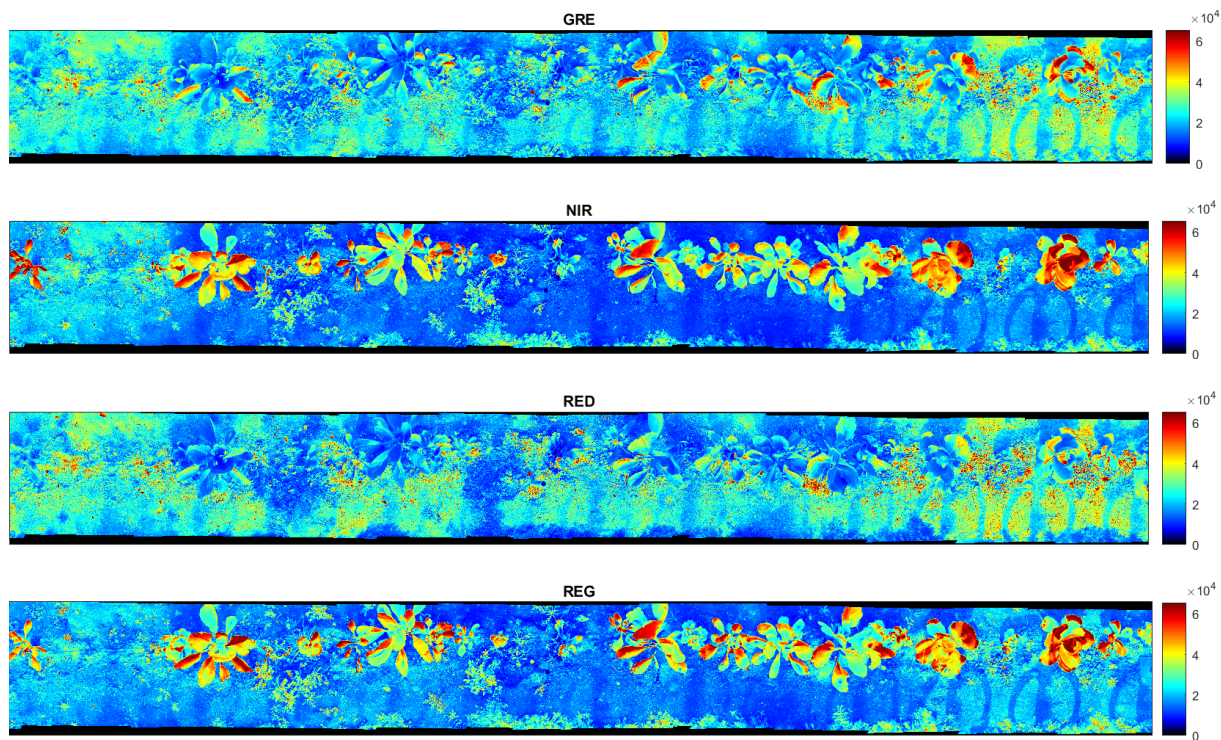


Figure D.19 Original spectral bands of Red Cabbage 2019 week 9.

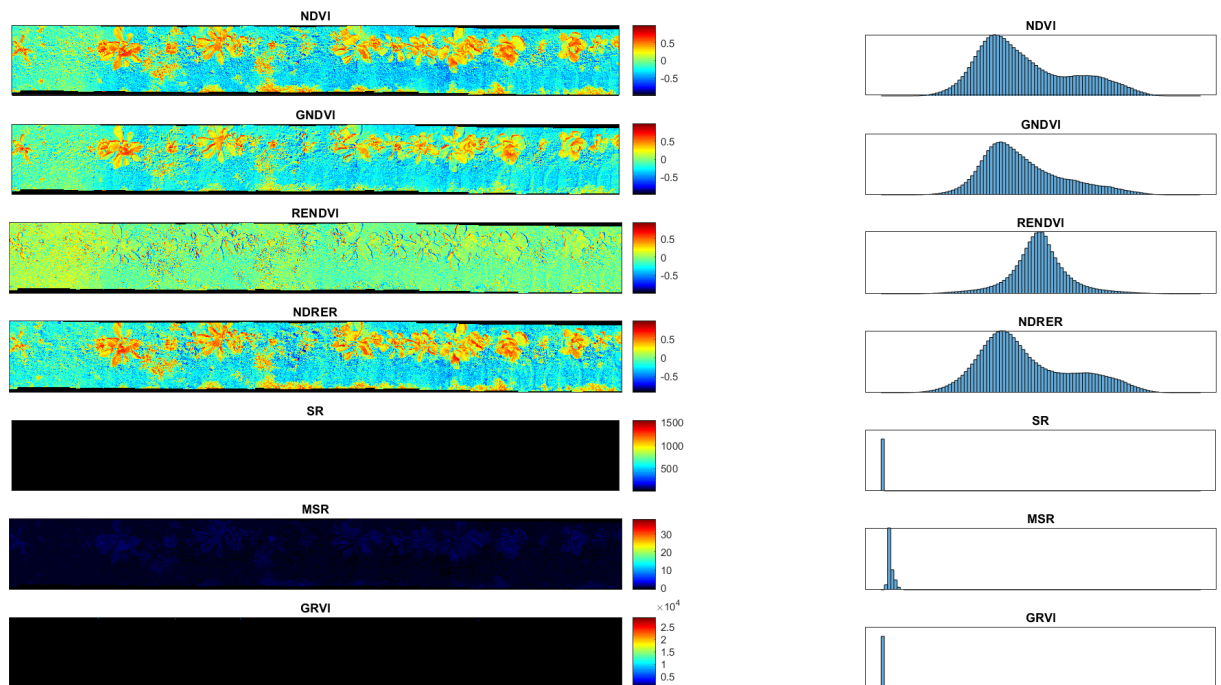


Figure D.20 Unprocessed VI's of Red Cabbage 2019 week 9 and their value distributions.

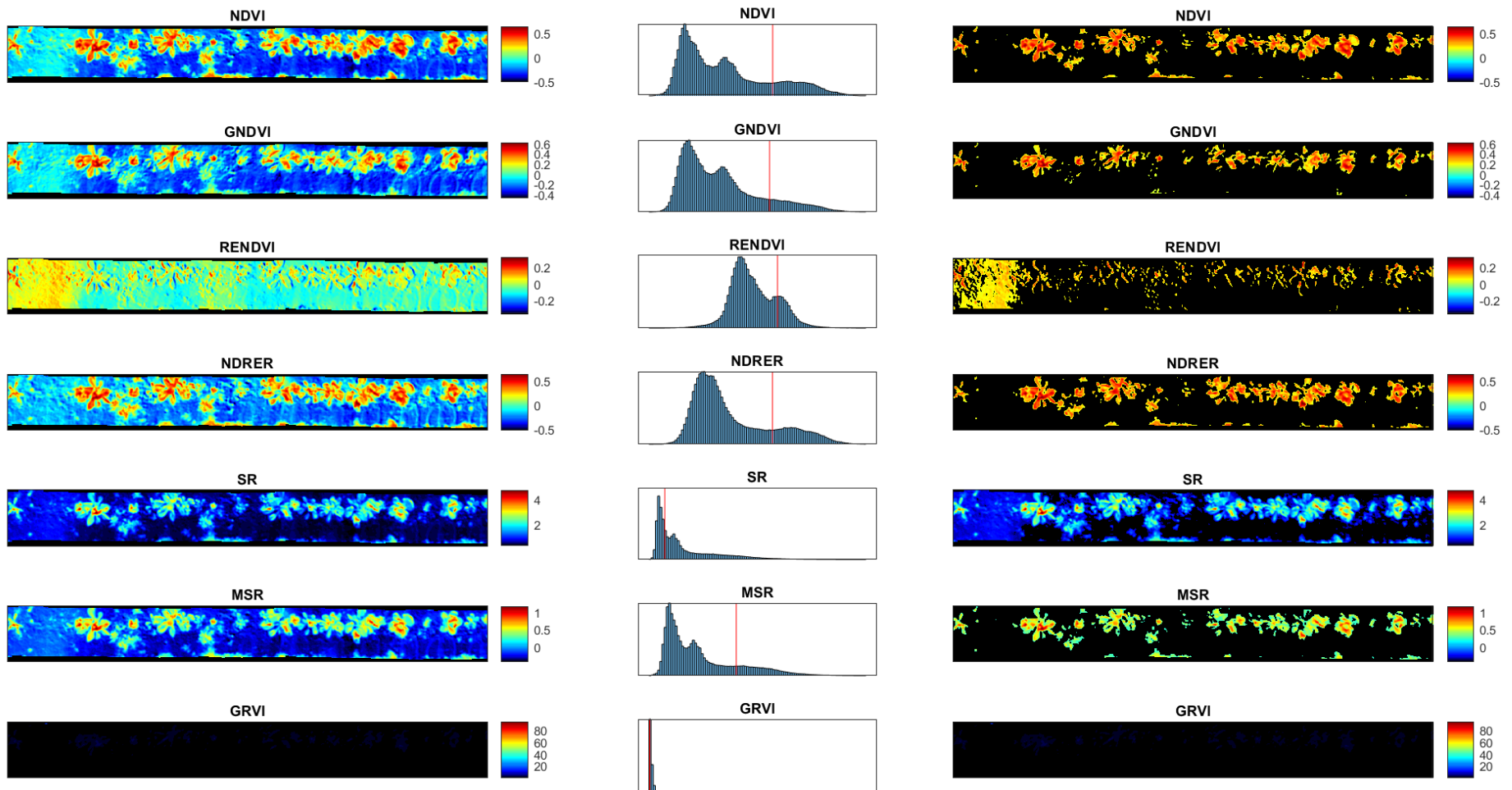


Figure D.21 Gaussian filtered VI's of Red Cabbage 2019 week 9 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.2.3 2019 - Week 10

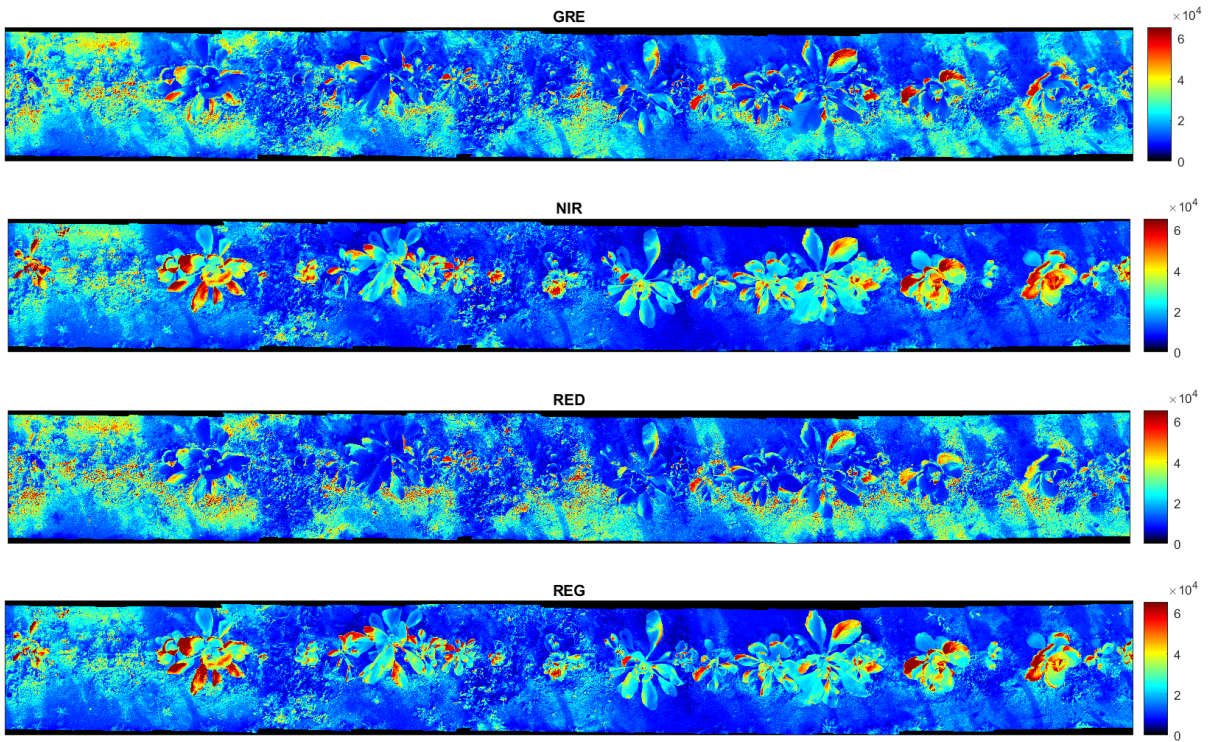


Figure D.22 Original spectral bands of Red Cabbage 2019 week 10.

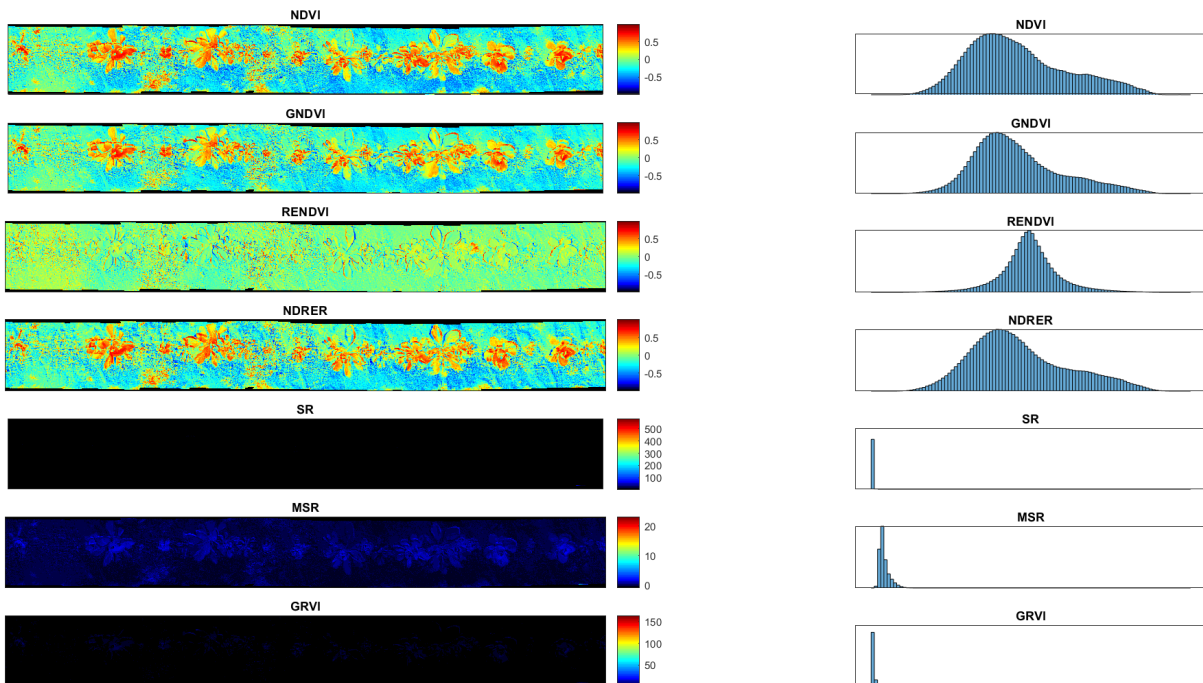


Figure D.23 Unprocessed VI's of Red Cabbage 2019 week 10 and their value distributions.

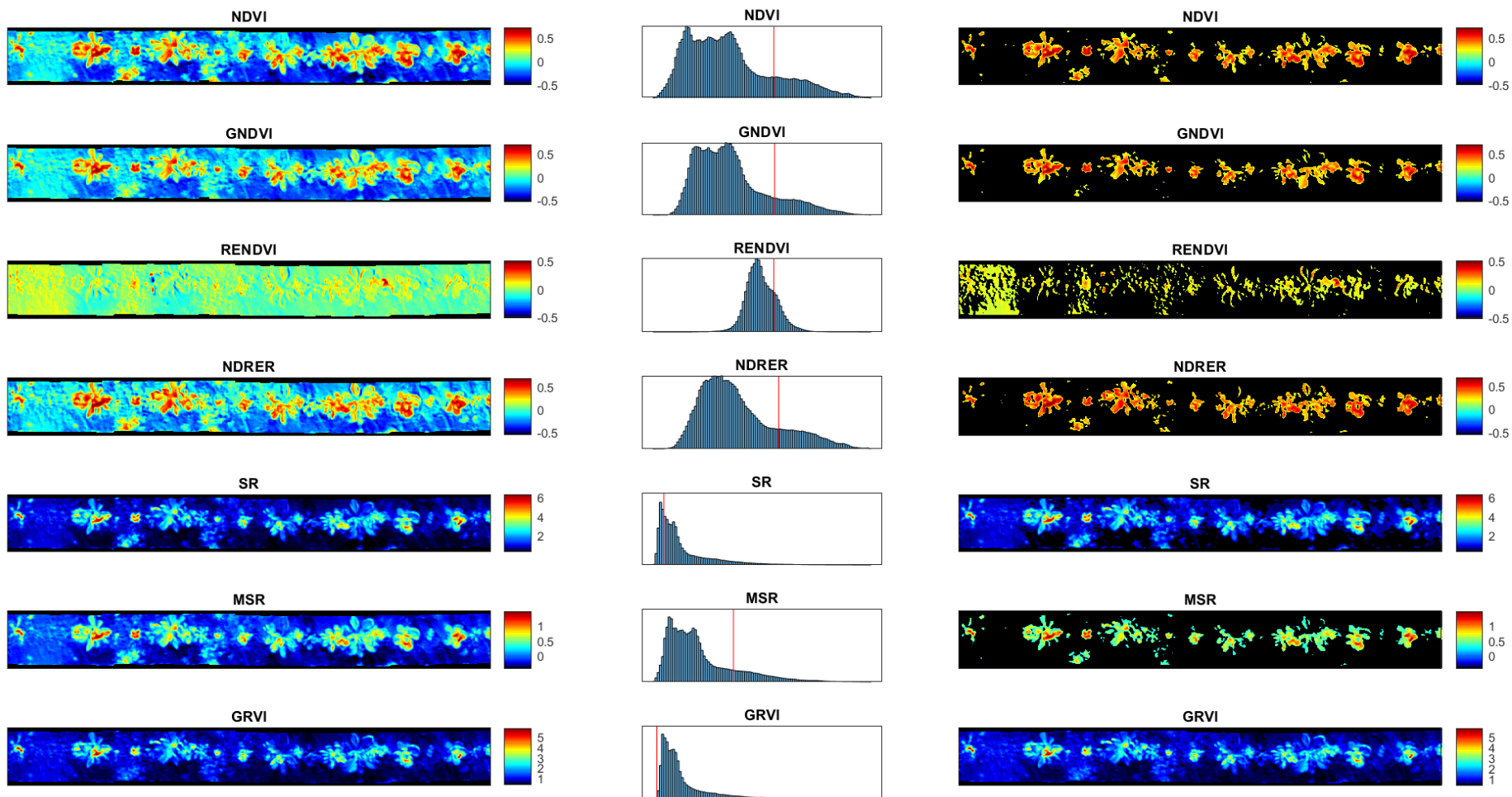


Figure D.24 Gaussian filtered VI's of Red Cabbage 2019 week 10 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.2.4 2019 - Week 11

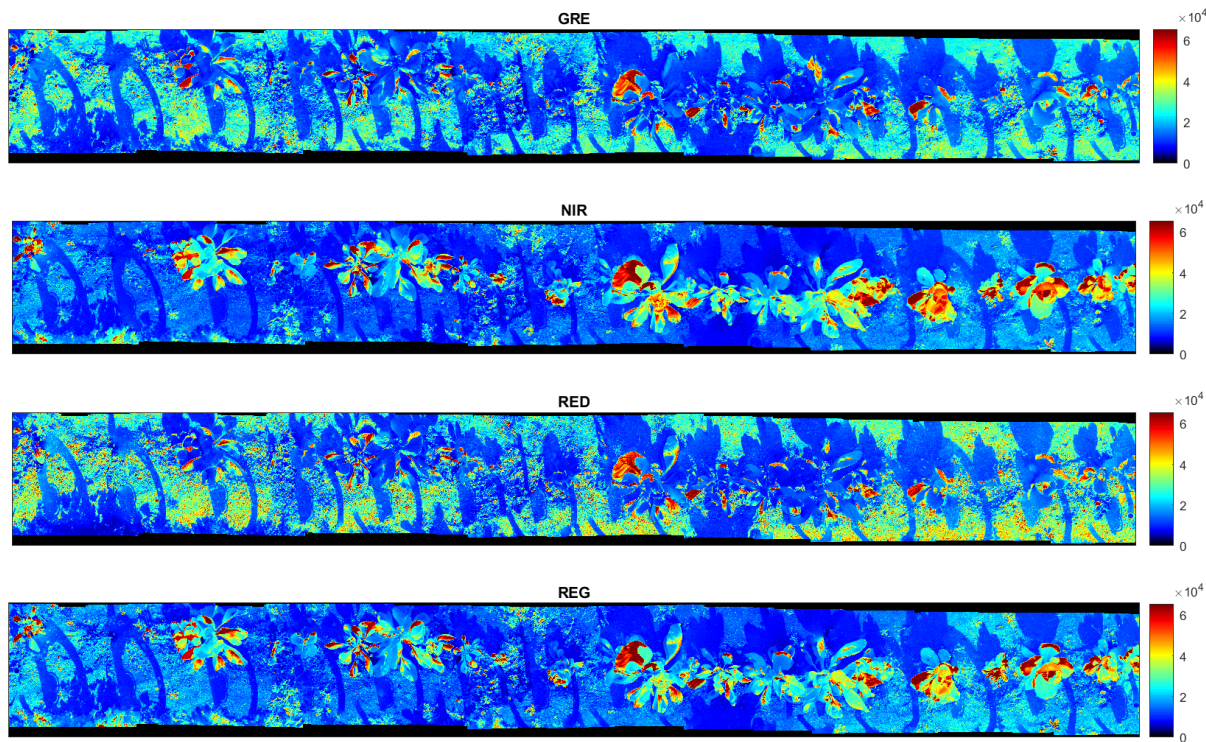


Figure D.25 Original spectral bands of Red Cabbage 2019 week 11.

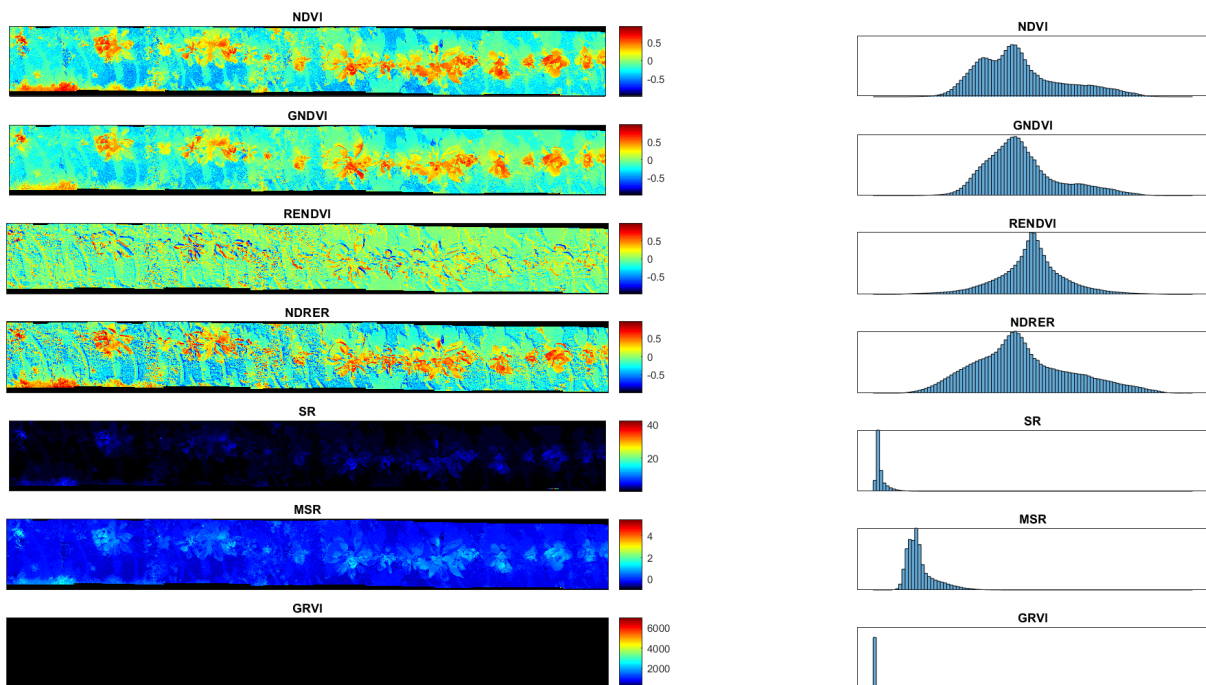


Figure D.26 Unprocessed VI's of Red Cabbage 2019 week 11 and their value distributions.

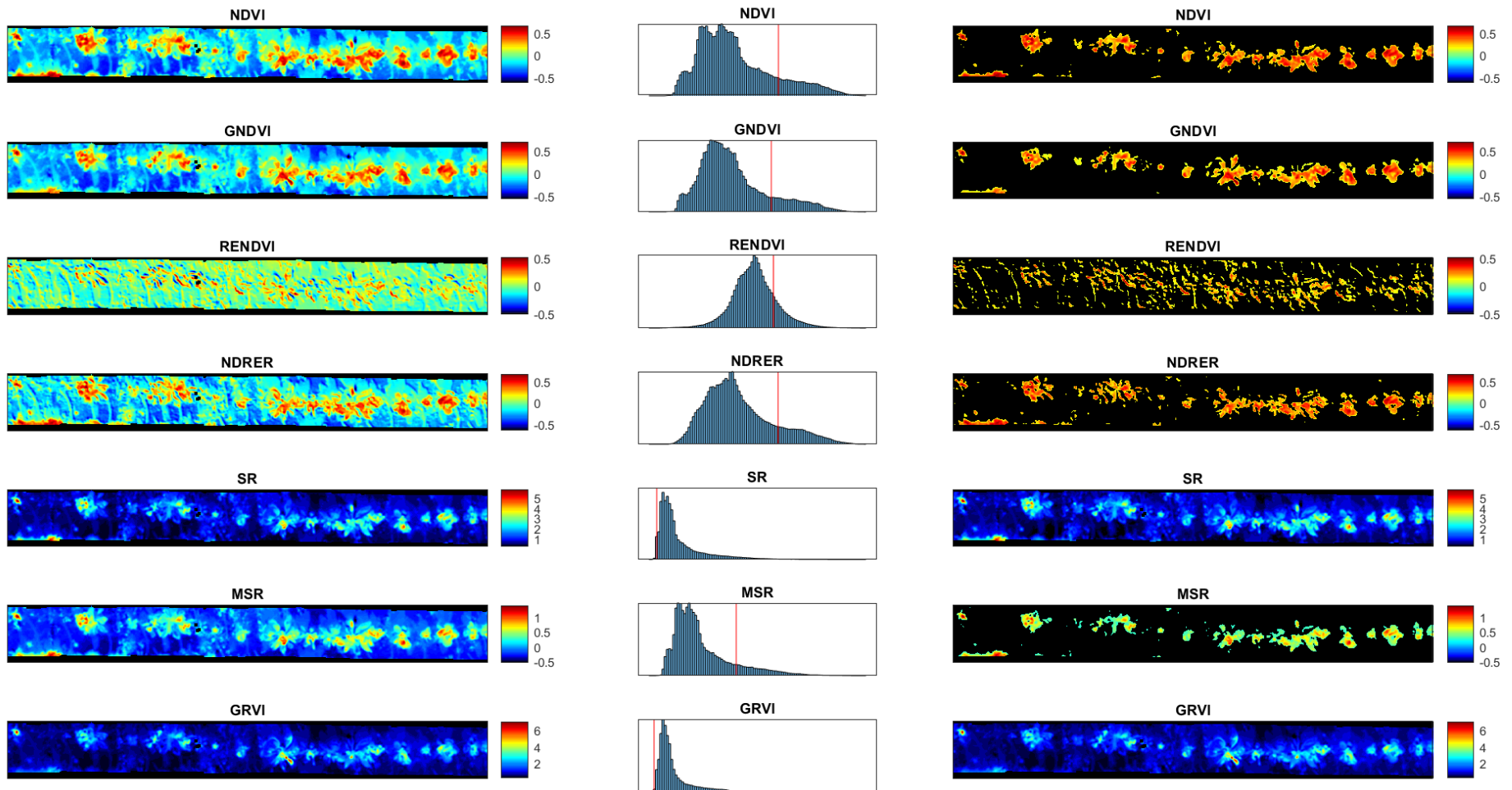


Figure D.27 Gaussian filtered VI's of Red Cabbage 2019 week 11 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.2.5 2019 - Week 12

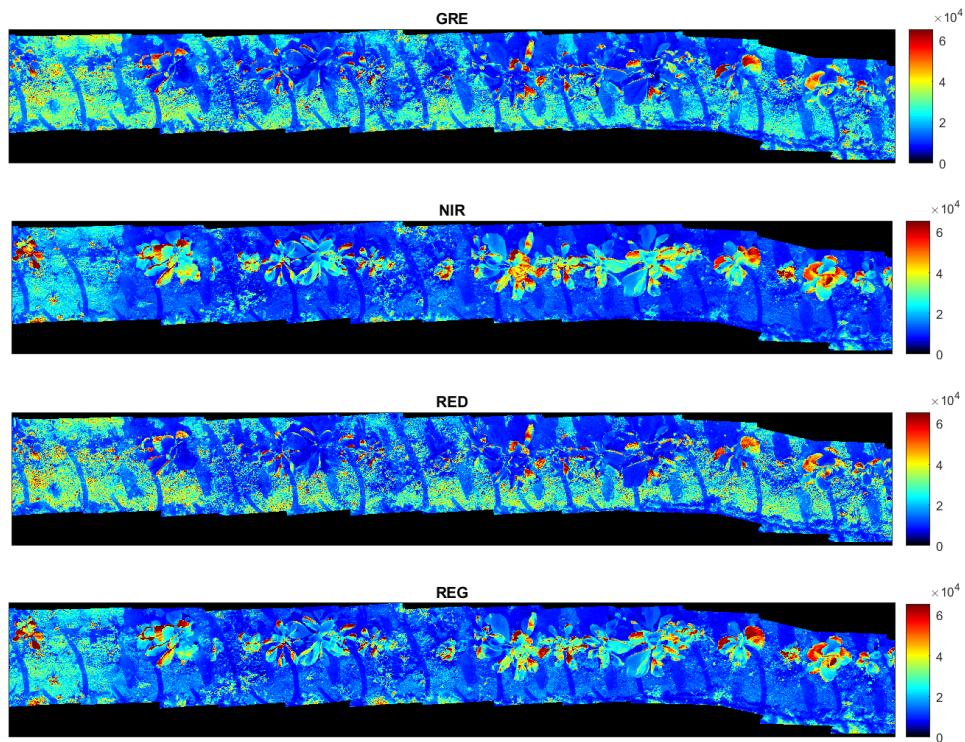


Figure D.28 Original spectral bands of Red Cabbage 2019 week 12.

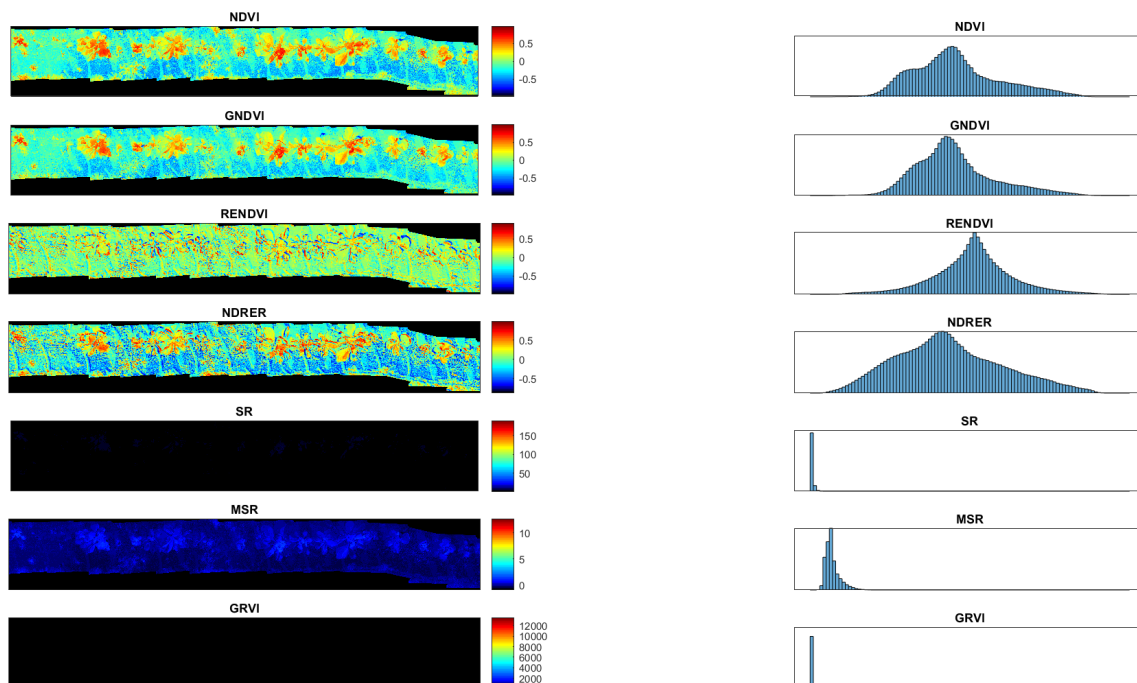


Figure D.29 Unprocessed VI's of Red Cabbage 2019 week 12 and their value distributions.

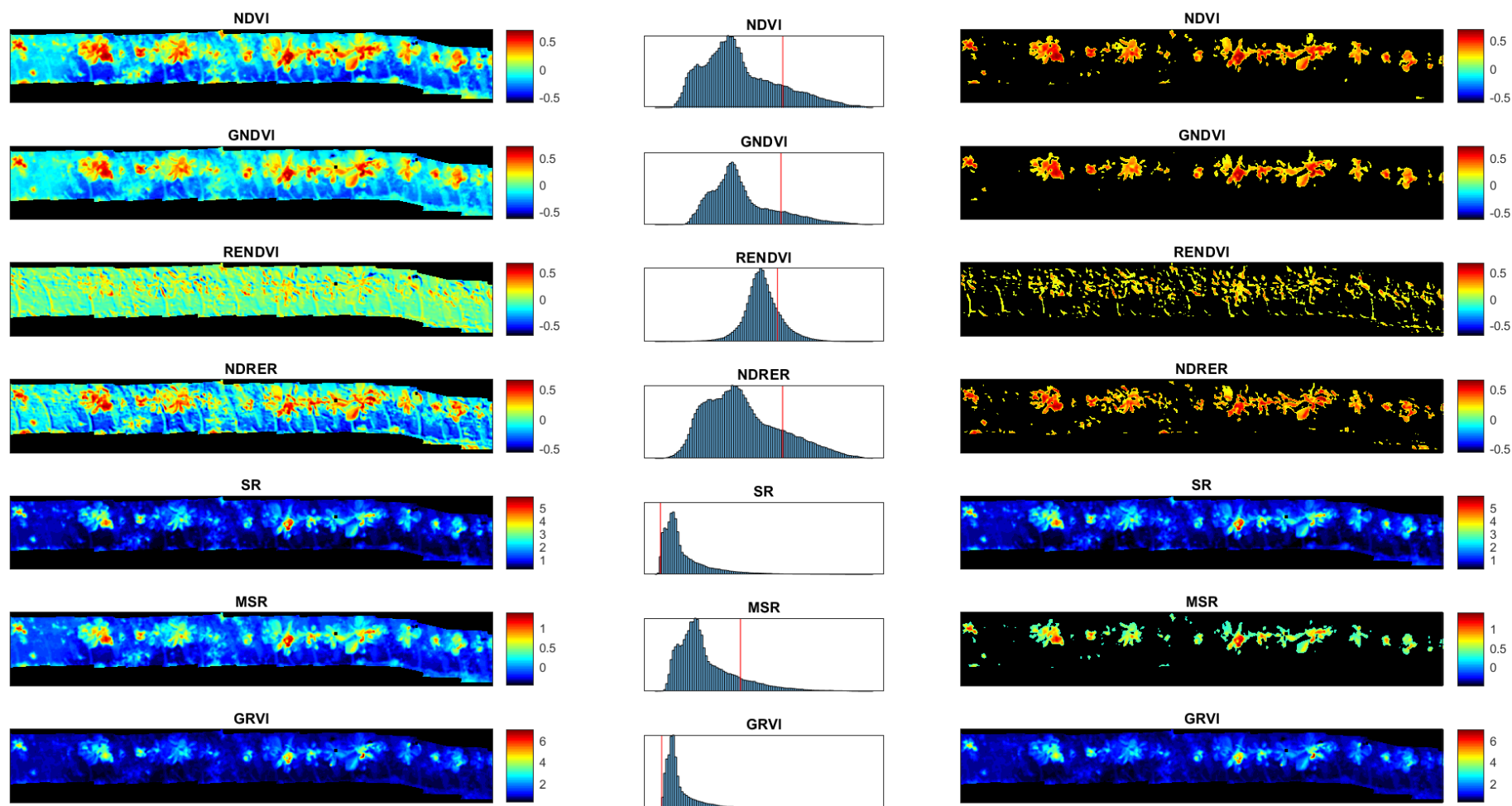


Figure D.30 Gaussian filtered VI's of Red Cabbage 2019 week 12 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3 Cabbage

D.3.1 2019 - Week 3

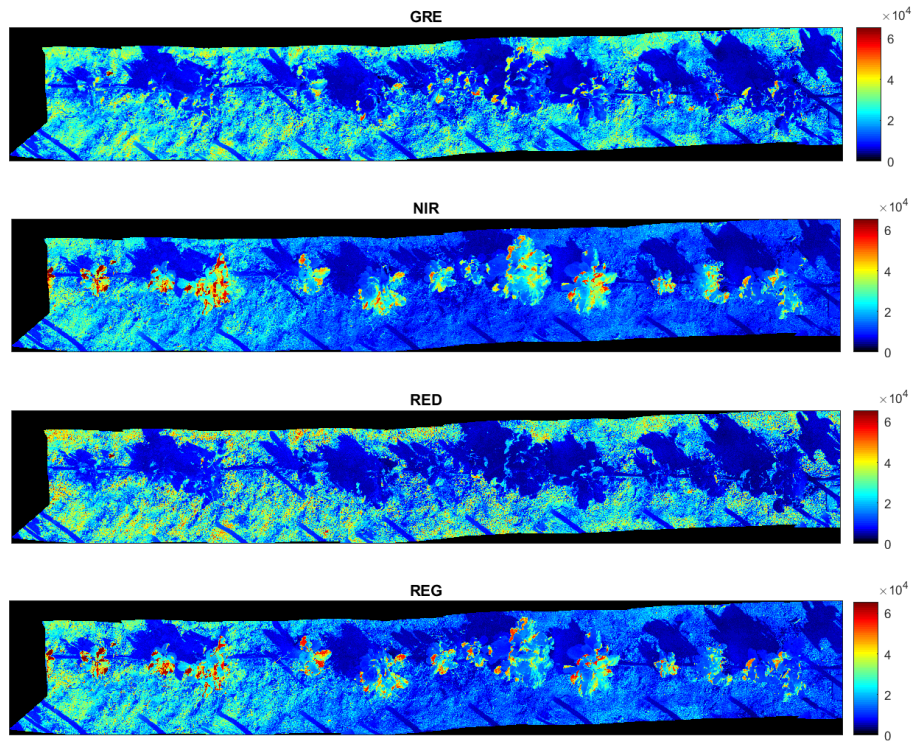


Figure D.31 Original spectral bands of Cabbage 2019 week 3.

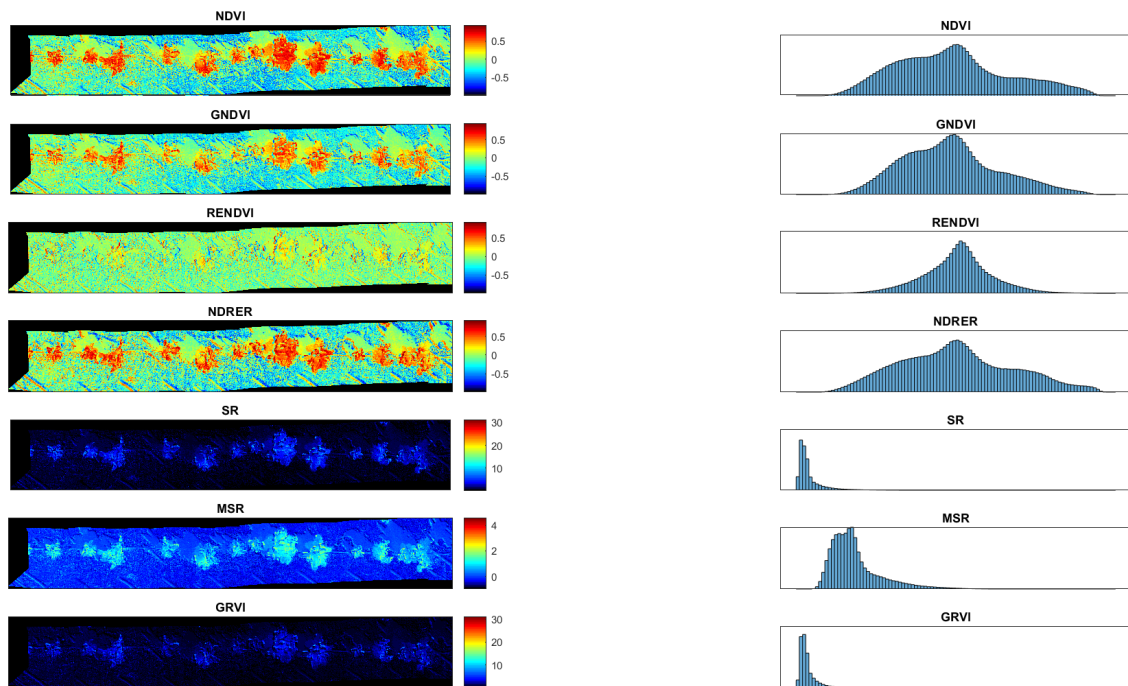


Figure D.32 Unprocessed VI's of Cabbage 2019 week 3 and their value distributions.

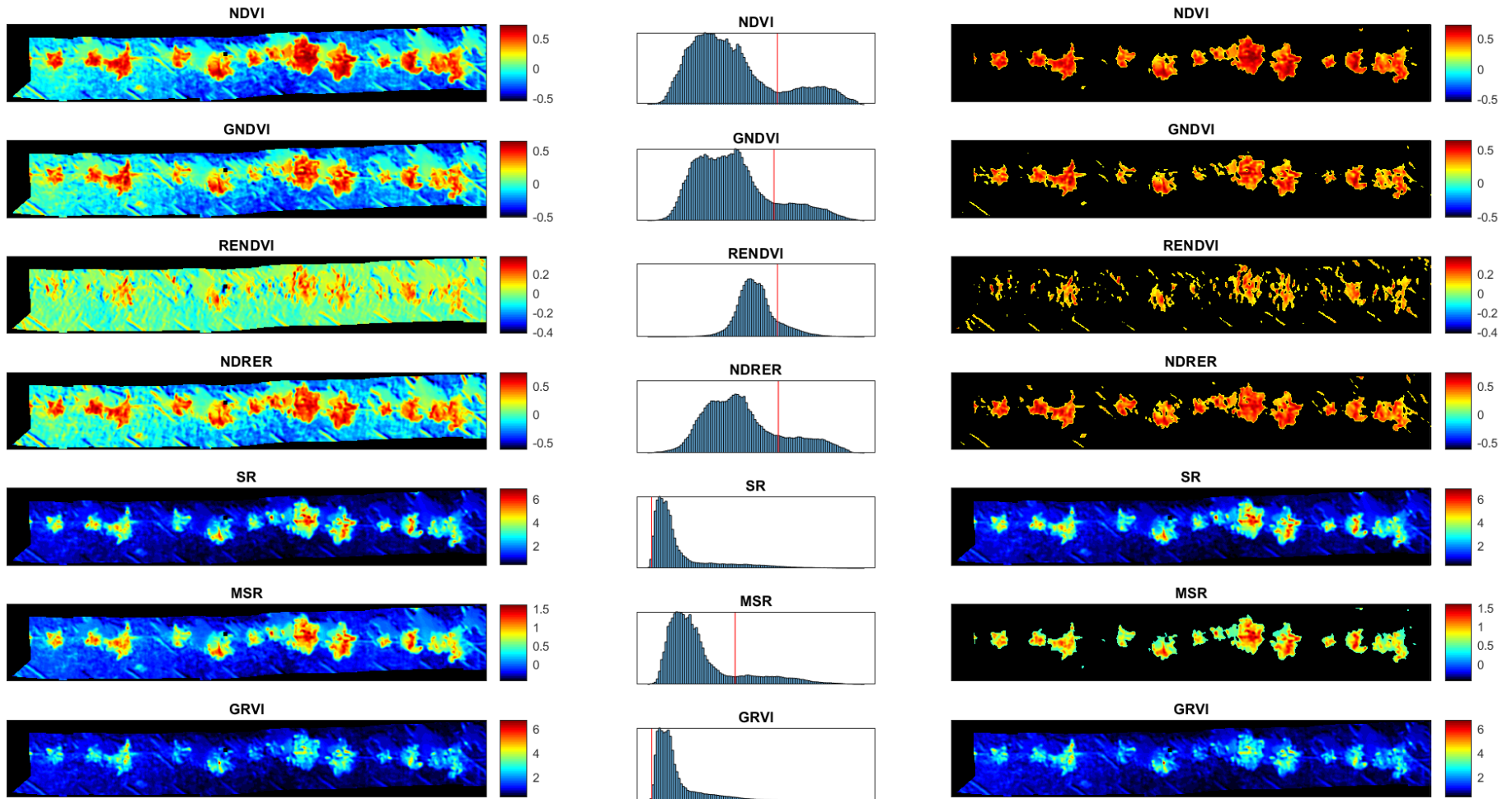


Figure D.33 Gaussian filtered VI's of Cabbage 2019 week 3 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3.2 2019 - Week 9

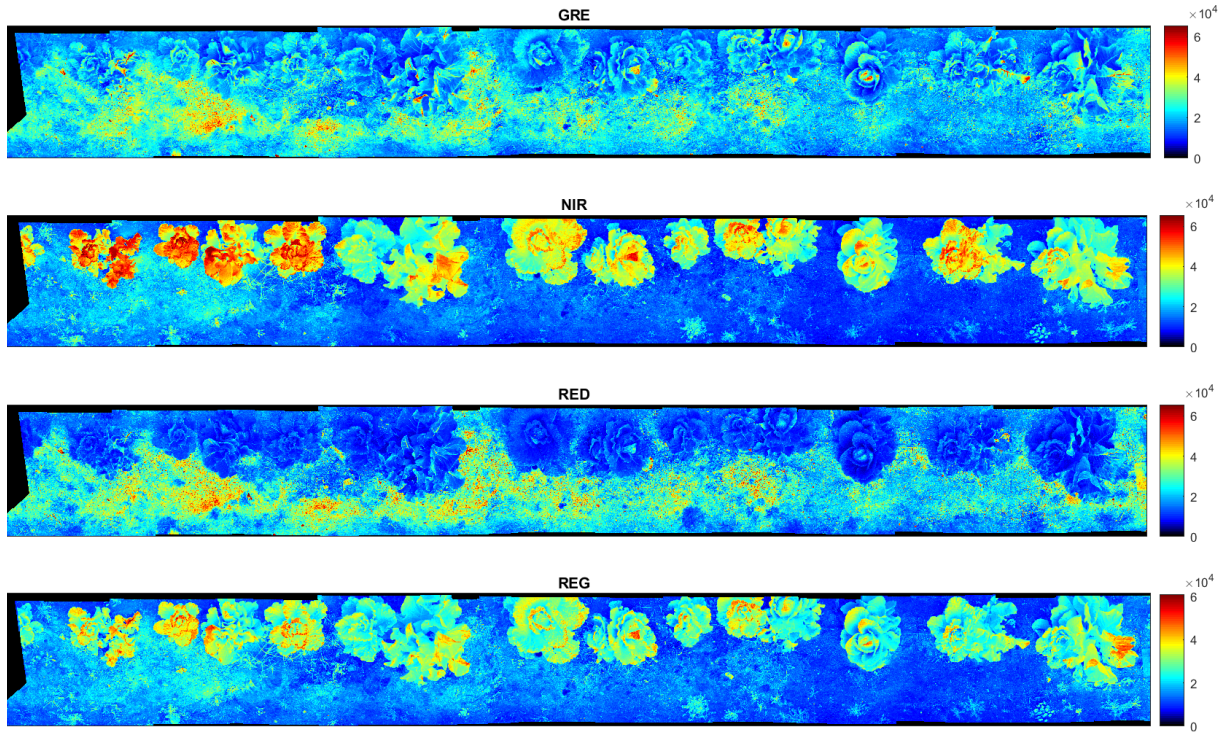


Figure D.34 Original spectral bands of Cabbage 2019 week 9.

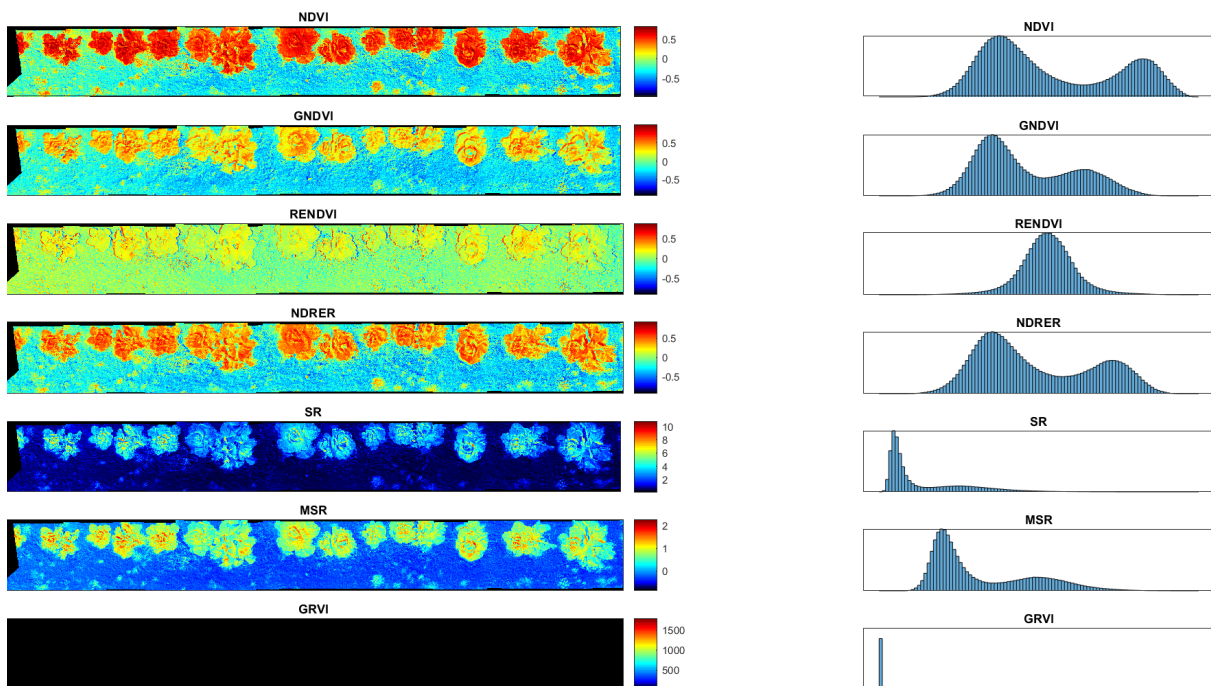


Figure D.35 Unprocessed VT's of Cabbage 2019 week 9 and their value distributions.

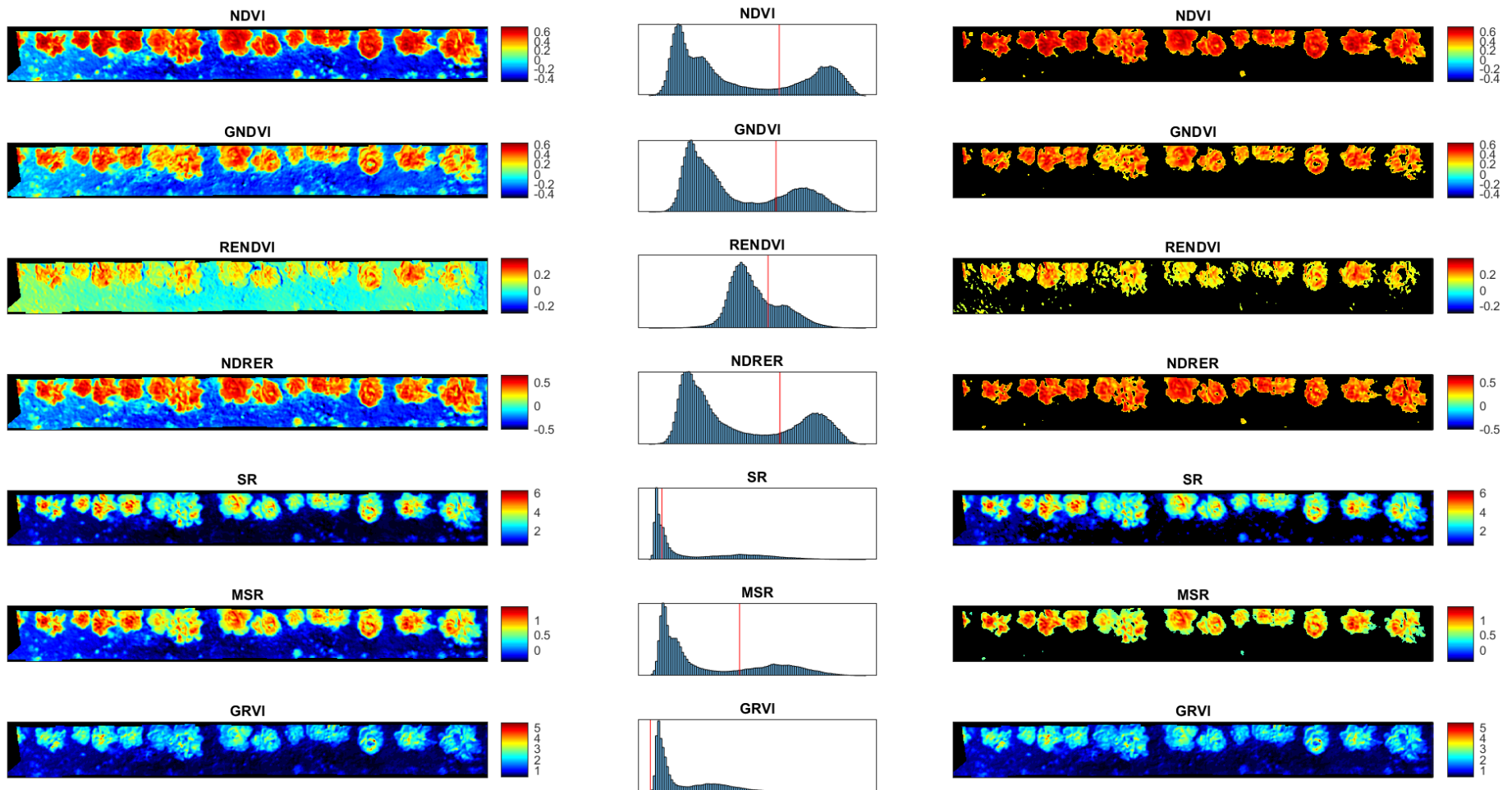


Figure D.36 Gaussian filtered VI's of Cabbage 2019 week 9 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3.3 2019 - Week 10

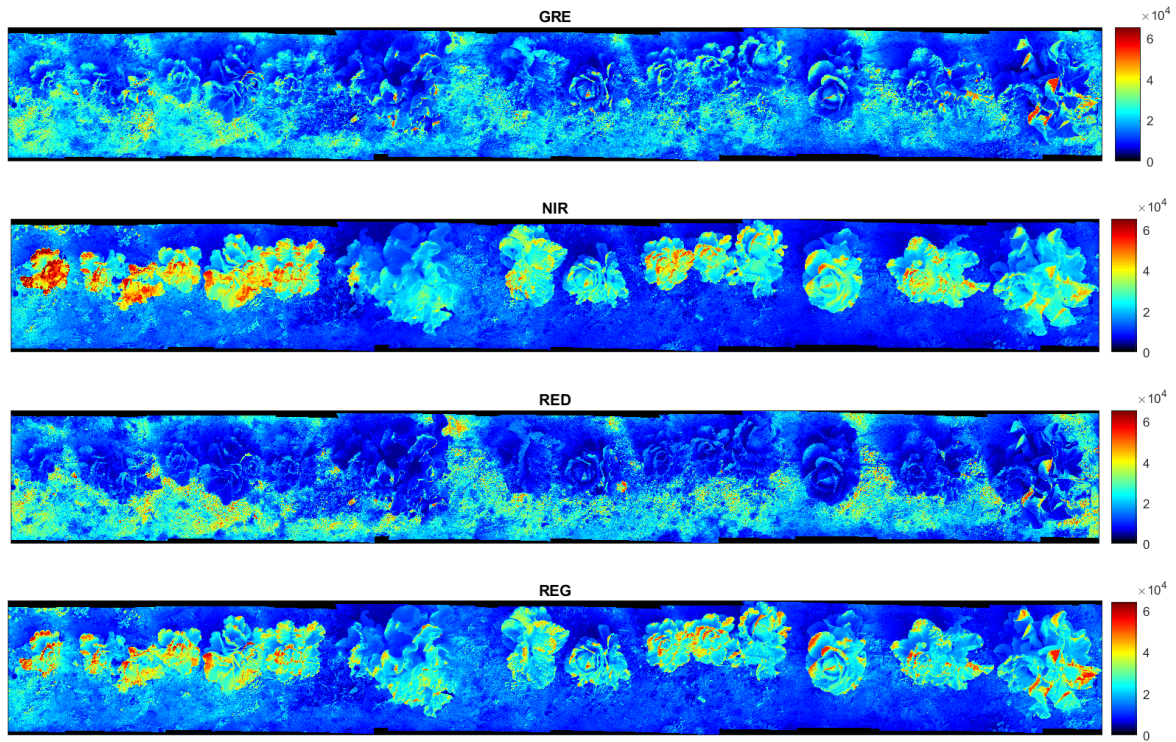


Figure D.37 Original spectral bands of Cabbage 2019 week 10.

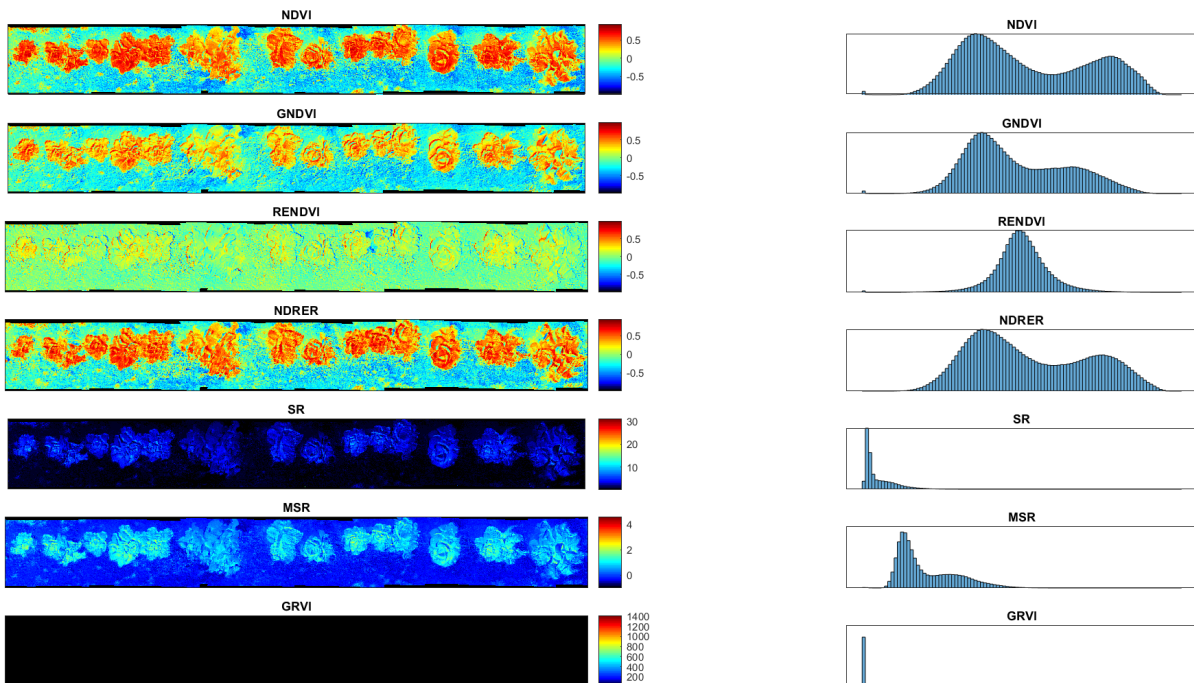


Figure D.38 Unprocessed VIs of Cabbage 2019 week 10 and their value distributions.

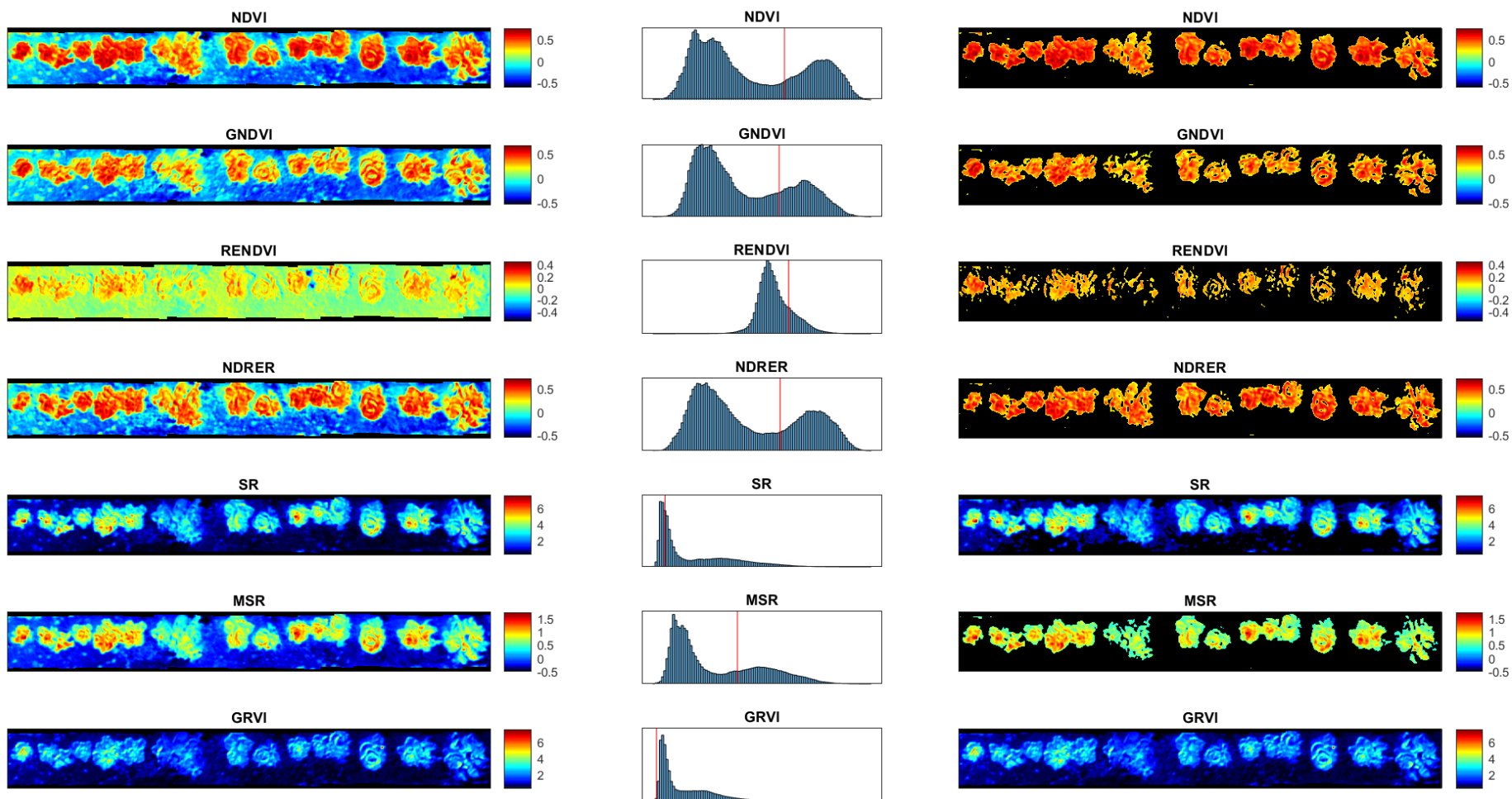


Figure D.39 Gaussian filtered VI's of Cabbage 2019 week 10 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3.4 2019 - Week 11

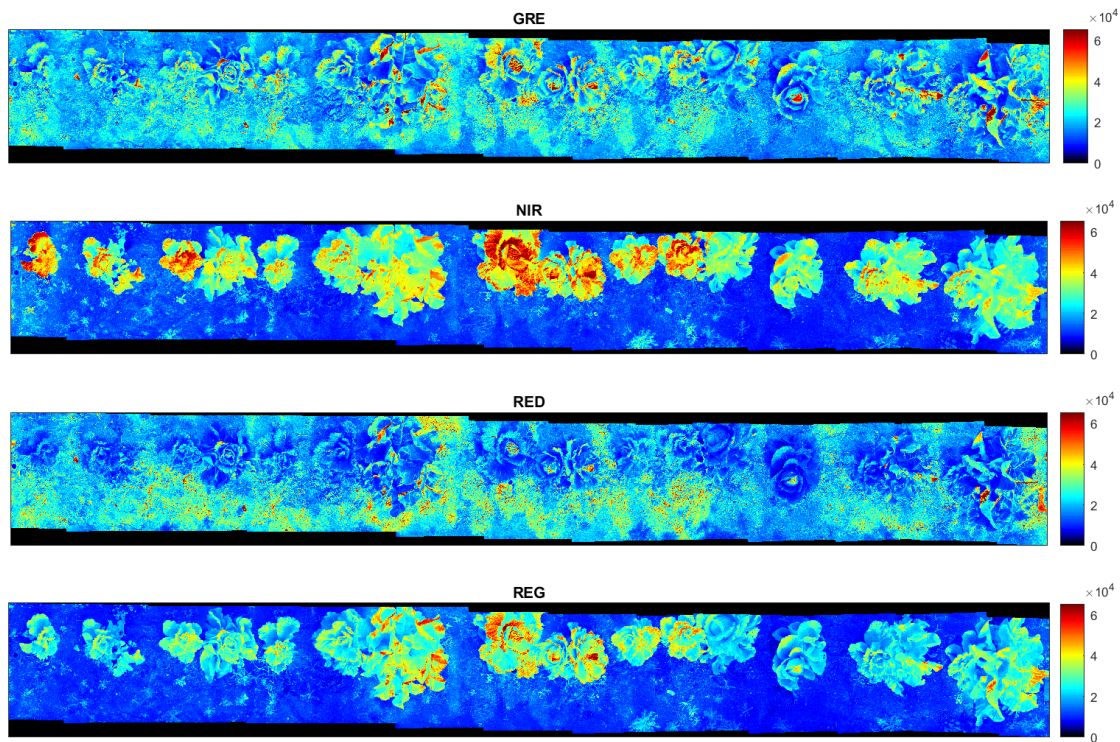


Figure D.40 Original spectral bands of Cabbage 2019 week 11.

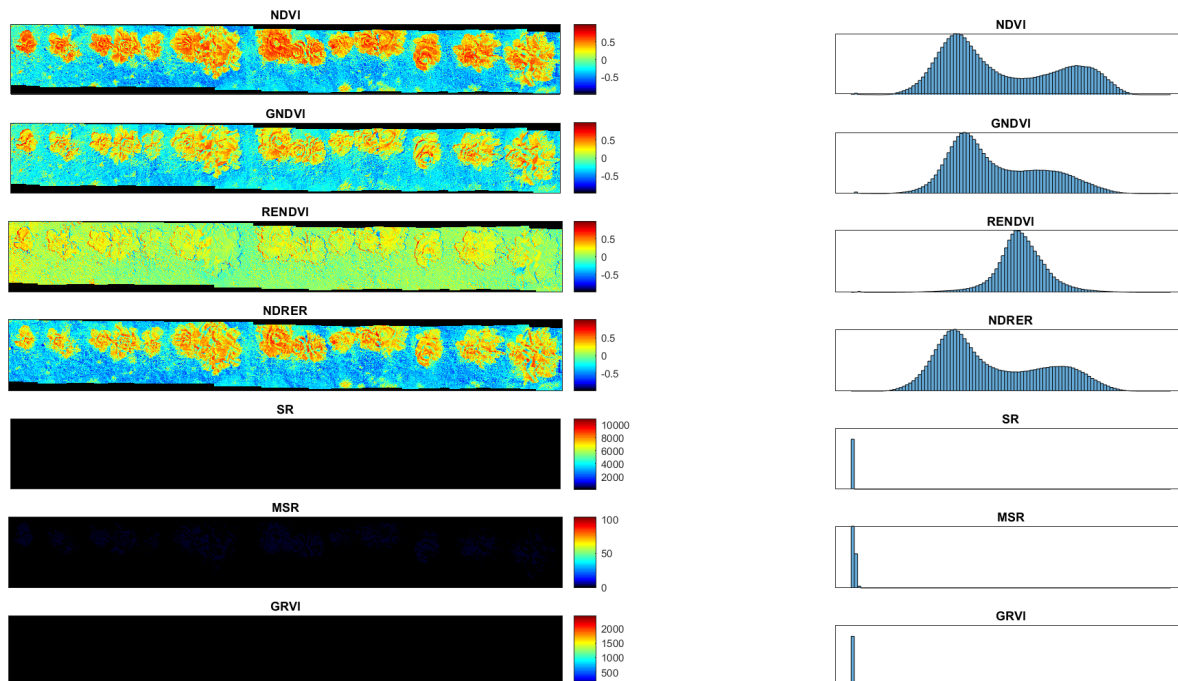


Figure D.41 Unprocessed VIs of Cabbage 2019 week 11 and their value distributions.

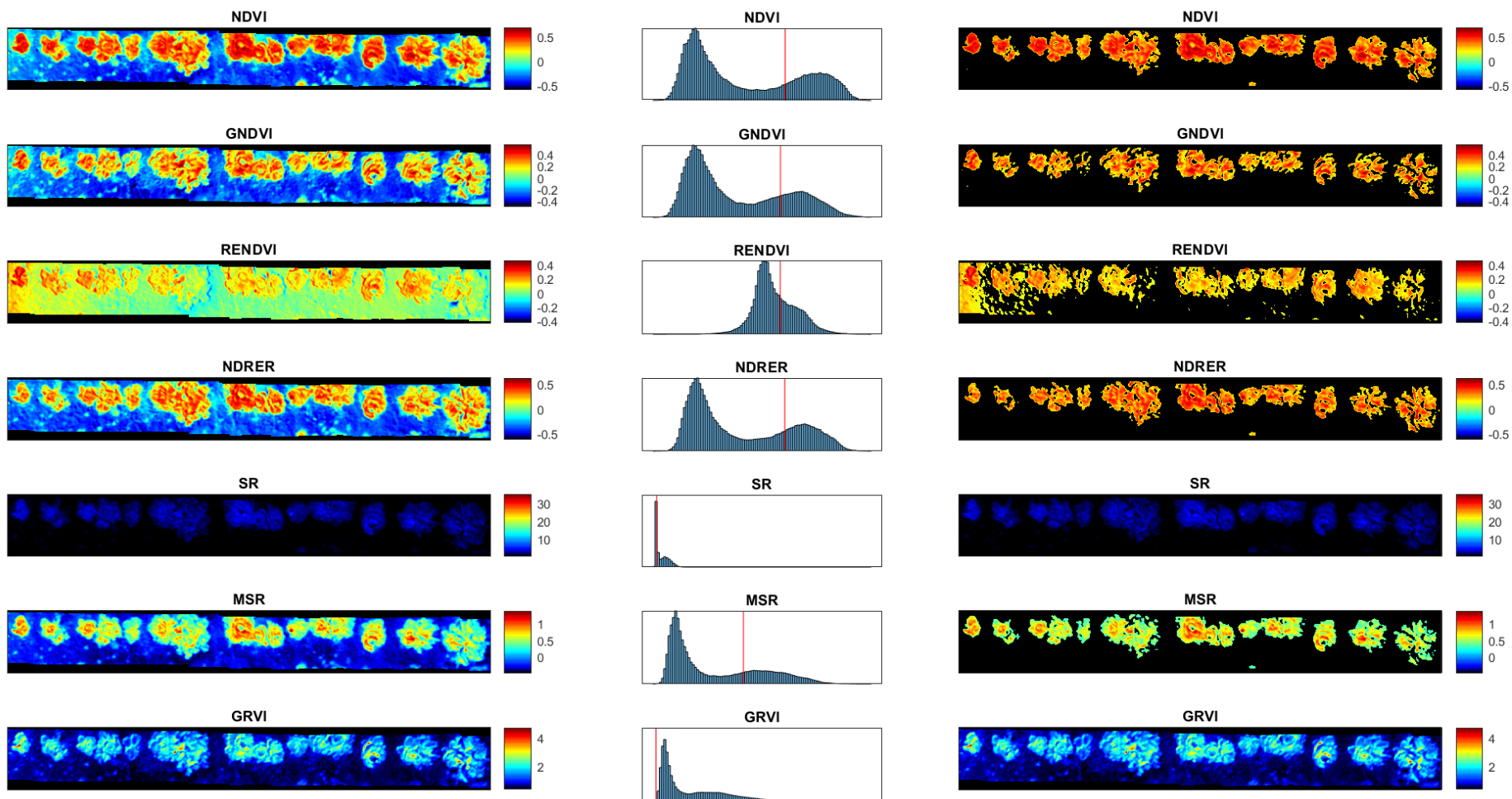


Figure D.42 Gaussian filtered VI's of Cabbage 2019 week 11 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3.5 2019 - Week 12

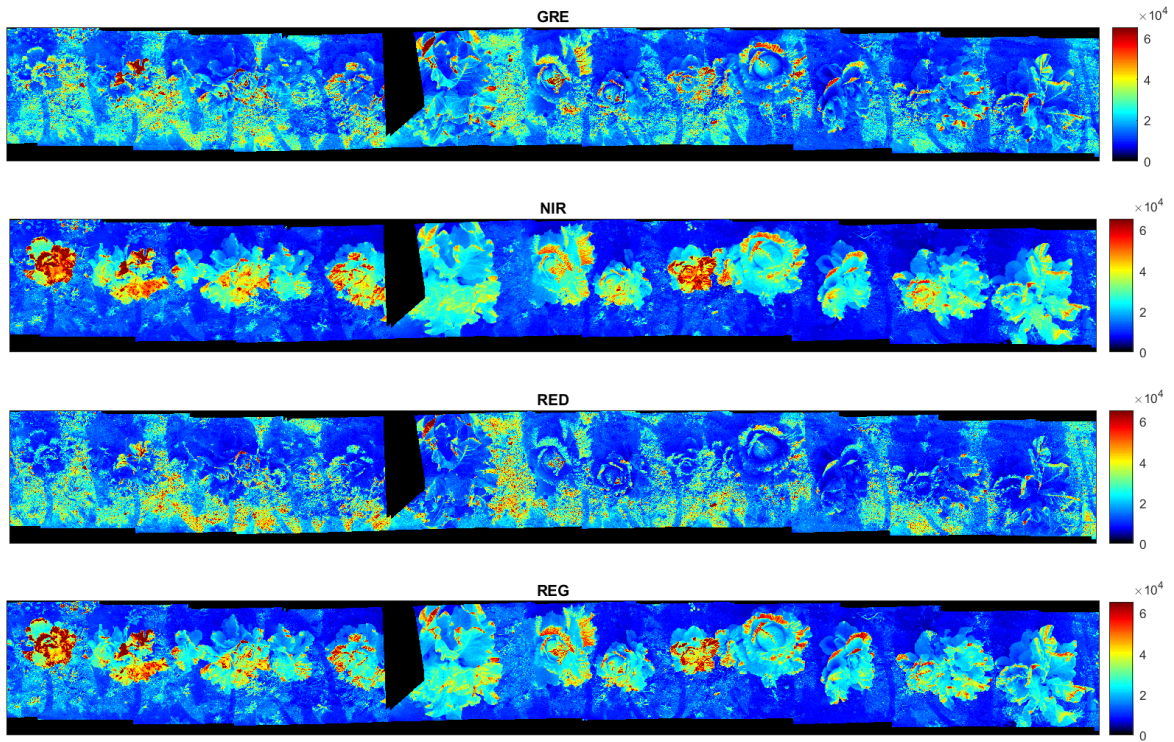


Figure D.43 Original spectral bands of Cabbage 2019 week 12.

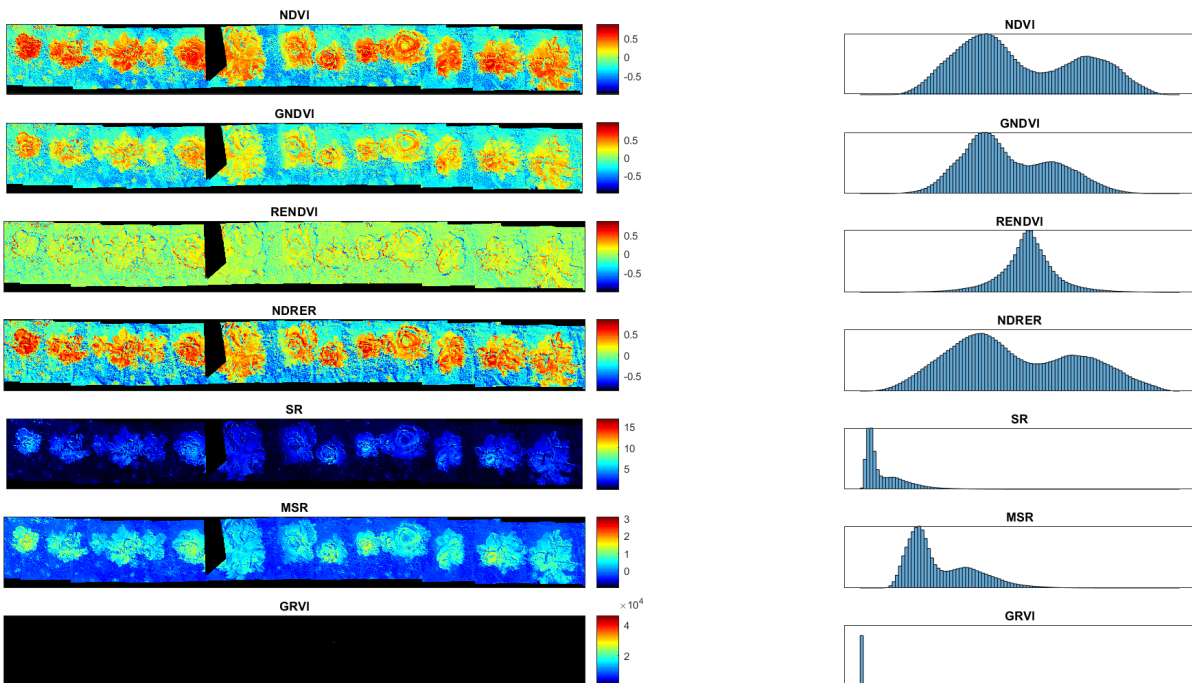


Figure D.44 Unprocessed VI's of Cabbage 2019 week 12 and their value distributions.

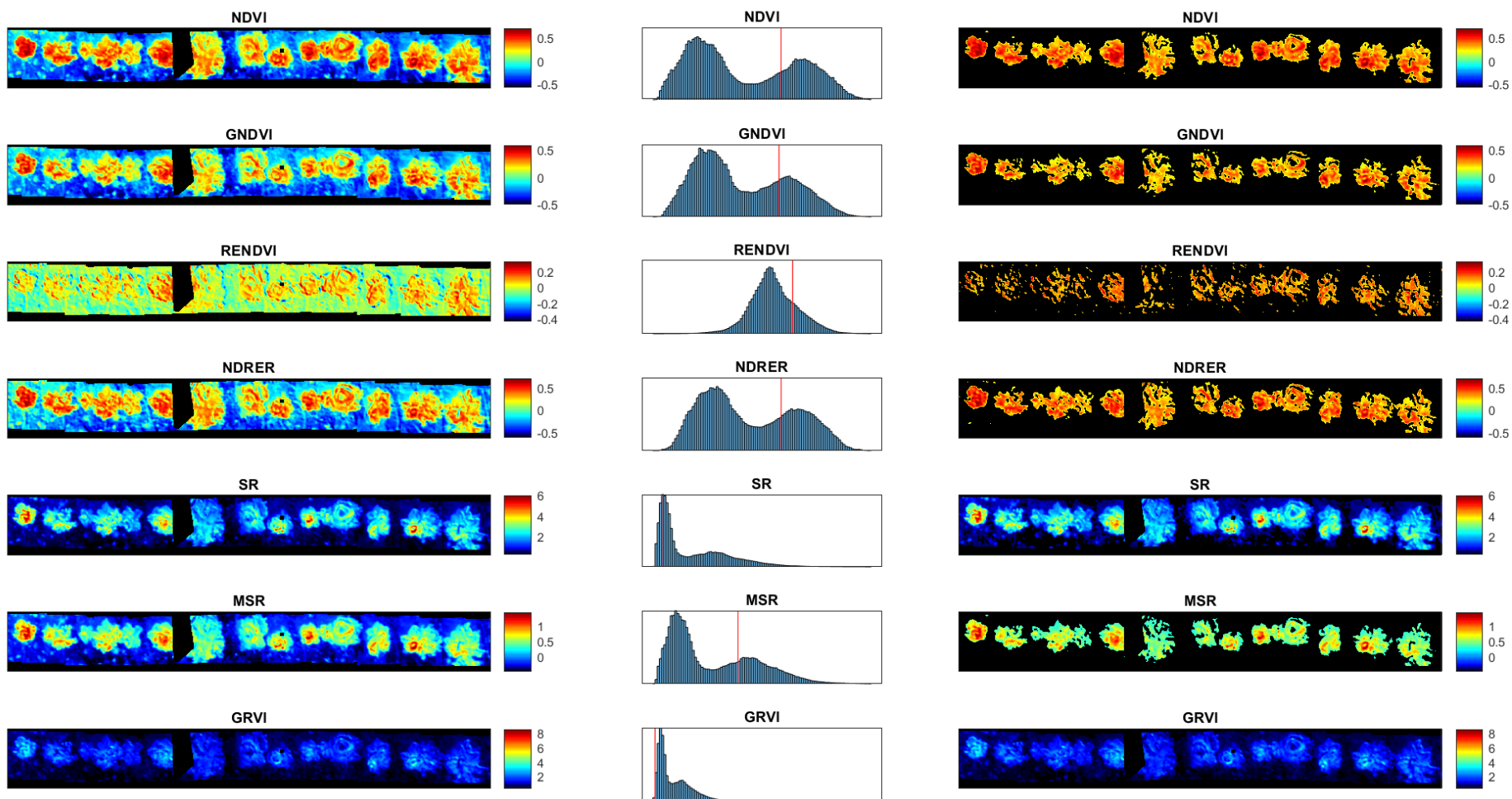


Figure D.45 Gaussian filtered VI's of Cabbage 2019 week 12 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3.6 2020 - Week 5

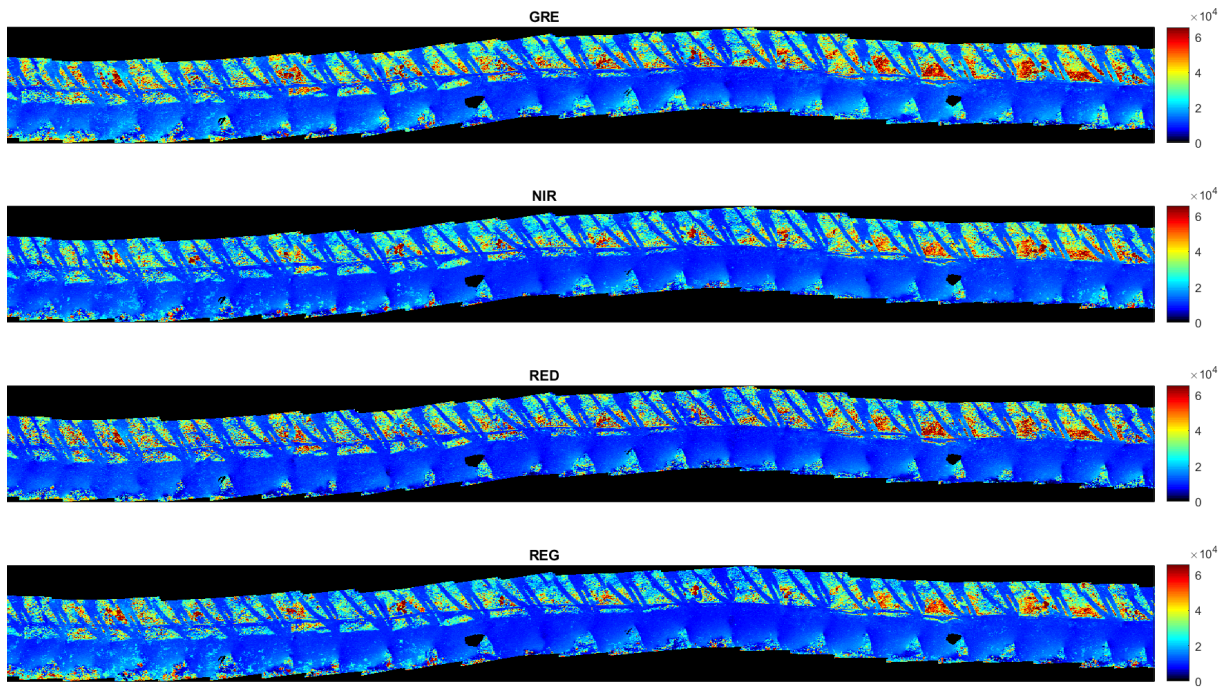


Figure D.46 Original spectral bands of Cabbage 2020 week 5.

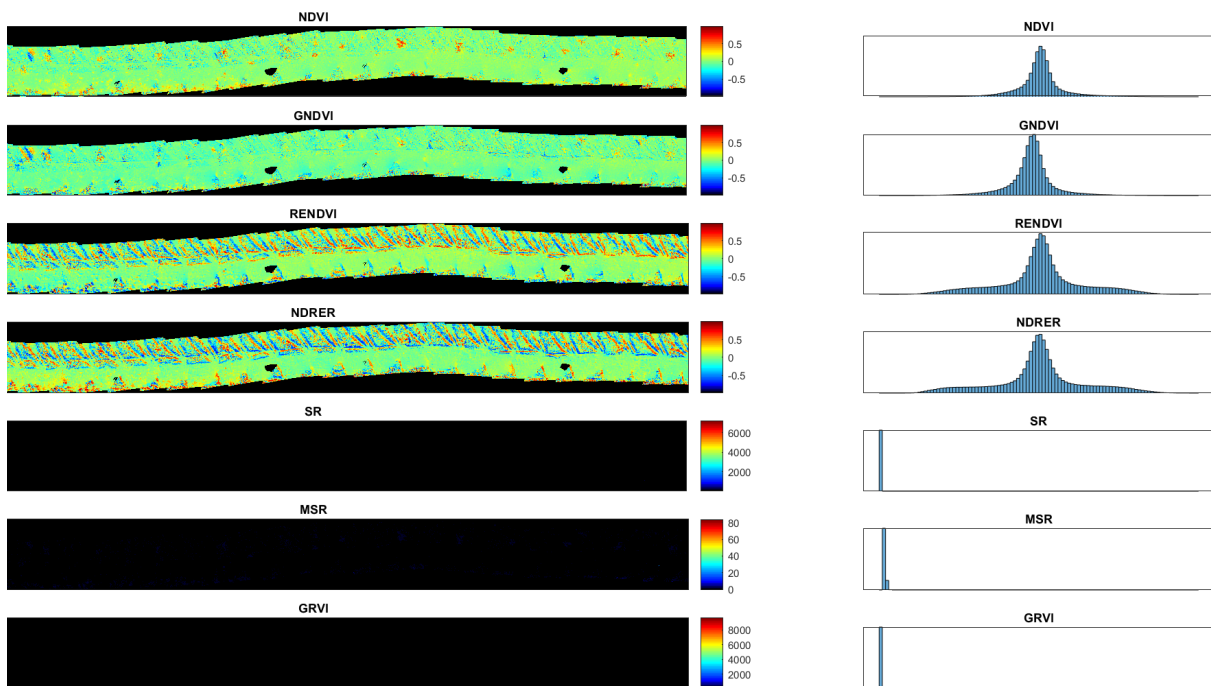


Figure D.47 Unprocessed VI's of Cabbage 2020 week 5 and their value distributions.

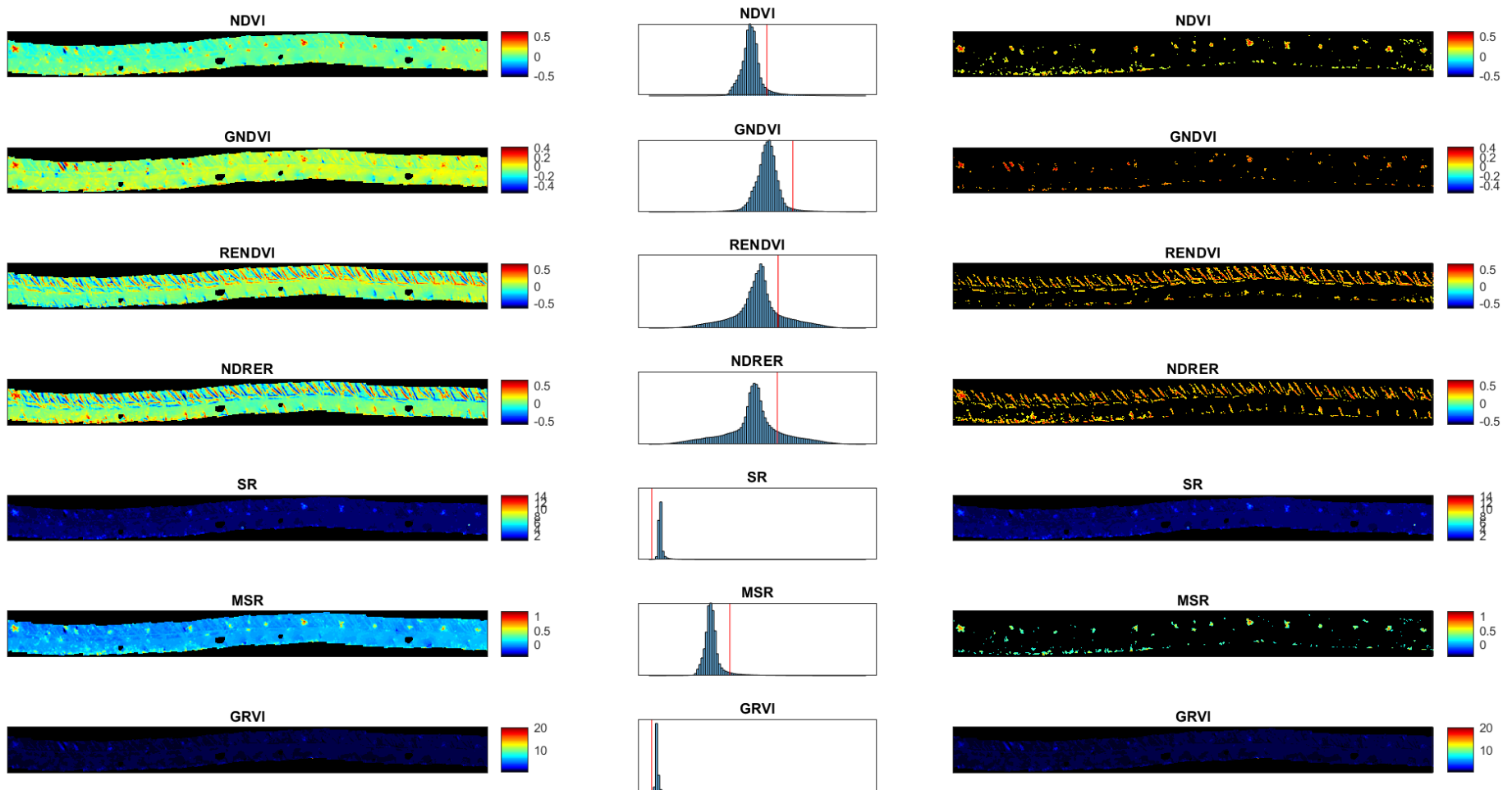


Figure D.48 Gaussian filtered VI's of Cabbage 2020 week 5 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3.7 2020 - Week 6

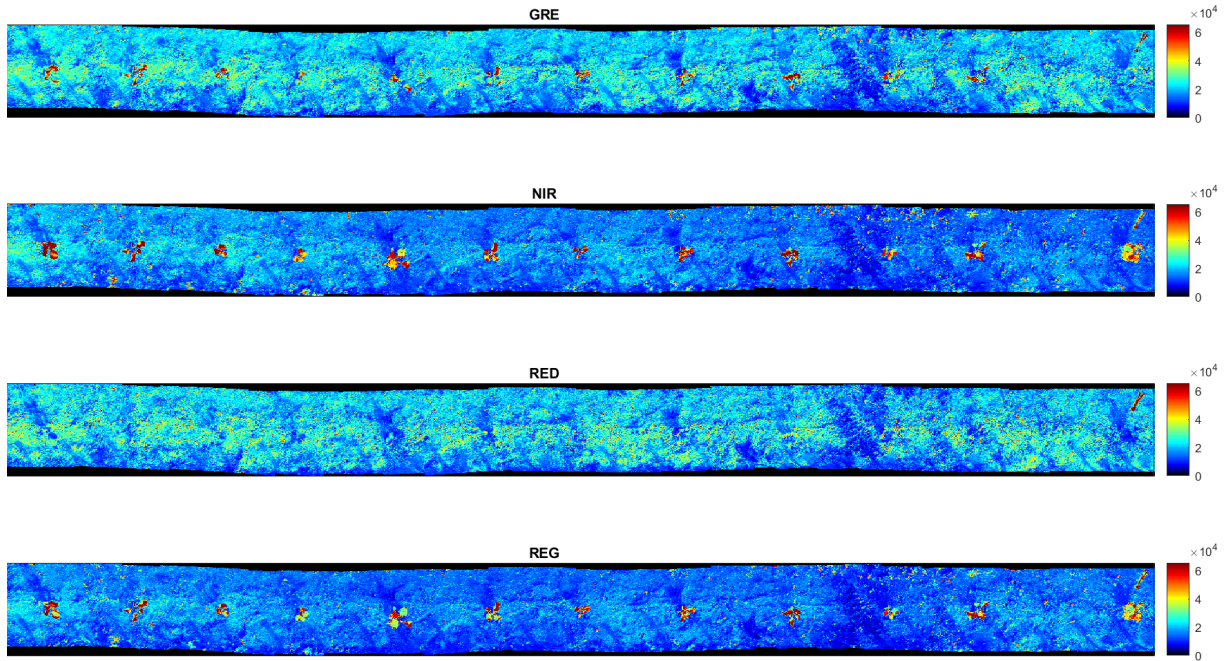


Figure D.49 Original spectral bands of Cabbage 2020 week 6.

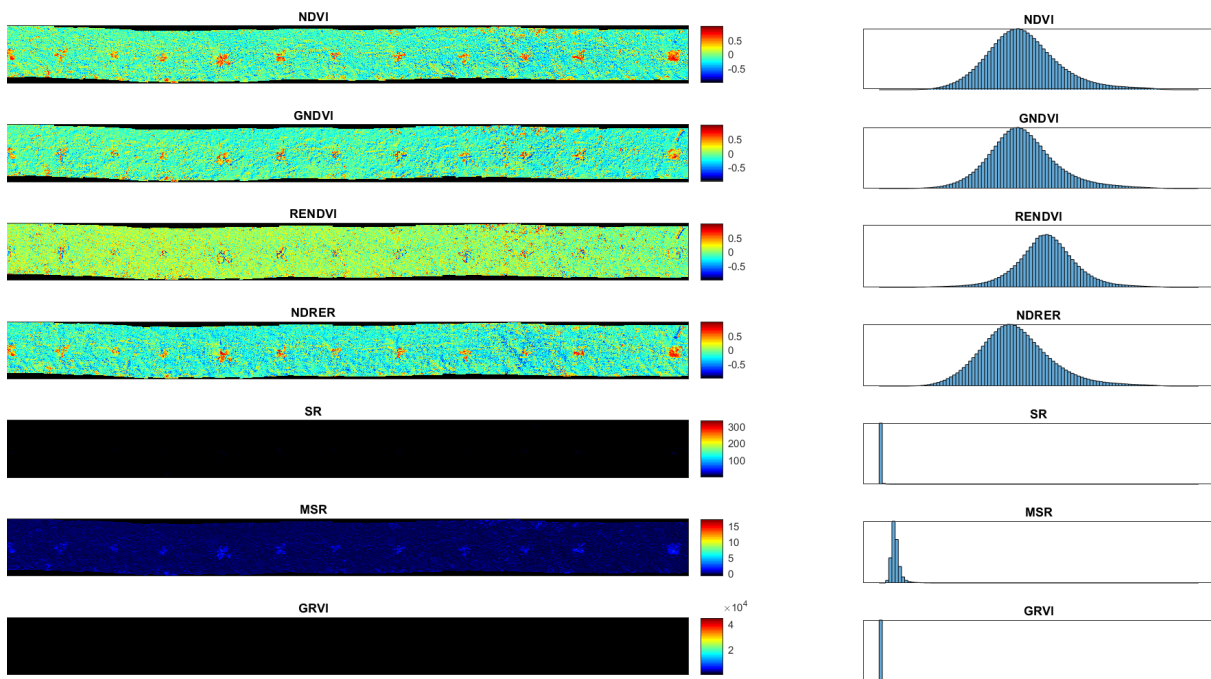


Figure D.50 Unprocessed VI's of Cabbage 2020 week 6 and their value distributions.

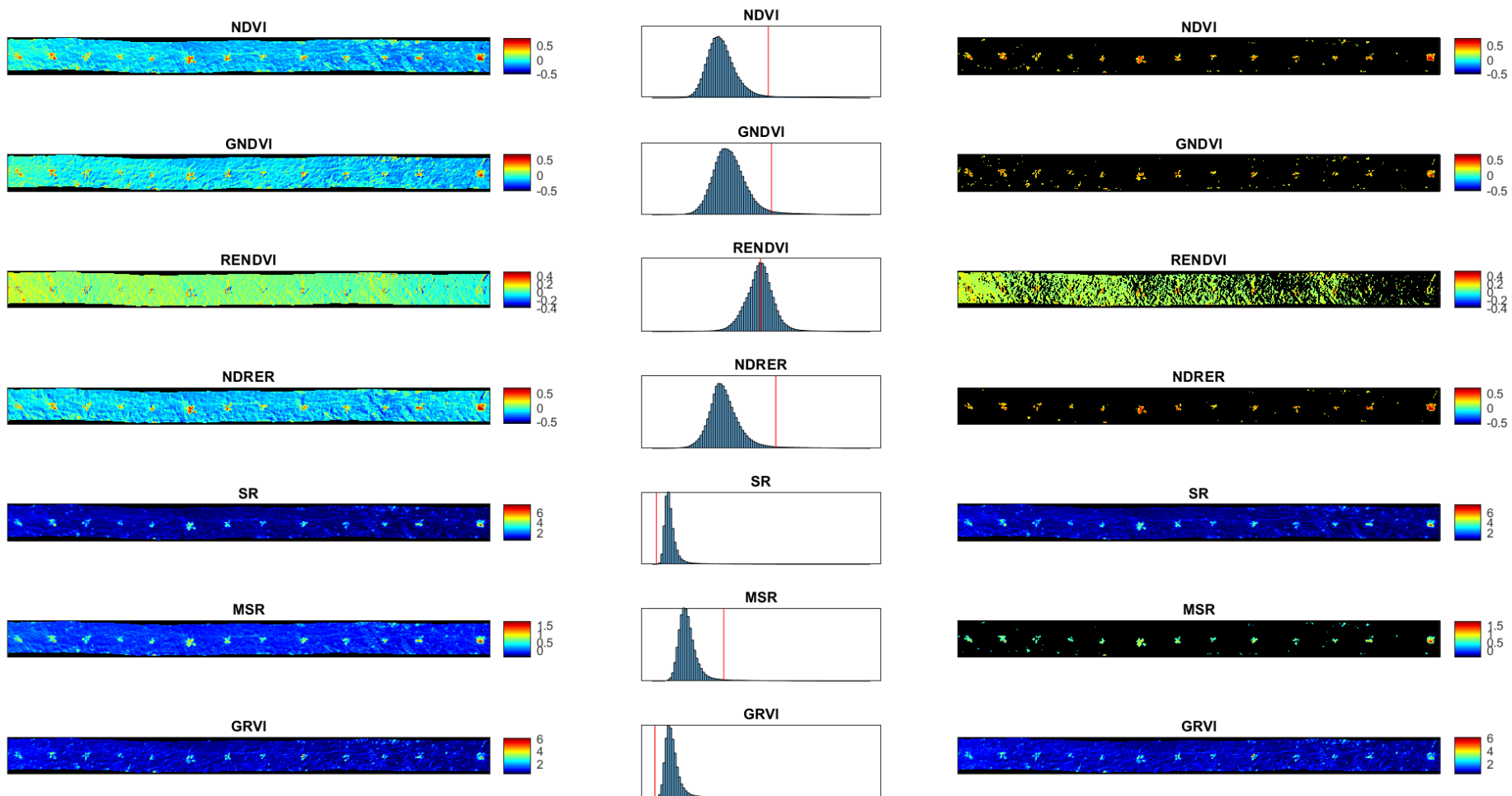


Figure D.51 Gaussian filtered VI's of Cabbage 2020 week 6 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.3.8 2020 - Week 7

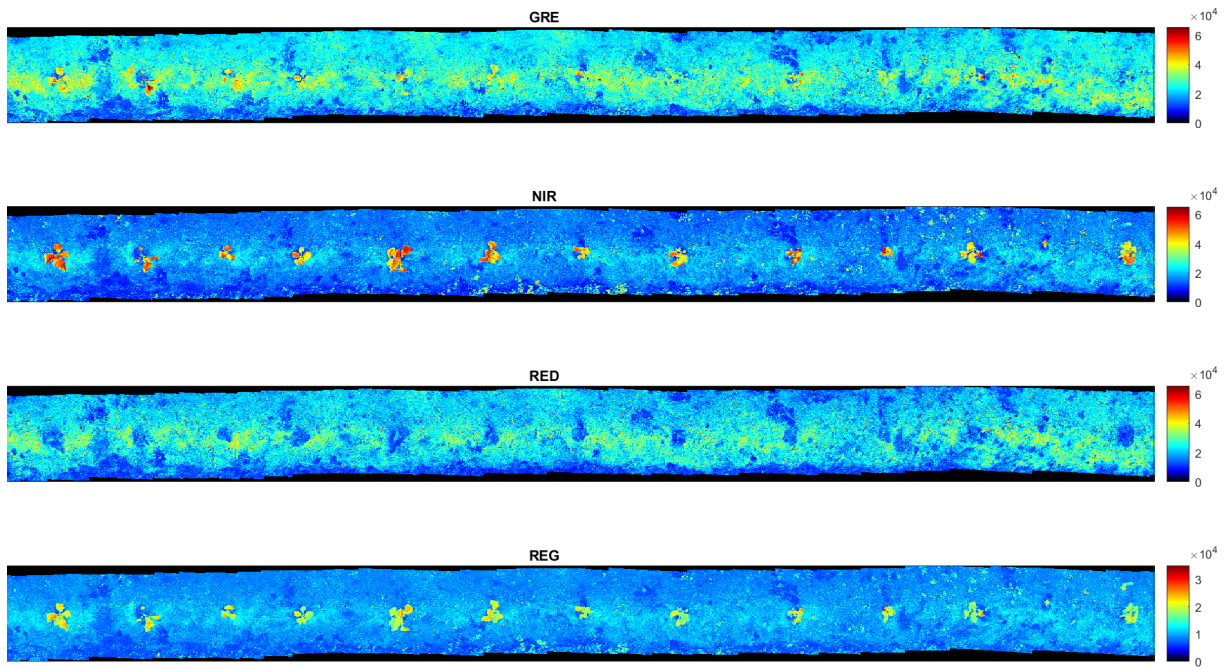


Figure D.52 Original spectral bands of Cabbage 2020 week 7.

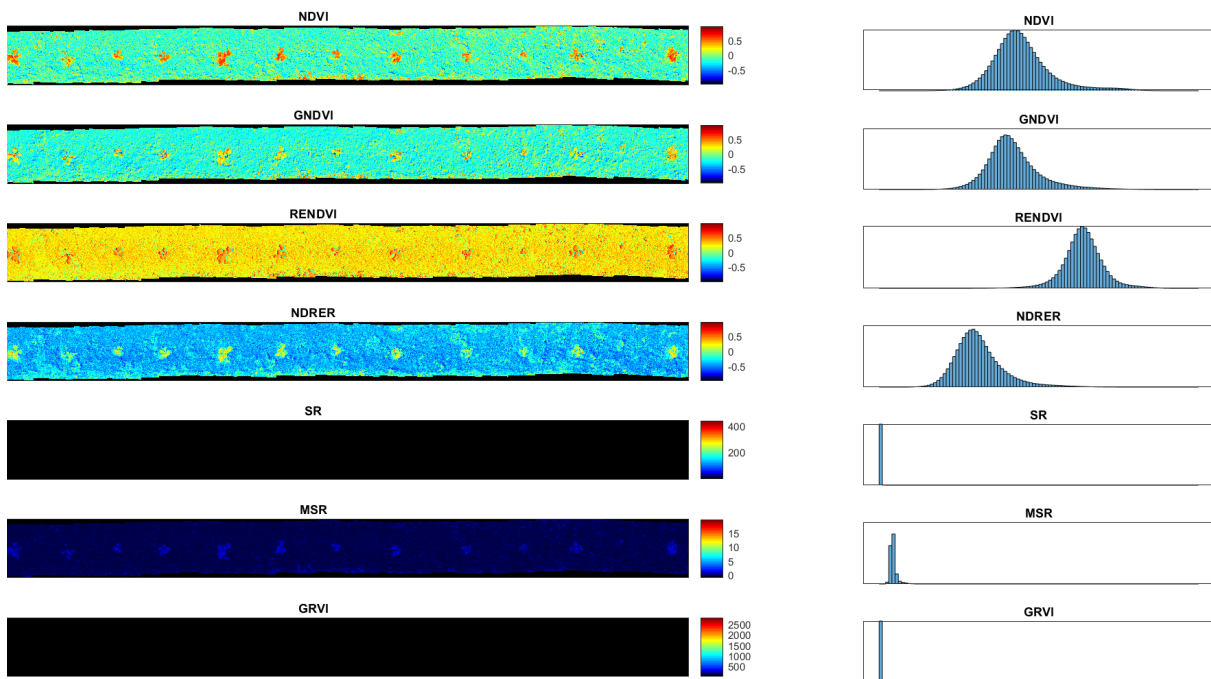


Figure D.53 Unprocessed VT's of Cabbage 2020 week 7 and their value distributions.

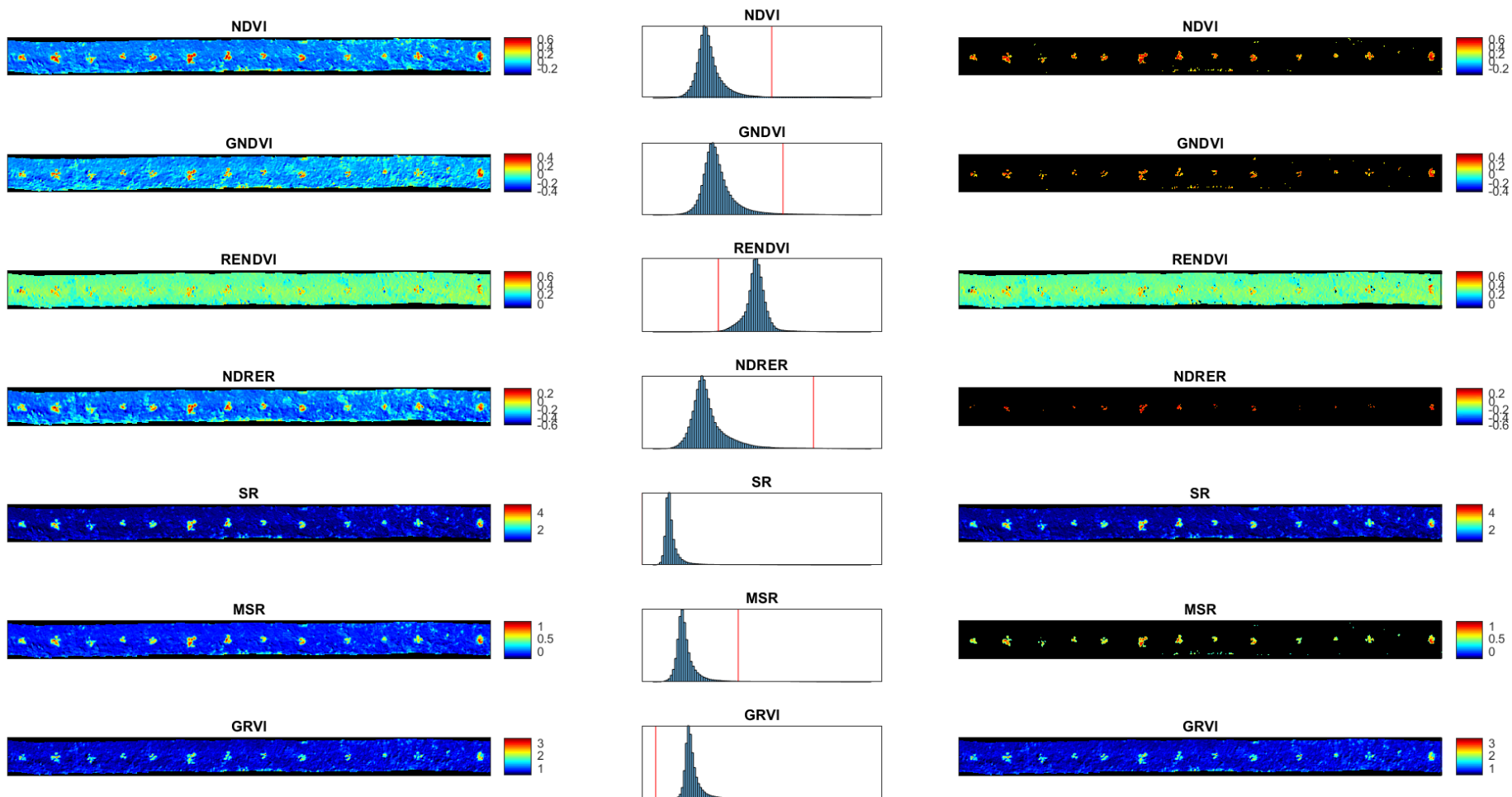


Figure D.54 Gaussian filtered VI's of Cabbage 2020 week 7 (left), the updated value distributions with in red the identified Otsu threshold (middle), and the resulting vegetation masks (right).

D.4 Statistics of Vegetation Indices over Time per Fertilisation Strategy

Of the masks included in the previous sections, some parameters can be extracted to summarise the result of that mosaicked image. More specifically, the western half of the field was fertilised with the minimal amount, which was doubled on the eastern half, as described in Section 3.4.2. The physical markers in the field were identified manually in each image set, and only the image between the markers was taken into account for these statistics. Firstly, each calculated VI yields an average value and a standard deviation per field half. The amount of soil coverage greatly influences this metric, which is why each of the VI's are also summarised for the masked case, where only pixels identified as vegetation are taken into account. Visually, these masks can be verified in the previous sections of this appendix. On the one hand these metrics say something about the quality of the VI mask, on the other hand they should give an indication of crop health provided that the masks are satisfactory. In Figure D.55 the dashed lines indicate the mean VI values of each week's image, and the solid lines their masked equivalents. As expected the masked means are consistently higher for each image where masking was at least somewhat successful, which is inherent to the definition of the VI's, as listed in Table 2.1. The influence of the crop health is expected to be more profound in the masked values, with the eastern half expected to be higher due to its fertilisation strategy. This does not seem to (consistently) be the case for any of the selected VI's for any of the crops.

Secondly, for each masked field-half the pixels that were identified as vegetation can be summarised in morphological characteristics, such as total area or mask perimeter. These are absolute counts in pixels, and are therefore not accompanied by a standard deviation whisker as was the case in the first metric. Furthermore, both values are inherent to the vegetation mask itself, so no dashed line can be added. Using the field of view (fov) angles, the imaged area can be converted from pixels to m^2 for both the total pixel counts per field-half, as well as for the masked areas, following Table 4.2. As seen in the previous sections, the imaged row length varied somewhat from week to week. The physical markers present in the field were identified manually in each row wherever possible. In the first two cabbage measurements and the second cauliflower measurement, however, the western half is not fully captured. To maintain comparable metrics across these weeks, the identified area was divided by the total area between markers, as included in Figure D.56. Similarly, Figure D.57 shows all the mask perimeters. Note that not all masks identify the vegetation pixels successfully, so not every data point in these graphs carries equal importance.

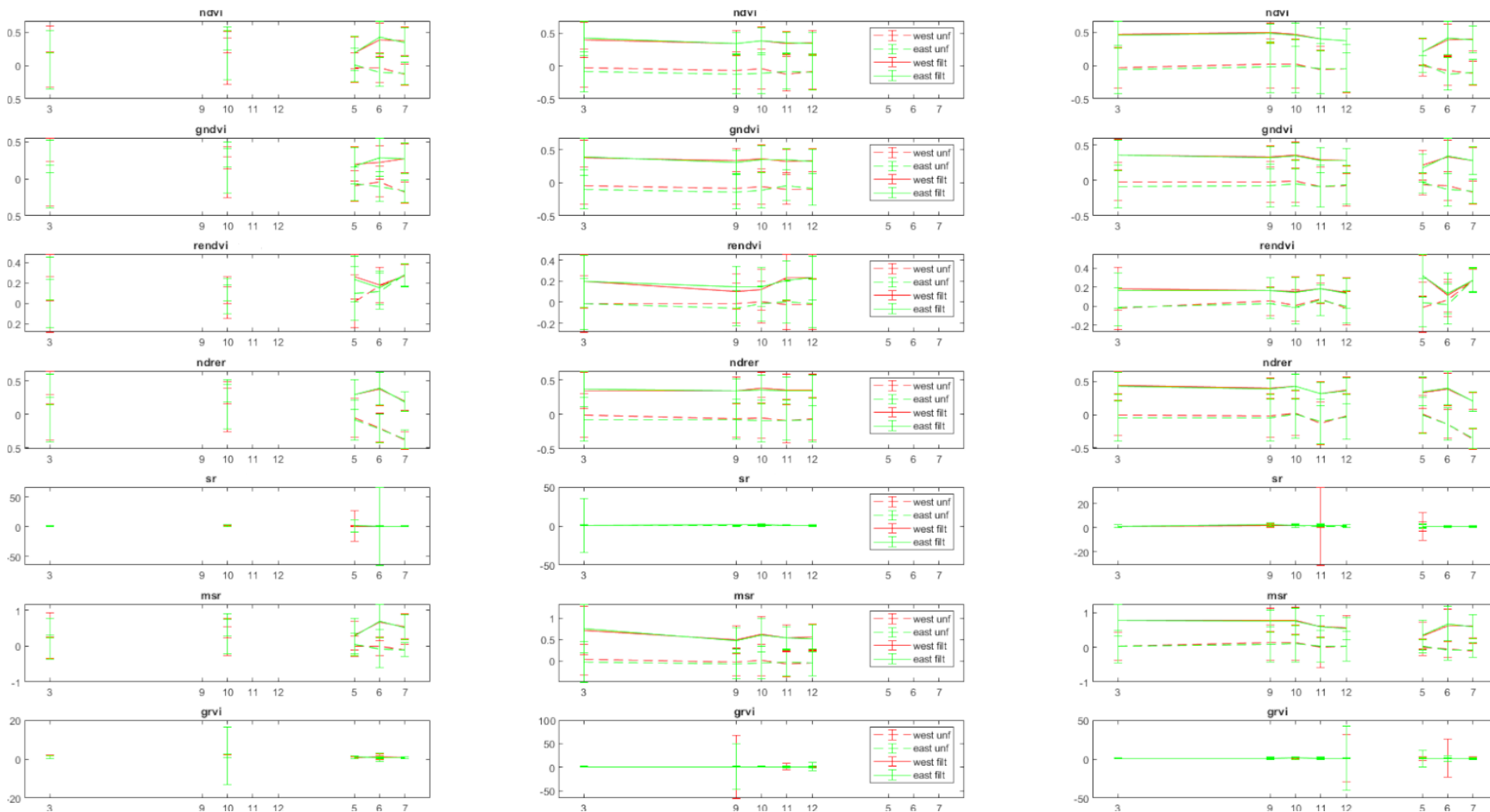


Figure D.55 Mean VI values with whiskers indicating the standard deviation. The legend is the same for all graphs and is indicated in the central column. The row denotes the VI, whereas the column denotes the crop type.

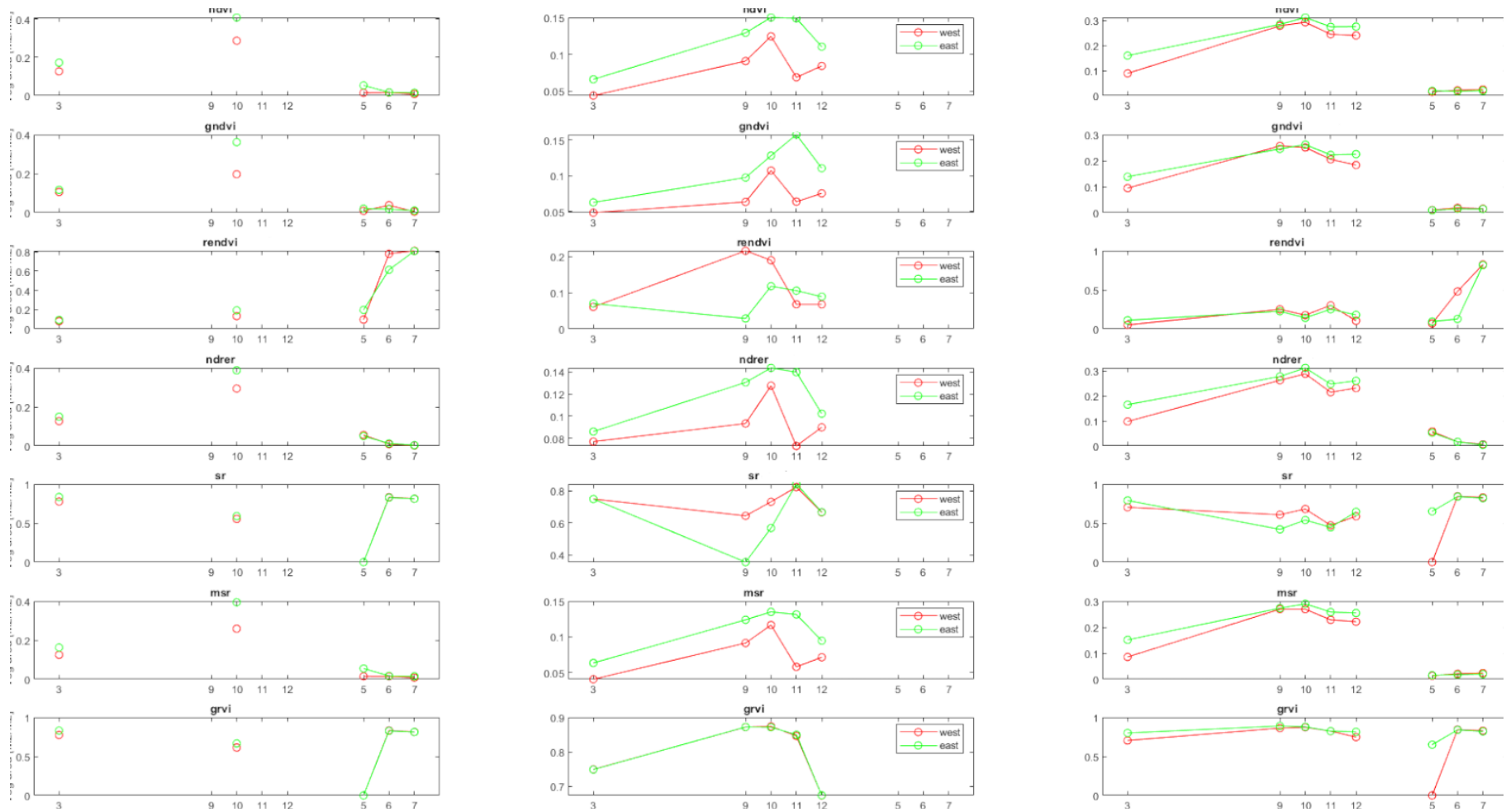


Figure D.56 Masked areas indicating vegetation, converted from total pixel count to m^2 per m^2 of imaged area. The main purpose of this conversion is to eliminate the effect of shorter measurements in some weeks, as not the entire row was visible in each dataset. The legend is the same for all graphs and is indicated in the central column. The row denotes the VI, whereas the column denotes the crop type.

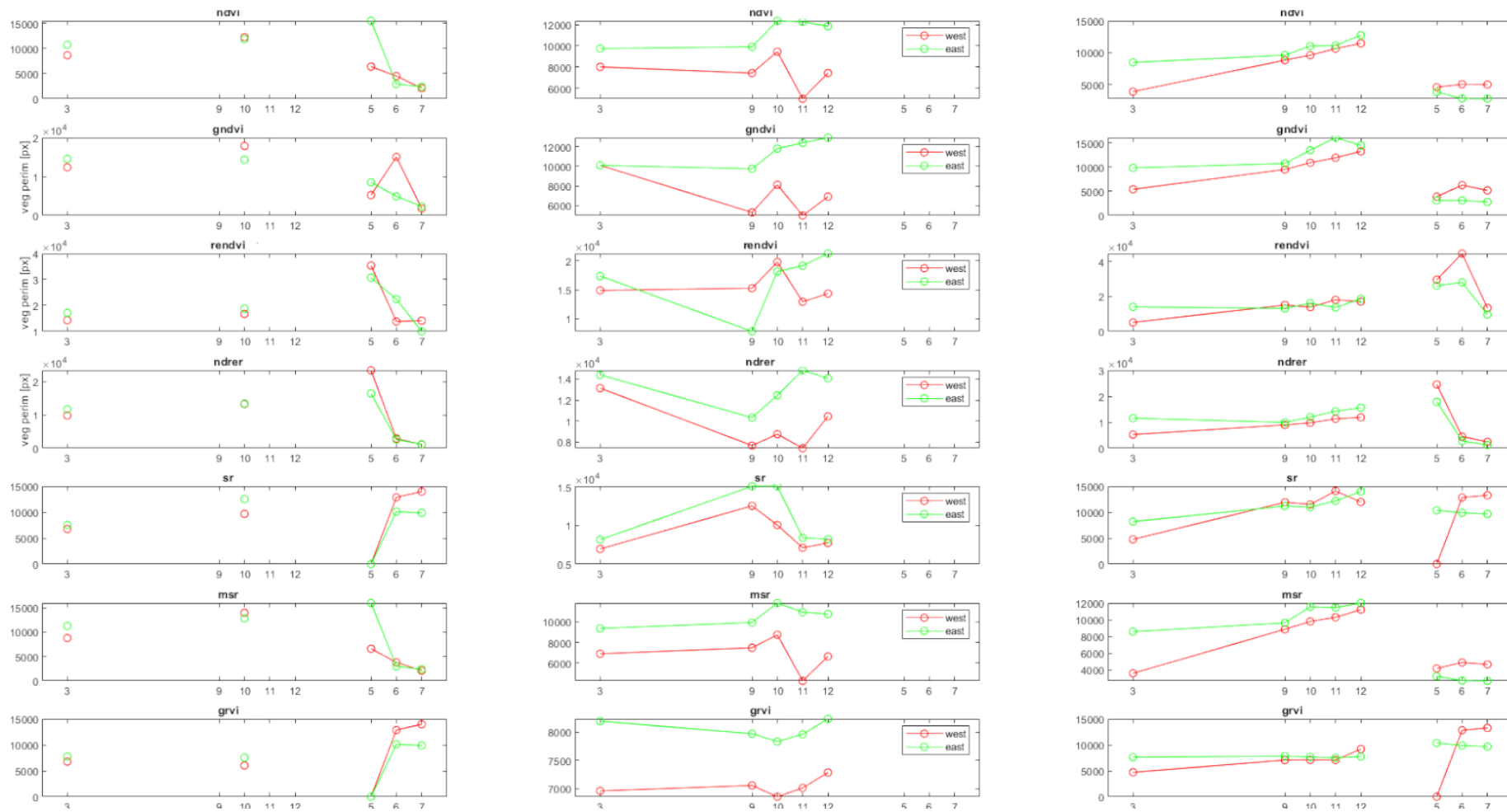


Figure D.57 Perimeters of masked areas indicating vegetation in absolute pixel count, as defined in Table 5.3. The legend is the same for all graphs and is indicated in the central column. The row denotes the VI, whereas the column denotes the crop type.