

INTRODUCTION

Sentinel-2 satellite launched in 2015 by European Space Agency seems to be an effective addition or even competitor of Landsat program. The major advantages of the Sentinel-2 program to be considered are high temporal (5 days revisit cycle) and spatial resolution(10 m RGB and VNIR bands, 20 and 60 M blue and SWIR bands). Sentinel-2 bands are spectrally placed very similar to Landsat. The data and processing software distributed under open source license and provided to the end users free and unrestricted access.

Despite these obvious advantages, Sentinel 2 program is youth, and its capabilities are not widely explored, especially in what degree it could be leveraged for Northern America earth resource perspective studies. Considering possible paid access to Landsat data shortly, Sentinel-2 data could be considered as an effective replacement of the Landsat imagery.

RESEARCH GOALS AND OBJECTIVES

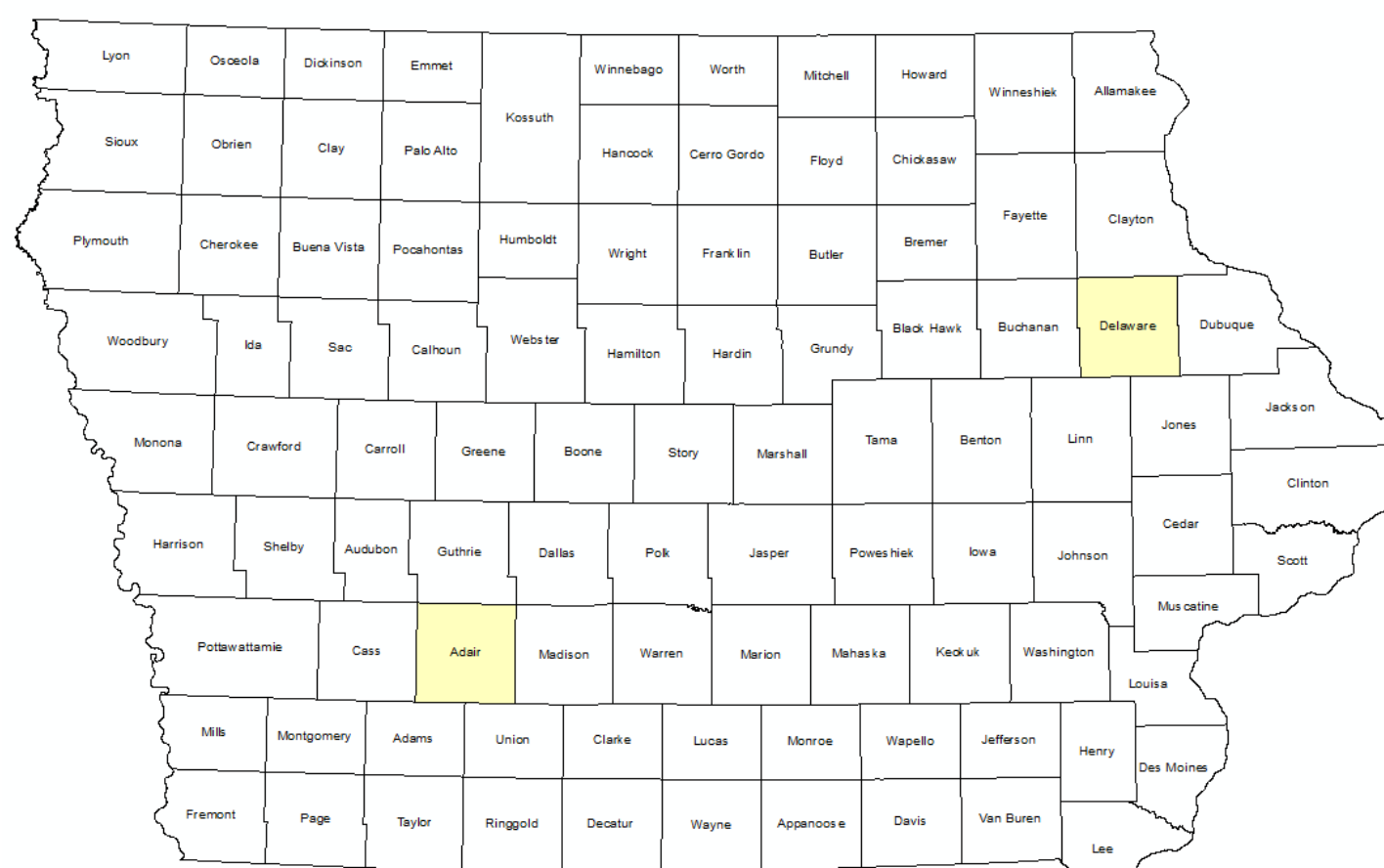
- ❑ Evaluate the accuracy of different supervised classification algorithms data suited for rural LU/LC classification and recommend which algorithms are best suited for LULC classification of the Sentinel-2 data.
- ❑ Evaluate the implication of the geometric correction on the accuracy of produced LULC classification results

STUDY AREA AND DATA SOURCES

The study area consists of two counties, both located in Iowa state, USA. They're similar in area, but Delaware county is twice populated as Adair county. Adair county could be considered more rural, and Delaware – more industrial. The quick facts for both counties are the following:

Delaware County:
Population: 17,153, Area: 579 mi², Prevailing LULC classes, according to CDL 2017, Corn: 51.3%, Soybeans 15.3%, Pasture: 13.25%

Adair County:
Population: 7,054, Area: 570 mi², Prevailing LULC classes: Corn: 33.9%, Soybeans: 32.0%, Pasture: 23.9%



Study areas location on the Iowa state map

For the study the following data was obtained:

Sentinel 2 scenes(level L1C): downloaded from ESA Copernicus Science Hub for the following Iowa counties: *Adair County*: Scene acquired *July 9, 2017*, *Delaware County*: Two scenes acquired *September 9, 2017*. Scenes have spatial resolution 10m per pixel for RGB and NIR bands(bands 2,3,4,8), 20m for NIR and SWIR bands(5-7,8a, 11,12) and 60 m for coastal aerosol, NIR and SWIR bands(1,9,10), provided in the ESA Granule format. (JPEG2000 files with index XML file)

Cropland Data Layer(2017): subset for both counties downloaded from CropScape Web GIS, consists of reference data for LULC classes for training and accuracy assessment purposes. It's a classified raster, provided in GeoTIFF or Erdas IMG format, 30m spatial resolution. Reported overall accuracy = 89.3% and Kappa= 0.862

NAIP 2017 aerial photos downloaded from Iowa GeoData website, RGB bands, 1m spatial resolution, MrSID format, 6m georeferenced accuracy per USDA documentation.

County boundaries of Iowa downloaded from Iowa GeoData website in a vector SHP format.

METHODOLOGY

Pre-processing:

Downloaded Sentinel-2 scenes in the internal ESA format were *atmospherically corrected* with ESA Sen2Cor tool(ATCOR algorithm) freely available from ESA website. Resulting Bottom of Atmosphere 60 and 20 meters image bands was *resized* to a 10-meter resolution to match RGB and VNIR band using Sentinels SNAP desktop software, *converted to ENVI format*, and *subset* by county boundaries from SHP files in ENVI. Then the subsets were *geometrically corrected*. NAIP 2017 data were used as reference data. Images were registered using *Registration Workflow* tool with the following settings: Matching method: Cross-Correlation, Minimum matching score: 0.8, Geometric model – Fitting global transform, Transform – First order polynomial, Maximum allowable error per tie point – 0.7.

Advanced settings – Matching band in base image: 3, in warp image – 2(blue band from Sentinel imagery and NAIP), and the export resolution was set to match pixel size from warp image to produce 10m per pixel output. Fifty-seven tie points with **total RMS 0.3230** were created for Delaware image, and 40 tie points with **total RMS 0.3212** were generated for Adair image.

According to the official Sentinel-2 documentation, for L1C/L2B processing level, scenes are georeferenced by the ground segment using ephemeris with accuracy not worse than 20m. According to the literature, actual geometric accuracy in between 7-12 meters in Europe(for study areas in Austria and Serbia), no studies on Americas

Processing: The *classification* was performed both on the georeferenced and non-georeferenced image subsets using the same training samples and ground truth ROI sets.

Training ROI was created by random selection of 200 pixels per each class from CDL 2017 layer. For Adair image these pixels were checked against NAIP aerial photo, and if any errors, points manually removed and recreated.

Supervised classification for the geometrically corrected and original subsets was performed using the following methods: *Binary encoding*, *Parallelepiped*, *Minimum Distance*, *Mahalanobis distance*, *Maximum likelihood*, *Support Vector Machine*, *Artificial Neural Network*, and *Random forest*. All the classification algorithms except Random Forest(RF) were ran using the default parameters in ENVI. RF algorithm was ran in EnMAP-Box software package.

Post-processing: *Ground truth ROIs* were created using *stratified random sampling*. 0.1% of the pixels for each class were selected from CDL image. Total 15800 pixels for Delaware County and 15315 pixels for Adair county were selected.

After the classification accuracy, *accuracy assessment* was performed using /Classification/Post Classification/Confusion Matrix Using Ground Truth ROI tool in ENVI. Having the accuracy assessment results, classification success was reviewed to find the best and worth performing algorithms.

RESULTS

The best-performing methods for supervised classification were *Artificial Neural Network*, *Maximum Likelihood*, *Support Vector Machine*, and *Random Forest*. *Mahalanobis distance* classification is somewhere in between, and *Binary encoding* and *Parallelepiped* classification algorithms could be considered as *worst performing* for Sentinel-2 imagery. Accuracy on Adair image was higher due to manual review of the randomly created training samples and less number of the classes (7 vs. 9)

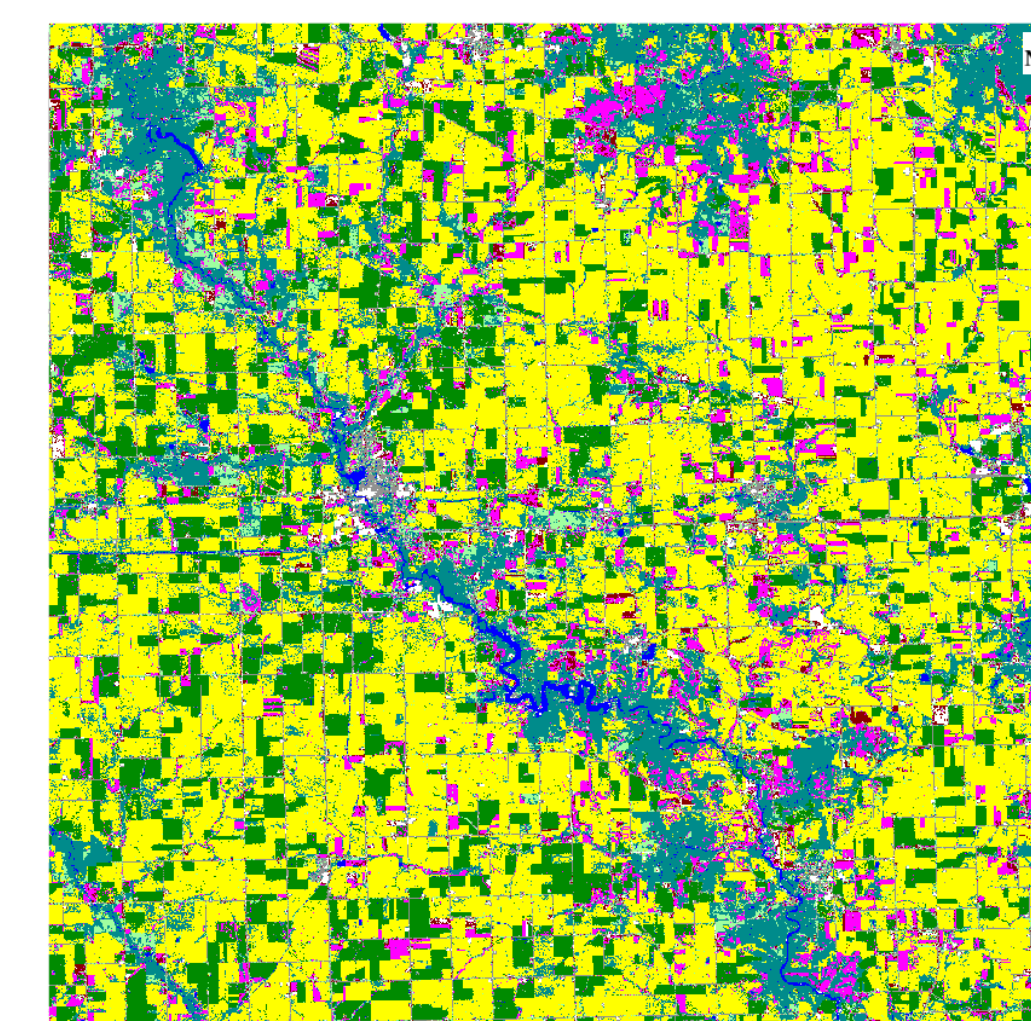
Geometrically corrected imagery using GCP did not show significant superiority in the classification results over original L1C imagery corrected by the ground segment by definitive ephemeris only. In average the classification methods yielded increase in overall classification accuracy of 0.8% between georeferenced and non-georeferenced Adair County images. Surprisingly, after geometric correction, the overall accuracy for ANN classification for Delaware County decreased from 73% to 64%(9% decrease). If not take into account such unexpected drop in the accuracy for Delaware image, overall classification accuracy increased in average by 1.16% for Delaware County. The total average increase of classification accuracy without taking into account the Delaware ANN result was 0.92%, which is negligible.

Table 1. Comparison of LU/LC classification accuracy by different algorithms

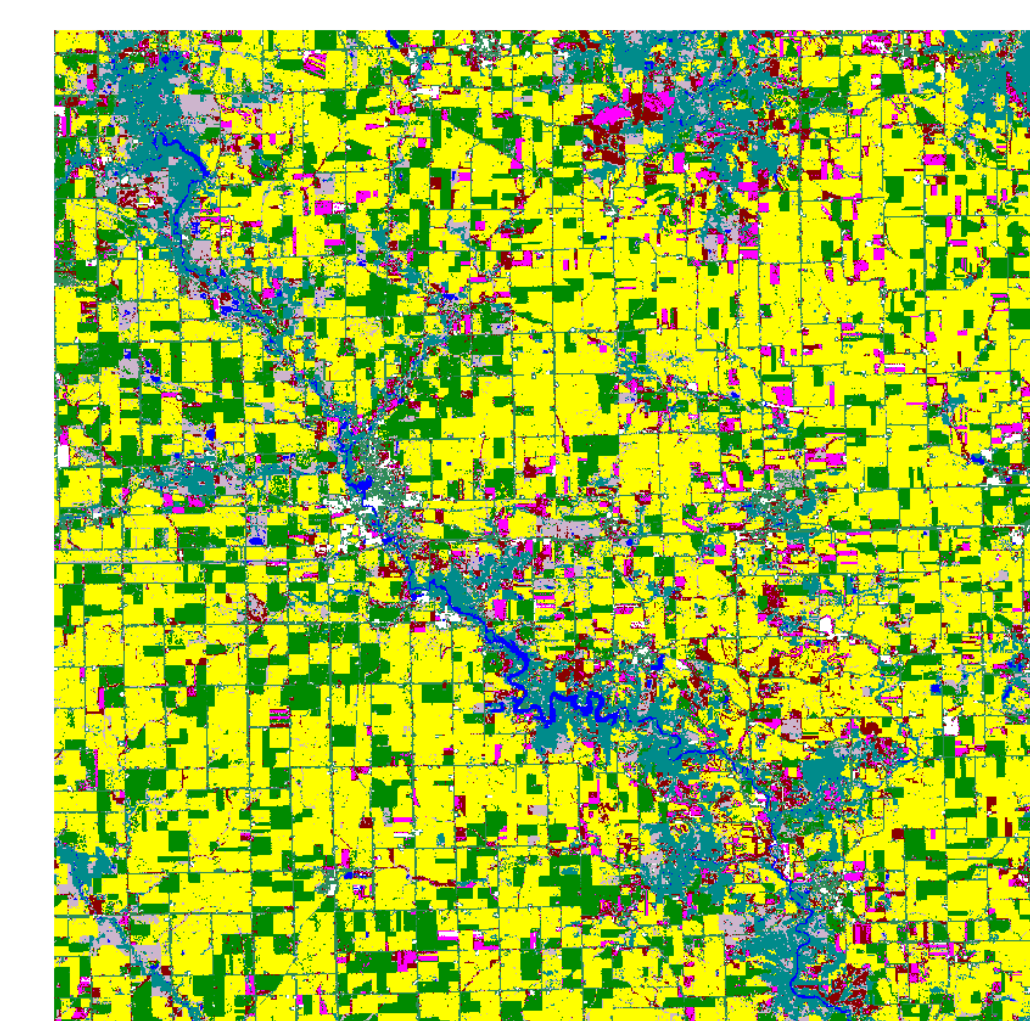
Classification algorithm	Adair %	Adair Georef %	Delaware %	Delaware Georef %	Acc. Δ Adair	Acc. Δ Delaware
Artificial Neural Network	77.2054	78.0607	73.6086	64.0313	0.8553	-9.5773
Maximul Likelihood	76.8658	77.127	71.2221	72.3305	0.2612	1.1084
Support Vector Machine	72.7261	72.8763	70.3537	71.1927	0.1502	0.839
Random Forest	75.1616	75.4097	70.0891	70.8123	0.2481	0.7232
Mahalanobis distance	71.7793	72.3996	62.9342	64.242	0.6203	1.3078
Minimum distance	54.9722	55.2204	61.4367	61.9568	0.2482	0.5201
Parallelepiped distance	41.3581	44.6229	45.7055	49.4232	3.2648	3.7177
Binary Encoding	30.2449	30.271	39.7566	39.6929	0.0261	-0.0637

Where *Adair %* - overall classification accuracy for Adair county(%) non-georeferenced dataset, *Adair Georef %* - accuracy for georeferenced dataset, same for *Delaware %* and *Delaware %* columns, *Acc. Δ Adair* and *Acc. Δ Delaware* – difference in classification accuracy between georeferenced and non-georeferenced datasets(%)

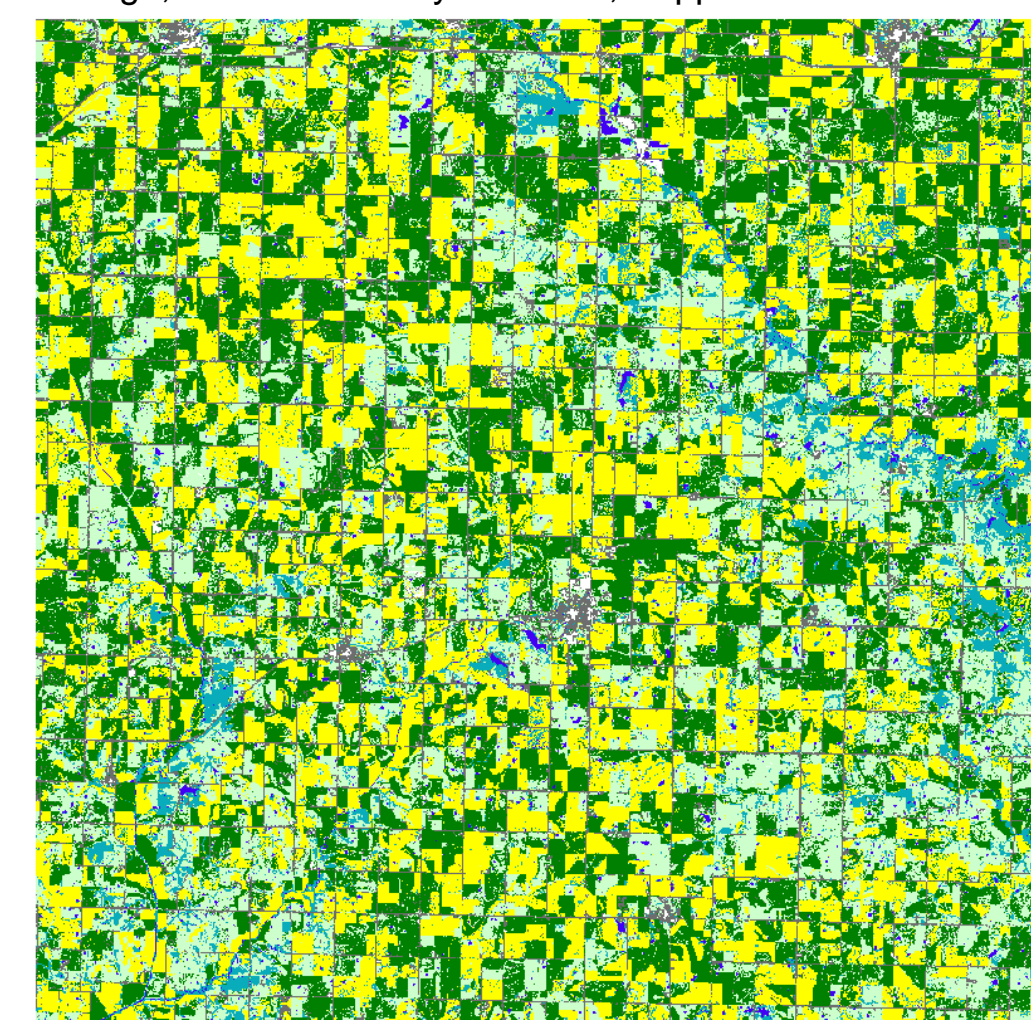
RESULTS



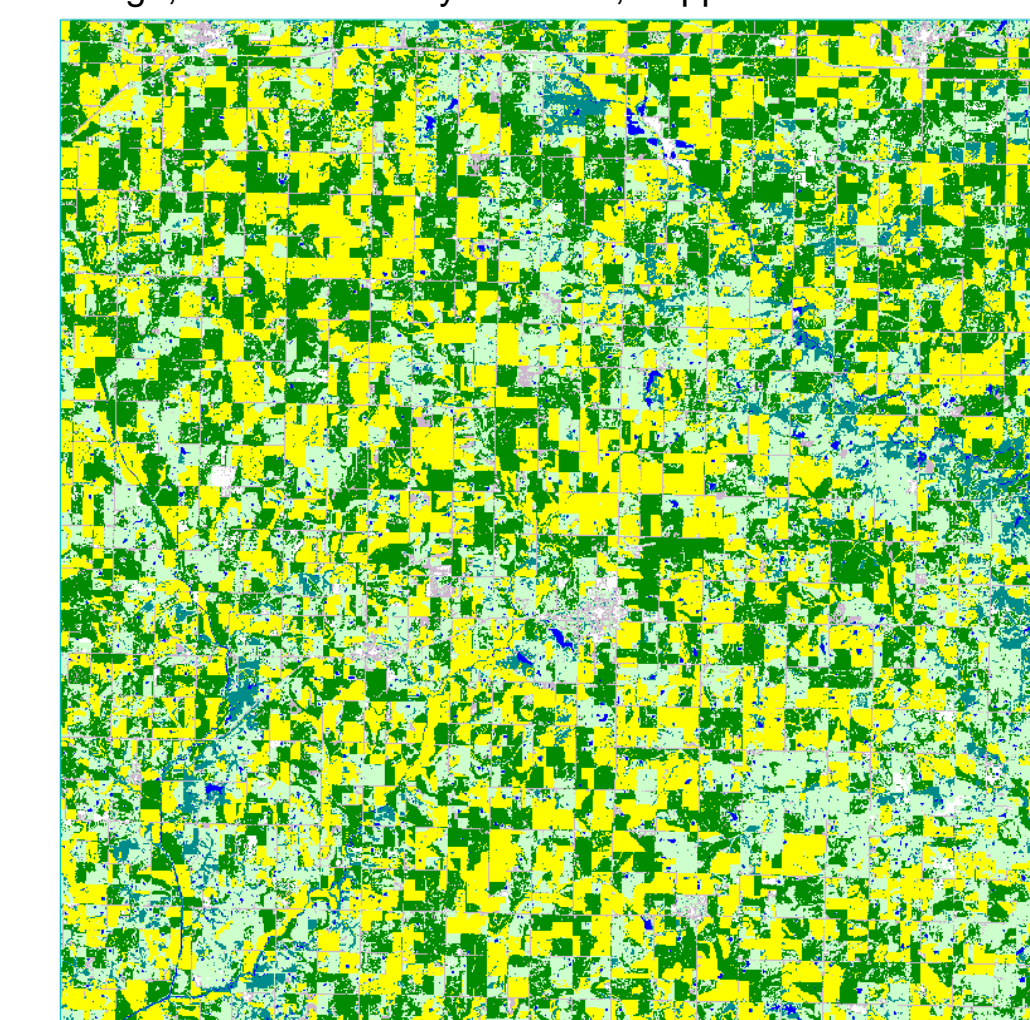
Maximum Likelihood classification of Delaware County image, overall accuracy = 71.2 %, Kappa value = 0.5953



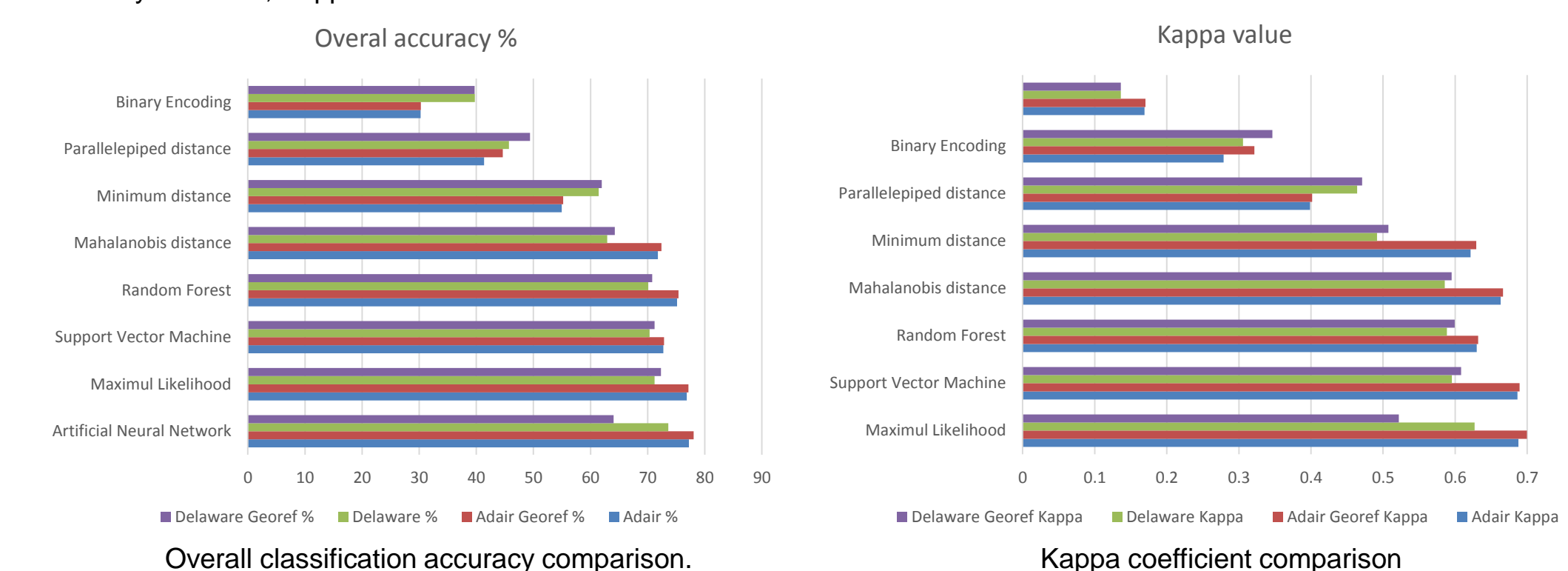
Artificial Neural Network classification of Delaware County image, overall accuracy = 73.6 %, Kappa value = 0.6268



Random Forest classification of Adair County image, overall accuracy = 75.6 %, Kappa value = 0.6630



Support Vector Machine classification of Adair County image, overall accuracy = 72.2 %, Kappa value = 0.6298



CONCLUSION

- ❑ The best-performing methods in terms of overall accuracy for supervised of Land use/Land cover classification of Sentinel-2 imagery for rural US landscapes were Artificial Neural Network, Maximum Likelihood, Support Vector Machine, and Random Forest algorithms. Regarding processing time, the fastest methods were Maximum Likelihood and Random forest algorithms, and the slowest – Support Vector machine.
- ❑ When the training data derived from the geometrically corrected ground truth image, the classification algorithms demonstrating steady but negligible accuracy increase around 1%. It could indicate that additional geometric correction of L1C Sentinel-2 products in most cases doesn't worth the efforts.