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Alabama Agriculture
Using NASA Earth Observations to Assess the Feasibility of Monitoring Water Retention in Winter and Cover Crops

DEVELOP Technical Report
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1. Abstract

This project leveraged NASA Earth observations, including Landsat 8 Operational Land Imager (OLI), Landsat 9 OLI-2, Sentinel-2 Multispectral Imager, Landsat 5 Thematic Mapper, and the Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG), to classify and map winter and cover crops, as well as to quantify soil water retention in northwest Alabama. Partnering with Alabama Drought Reach, the project aimed to provide data-driven insights supporting the organization's mission of improving drought-related decision making and communication with local farmers. At the time, Alabama Drought Reach lacked field-scale data to quantify how cover crops influence soil water retention. In response, this project used satellite remote sensing and Normalized Difference Vegetation Index calculations to classify and map winter and cover crop coverage in northwestern Alabama, a region affected by variable rainfall and drought events. Results indicated that fields using cover crops exhibited higher soil water retention compared to fields without, highlighting the benefits of expanding cover cropping as a drought-resilience strategy. Limitations related to data resolution and seasonal vegetation changes were noted, but overall, the results demonstrated the feasibility of deploying NASA Earth observations for monitoring and calculating the effectiveness of winter and cover crop implementation.

Key Terms

remote sensing, Landsat, Sentinel, drought, NDVI, winter crop, cover crop

2. Introduction

2.1 Background Information and Scientific Basis

Drought is one of the costliest natural disasters, resulting in risks to agriculture, water resources, and the economy (Gu et al., 2007). In the agricultural sector, yields and quality of crops are impacted negatively by mid-summer drought which puts many producers behind schedule on growing and harvesting (Otkin et al., 2013). Practical solutions to better prepare for the consequences of drought are increasingly being sought out in the state of Alabama (Mishra et al., 2017). For instance, one tool for drought mitigation within the agricultural sector is cover cropping. Cover cropping is a conservation practice used during off-seasons to benefit soil health (Wallander et al., 2021) by building organic matter, reducing soil erosion, and enhancing water retention (Snapp et al., 2022). Cover crops, such as cowpea and sorghum are planted in the fall after the primary crop is harvested and remain in the field over winter. Winter crops, such as wheat, are also planted during the same period and enhance soil structure, promote water retention, and reduce nutrient loss similar to cover crops (Graybill et al., 2024). The key difference between a winter crop and a cover crop is that winter crops are harvested for sale.

With the increase in popularity of cover cropping taking place over the past decade, research can still play a critical role in understanding the benefits and facilitate their further expansion. The adoption of cover crops in the United States increased from 3.4%in 2012 to 5.1% in 2017 (Wallander et al., 2021), and 2,251 farms in Alabama purchased cover crop seeds in 2022 alone—accounting for 15.4% of farms and 4.4% of total cropland acres (Vilsack & Hamer, 2024). The prevalence of this farming practice in Alabama continues to increase likely due to its reported effectiveness. Wallander et al. (2021) and Haruna et al. (2020) posit that cover crop practices increase water retention by as much as 629% compared to soil with no cover crop practices; however, the extent and location of cover crops is not often quantified at the field scale.

Given the promising benefits of winter and cover crops in enhancing soil health and water retention, it is increasingly necessary to find ways to monitor their adoption and effectiveness on a wider scale since cover cropping is a voluntary choice made by farmers at the field level (Roesch-McNally et al., 2017). Effectively communicating the benefits of winter and cover crops could encourage increased adoption. By continuing to quantify these impacts, researchers could support farmers in making sustainable choices in their own farming practices. One way to quantify these impacts is by using Earth observation data. The increase of freely accessible Earth observation data enables the application of remote sensing in mapping wintertime vegetative groundcover. Vegetation indices derived from remote sensing, such as the Normalized Difference Vegetation

Index (NDVI; Equation 1; Gao, 1996), have been widely used to identify and evaluate cover crop coverage during the winter (Ahmed et al., 2023). Moreover, NDVI has been used in previous studies as a reliable vegetation index in agricultural research at large (Hively et al., 2015; Kc et al., 2021; Ahmed et al., 2023). NDVI measures the amount of greenness by using the near-infared (NIR) and visible red bands reflected by vegetation and different values of NDVI can give insight into different growth stages of winter and cover crops (Ahmed et al., 2023).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

2.2 Project Partners and Objectives

Traditionally, research involving satellite imagery and remote sensing has not always been communicated with farmers in an accessible manner, leaving a gap between those conducting research and those who apply this research on a practical level. Our project partner, Alabama Drought Reach, aims to bridge the gap by making this research more accessible to local farmers. Alabama Drought Reach is a collaborative partnership between the Auburn University Water Resources Center and the Office of the State Climatologist, at the University of Alabama, Huntsville, along with support from the Alabama Cooperative Extension System. This organization's mission is to monitor the agricultural impact of drought and improve drought-related communications in Alabama. Alabama Drought Reach's focus for this project is to understand how winter and cover crops mitigate the impact of drought on agriculture by enhancing water retention in the soil. While they aim to use remote sensing to evaluate these practices, they do not currently have access to field scale data on these crops' specific impacts.

Additional data regarding the impact of winter and cover crop practices on water retention in Alabama would support Alabama Drought Reach's mission of effective drought communication by providing local farmers with evidence of the feasibility and benefits of these practices. This project also serves as a case study to provide a deeper understanding of the extent to which winter and cover crops can enhance water retention and mitigate drought in the state of Alabama. Overall, as drought communicators, Alabama Drought Reach aims to help farmers make informed decisions on mitigating drought on local farmland by translating research into concrete insights.

Previous studies have taken a remote sensing approach by harnessing NDVI data to map winter and cover crops. The United States Geological Survey used NDVI from Landsat and System Probatoire d' Observation de la Terra (SPOT), the National Agricultural Statistics Service Cropland Data Layer from the United States Department of Agriculture (USDA), and windshield surveys to analyze green wintertime vegetation on agricultural fields in the Chesapeake Bay watershed from 2010 to 2013 (Hively et al., 2015). Their in situ verified results determined an NDVI threshold value that can be used to identify winter and cover crops. Kc et al. (2021) harnessed this threshold using Landsat satellite imagery and ground-truth data points to map the use of winter and cover crops in the Maumee River watershed from 2008 to 2019. Kc et al. (2021) also considered the growth stages and plant phenology derived from NDVI to characterize winter and cover crop growth with a machine learning approach. These two studies were conducted in the Eastern and Midwestern United States as the highest cover crop adoption rates are found in the Eastern United States, Midwest, and Great Lakes regions (Wallander et al., 2021). Similarly, Ahmed et al. (2023) evaluated cover cropping extent from 2013 to 2019 in the Arkansas portion of the Mississippi Alluvial Plain delta with Landsat satellite-imagery-NDVI, USDA Natural Resource Conservation Service global positioning system points, Cropland Data Layer, and the Google Earth Engine platform for machine learning.

To accomplish a similar task for Alabama Drought Reach, we used numerous Earth observations in this project to calculate NDVI: Landsat 5 Thematic Mapper (TM) and Harmonized Landsat Sentinel-2 (HLS), which combines Landsat 8 Operational Land Imager (OLI), Landsat 9 OLI-2, and Sentinel-2 MultiSpectral Instrument (MSI). To estimate water retention, environmental parameters such as rainfall were essential, so we used the Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG) for precipitation data. These methods of remote sensing data acquisition and processing can vastly increase Alabama Drought Reach's capacity to analyze Earth observations to assess the impact of winter and cover crops and communicate effectively to farmers and decision-makers. As a result, we derived two main objectives based on the partner's needs. The first objective was to classify and map winter and cover crop coverage. Second, we aimed to quantify soil water retention and compare soil water retention within respective classes to estimate the impact of winter and cover crops. Through these objectives the project aimed to support Alabama Drought Reach's mission relating to prioritization of research in mitigation and strategic planning for drought.

2.3 Study Area and Study Period
Alabama Drought Reach's support partner, the Alabama Cooperative Extension System, spreads itself across the entire state of Alabama into seven different administrative regions known as Strategic Extension Teams (SETs). The study area for this project encompasses eleven counties within the Northwestern SET (Figure 1), where there is a high density of cropland along the Tennessee River. This area was chosen at the request of Alabama Drought Reach based on its unique geographical location in addition to its potential for reproducible insights across other SETs. Highlighting historical drought periods in the state of Alabama (2008, 2016 and 2023), and although cover crops are planted year-round, we placed a specific focus on the growing season for winter and winter cover crops (September and November). The Northwestern SET provides a valuable case for analyzing the potential benefits of these crops in improving water soil retention and fulfilling Alabama Drought Reach's mission.

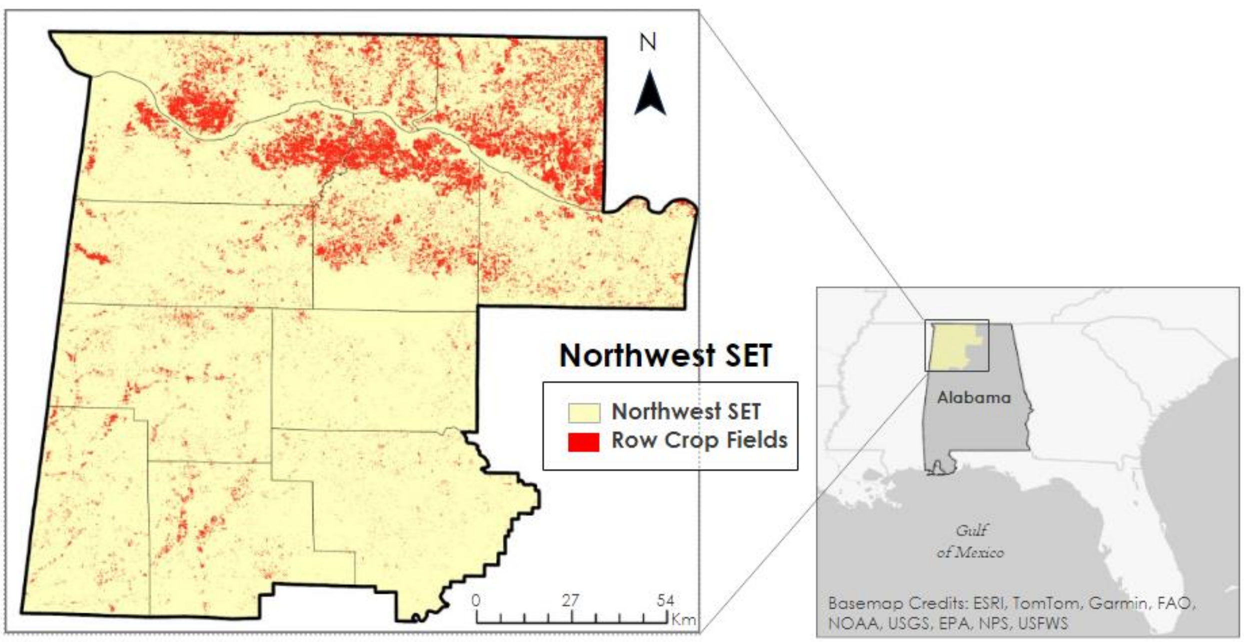

Figure 1. Row crop fields in the Northwestern Alabama SET.

3. Methodology
3.1 Data Acquisition
We sourced Earth observation data from various repositories (Table 1), including the Goddard Earth Sciences Data and Information Services Center (GES DISC), and the Land Processing Distributed Active Archive Center (LP DAAC). We acquired Landsat Collection 2 Level 2 Universe Transverse Mercator Surface Reflectance data from the United States Geological Survey SpatioTemporal Asset Catalog through Microsoft Planetary Computer application programming interface in Jupyter Notebook using Python 3 and selected Landsat 5 TM scenes with less than 20% cloud cover. Similarly, through the "earthaccess" library search function in Jupyter Notebook Python 3, we obtained HLS Surface Reflectance Daily Global 30m and HLS Sentinel-2 MSI Surface Reflectance Daily Global 30m data from LP DAAC. We queried HLS and Landsat 5 data using the study area boundary and a temporal parameter of January 1 to March 31 for each year. We chose this period to avoid conflict with the typical earliest cash crop planting date in Alabama,

March 15 (USDA National Agricultural Statistics Service, 2010). For precipitation data, we extracted GPM IMERG at a precipitation intensity of millimeters per day from Giovanni online data system, developed and maintained by the NASA GES DISC. Working with our partner, we found precipitation at a finer temporal resolution than millimeters per day was not necessary since we were averaging over the span of three months.

Table 1
Data acquisition information

Satellite & Sensor	Data Type	Parameter	Use
Landsat 8 OLI	Earth Observation	Surface reflectance	Calculated NDVI with Harmonized Landsat and Sentinel-2 (HLS) data for 2016 and 2023.
Landsat 9 OLI-2	Earth Observation	Surface reflectance	Calculated NDVI with HLS data for 2016 and 2023.
Sentinel-2 MSI	Earth Observation	Surface reflectance	Calculated NDVI with HLS data for 2016 and 2023.
Landsat 5 TM	Earth Observation	Surface reflectance	Calculated NDVI for 2008.
GPM IMERG	Earth Observation	Precipitation	Precipitation data to identify rainfall patterns which is a variable in the water infiltration analysis.
	Ancillary	Crop-specific land cover	Source for cropland data which is a source for winter and cover crop mask.
USDA gSURRGO Data	Ancillary	Soil type	Variable in water infiltration analysis.
Cover Crop GPS	Ancillary	Crop-specific land cover	Validation of winter and cover crop mask.

Likewise, we collected cropland and soil type data from publicly available resources. We exported the Cropland Data Layer, a key source of agricultural land use information, from the USDA National Agricultural Statistics Service CropScape website for the purpose of focusing our study area. We obtained Gridded Soil Survey Geographic (gSURRGO) data, collected by the USDA in October 2023, for soil type classification purposes.

Alternatively, ground-truth data of cover crop implementation is not freely available nor copious in our study area—further highlighting our partner's need. Alabama Drought Reach provided cover crop GPS data collected by Auburn University which we utilized for validating our winter and cover crop mask. To supplement this dataset, we viewed Planet Labs satellite imagery from January 1 to March 31 through Planet Explorer for winter and cover crop validation.

3.2 Data Processing

To prepare the data for analysis, we calculated NDVI to classify winter and cover crops and extracted a crop field mask to identify row crop fields in our study area. In Jupyter Notebook, we calculated NDVI from Landsat 5 TM scenes for the year 2008 using the built-in NDVI tool within the "xarray multispectral" Python package. We then clipped Landsat 5 TM NDVI scenes from 2008 to the Northwest SET study area and exported for further processing in ArcGIS Pro 3.3.1. After clipping to the study area, HLS granules specifically had to be filtered to exclude negative NIR and Red values, scaled, and masked using the F-mask band values included with HLS. We used a scale factor of 0.0001 that was recommended in the HLS Product User Guide (Ju et al., 2023). For HLS imagery we calculated NDVI using a custom function (Equation 1) modified from LP DAAC's HLS tutorial (United States Geological Survey, 2024). After exporting HLS NDVI scenes for 2016 and 2023, we imported each year's collection of NDVI rasters into ArcGIS Pro 3.3.1 and composited overlapping rasters for each scene via the "Cell Statistics" tool using "Maximum (Ignore No Data) thus taking the maximum NDVI from January 1 to March 31. This was followed by the "Mosaic Raster" tool which we used to mosaic all scenes into a single raster for each year also using the maximum for overlapping scenes. This resulted in three maximum NDVI raster layers: NDVI 2008, NDVI 2016, and NDVI 2023 (Figure 2).

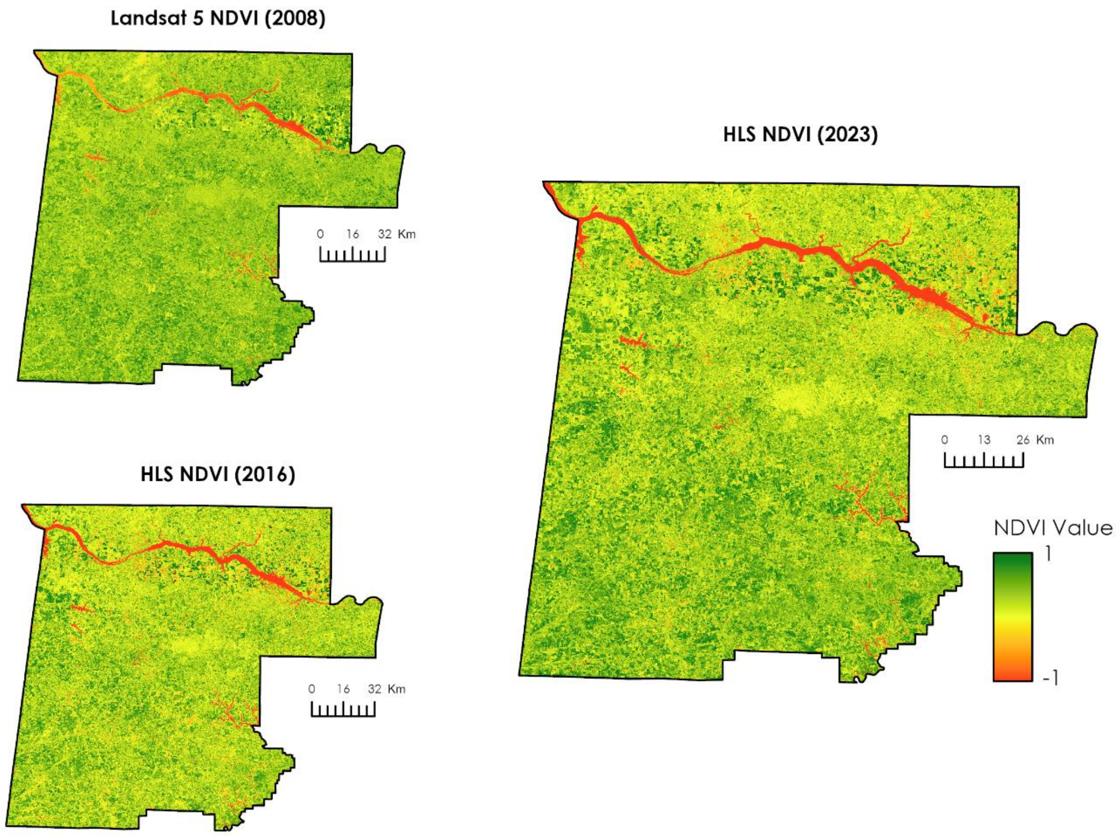

Figure 2. Maximum NDVI composite images (Jan 1–Mar 31; 2008, 2016, 2023).

The crop field mask that we generated illustrates where row crop fields exist and represents the finer study area for analysis. The USDA Cropland Data Layer includes 254 cropland classes, including row crops (e.g. corn, soybeans, cotton, peanuts), specialty crops (e.g. cucumbers, onions, orchard, citrus), and other landcover classes (e.g. forest, wetlands, aquaculture, barren, pasture/grass). We had to exclude cropland types that typically would not use cover or winter crops and therefore were not of interest to our partner. In ArcGIS Pro 3.3.1, the crop field mask was extracted from the Cropland Data Layer for 2008, 2016 and 2023 using the "Con" tool by isolating row crop fields based on USDA attribute classification.

3.3 Data Analysis

3.3.1 Winter and Cover Crop Map

To create the winter and cover crop maps, we had to determine what NDVI threshold value would distinguish winter and cover crops from barren fields. We originally intended to use a NDVI value of 0.3 from similar studies, but we found this classified 98% of our cropland as containing cover or winter crops, likely due to our study area having a warmer climate (Hively et al., 2015; Kc et al., 2021; Ahmed et al., 2023). To determine our own NDVI value, we collected reference data for locations with and without winter and cover crops in the winter of 2023 using a random sampling approach. For this process we used ArcGIS Pro 3.3.1 to randomly generate 100 points within the study area. Then, we visually classified these points as being green or not green based on high-resolution Planet Labs data viewed through the Planet Explorer platform. We focused on images toward the end of the winter season, which is when winter and cover crops would be the most vibrant and identifiable but before the fields were prepared for the main growing season (Figure 3). We recorded these reference classifications and the corresponding NDVI values for each point in a spreadsheet, then imported it into Python 3 and used the "sklearn" package to randomly divide them into a group of 70 points for analysis and a group of 30 points for validation.

Figure 3. Classifying green fields (Source: Planet Explorer).

With the analysis group, we calculated the standard deviation for the NDVI values and decided to use one standard deviation below the mean for our threshold value. We based the threshold on one standard deviation because the data resembled a normal distribution; therefore, this threshold accepted most points while excluding low outliers. From the analysis group, the threshold NDVI was calculated as 0.635 (Figure 4). When we tested this threshold on the validation group, it was found to be 93% accurate overall, with 28 points classified correctly and 2 points containing cover crops misclassified as being barren (Figure 5). No barren points were misclassified as containing cover crops. We then applied this threshold value of 0.635 to the NDVI map of the field crop mask to generate our winter and cover crop map.

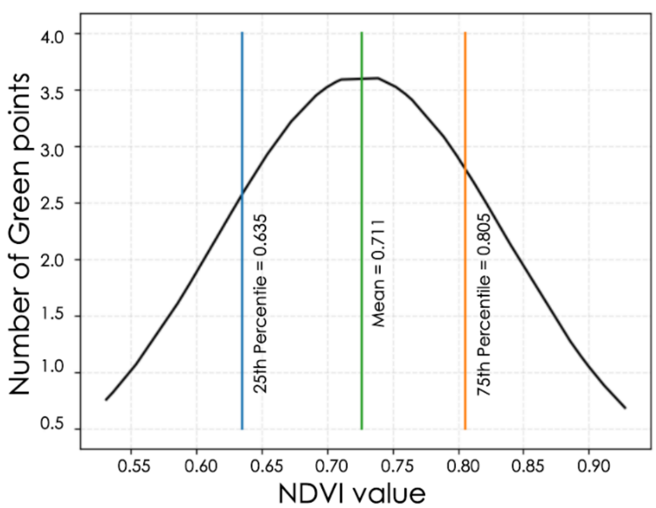

Figure 4. Testing data distribution for NDVI threshold calculation.

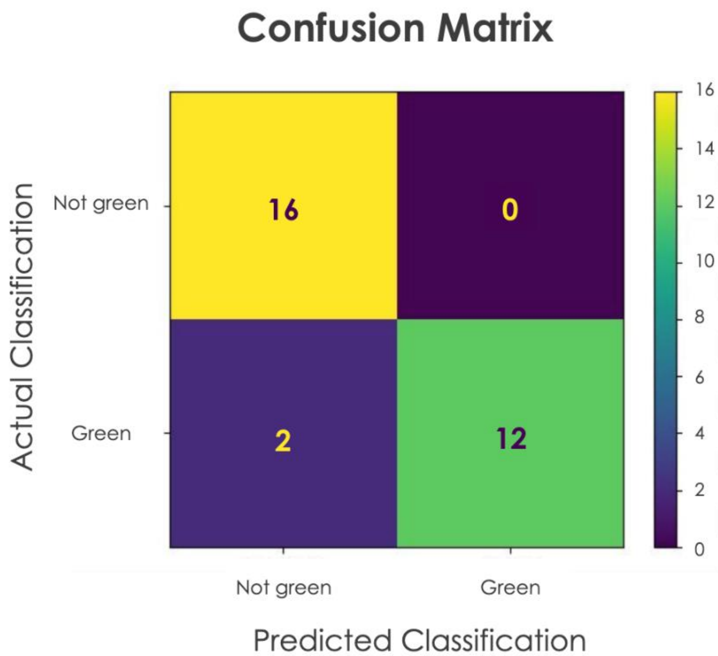

Figure 5. Confusion Matrix results displaying error of an NDVI threshold of 0.635 tested on 30 validation points.

3.3.2 Water Retention Package

We generated a water retention map by applying the Soil Conservation Service-Curve Number (SCS-CN) method to raster datasets containing precipitation data, soil survey data, and our winter and cover crop maps (USDA National Agricultural Statistics Service, 2004; Equation 2). Curve numbers are a hydrological parameter ranging from 30 to 100 for predicting runoff due to rainfall, where a lower curve number indicates more permeable soil. To calculate these curve numbers, we first determined the soil group from the Gridded Soil Survey Geographic (gSURRGO) Database. The soil groups A, B, C, and D are used to represent soil permeability, with A being the most permeable and D being the least. The gSURRGO dataset lists some soil types as being combined, such as A/D, which refers to how the permeability changes whether the soil is drained or undrained. For the combined types, we conservatively converted them to the least permeable option. We generated the curve number raster based on the 2019 National Land Cover Database lookup table, which provides estimates for curve numbers based on soil group and land use (Dewitz, 2021). When using this lookup table, we categorized areas of the winter and cover crop map that did not contain winter or cover crops as barren land, and parts that did as grassland/herbaceous. We did this because winter and cover crops are more similar to grass and herbaceous plants than they are to row crops or to other categories in the table. We calculated the average water retention (F) in millimeters per day based on the precipitation (P), the runoff (Q), the curve number (CN), and the potential maximum runoff after retention begins (S; Equations 2 – 4; USDA National Agricultural Statistics Service, 2004). The water retention map of the study area was calculated in ArcGIS Pro 3.3.1 by inputting the formula into the "Raster Calculator" tool.

$$F = (P - 0.2S) - Q \tag{2}$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{3}$$

$$S = \frac{1000}{CN} - 10 \tag{4}$$

Where:
F = actual retention after runoff begins, in millimeters per day
S = potential maximum retention after runoff begins (S > F), in millimeters per day
Q = actual runoff, in millimeters per day
P = actual rainfall (P > Q), in millimeters per day

3.3.3 Hotspot Analysis

Once we created our winter and cover crop maps and our water retention maps, we generated hotspot maps using the "Hot Spot Analysis (Getis-Ord Gi*)" tool in ArcGIS Pro. This tool evaluates each point in the context of neighboring points, finding statistically significant hotspots where a point with a high value is surrounded by other points with high values. It also finds cold spots where points with low values are surrounded by other points with low values. For our winter and cover crop map, the hot spots indicate areas with a high density of winter or cover crops, and the cold spots indicate areas with a high density of barren land. For the water retention map, the hot spots indicate areas with a high concentration of fields with high water retention while the cold spots indicate areas with a high concentration of fields with low water retention.

4. Results

4.1 Analysis of Results

4.1.1 Winter and Cover Crop Map

Based on the winter and cover crop map, we found that during the winter of 2023, 21.6% of row crop fields in the study area contained either winter or cover crops. Larger areas of cropland near the Tennessee River are more likely to contain winter or cover crops (Figure 6). In contrast, dispersed cropland in the southern and western parts of the study area is less likely to contain cover or winter crops. The hot spot analysis revealed that winter and cover crop area increased between 2008 and 2023, most notably near the Tennessee River (Figure A1).

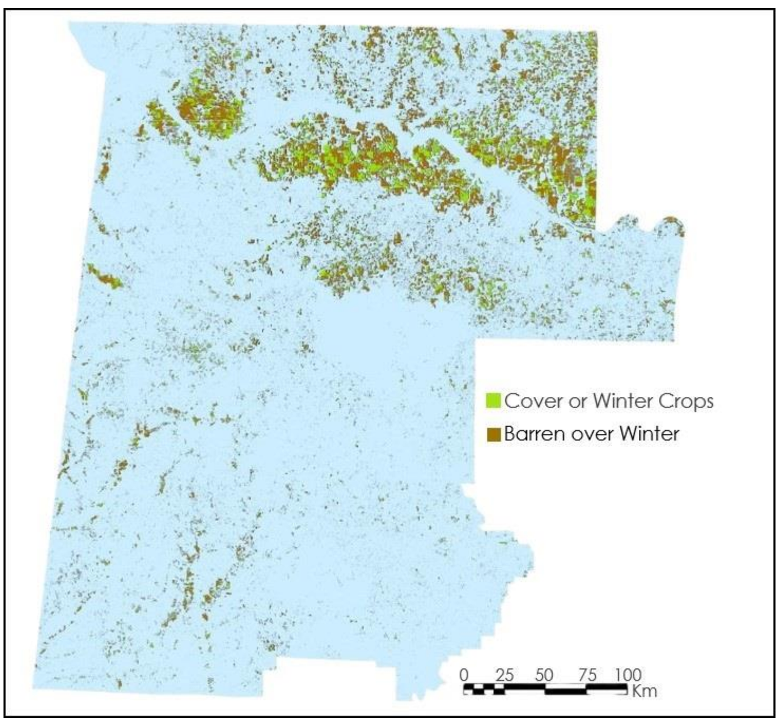

Figure 6. The distribution of row crop fields that contained winter or cover crops in the winter of 2023 and of those that were barren over the winter of 2023.

4.1.2 Water Retention Hotspots

The water retention map showed areas of increased average water retention primarily along the Tennessee River, but also in the northeastern and central regions of the study area (Figure 7; Figure A2). In contrast, we found cold spots for water retention along the north and west edges of the study area, as well as in the southeast region. Both hot spots and cold spots are present with high confidence, indicating high statistical significance. In comparison to our winter and cover crop map (Figure 6), areas with a higher density of row crop fields appear to also contain large hotspots for high water retention.

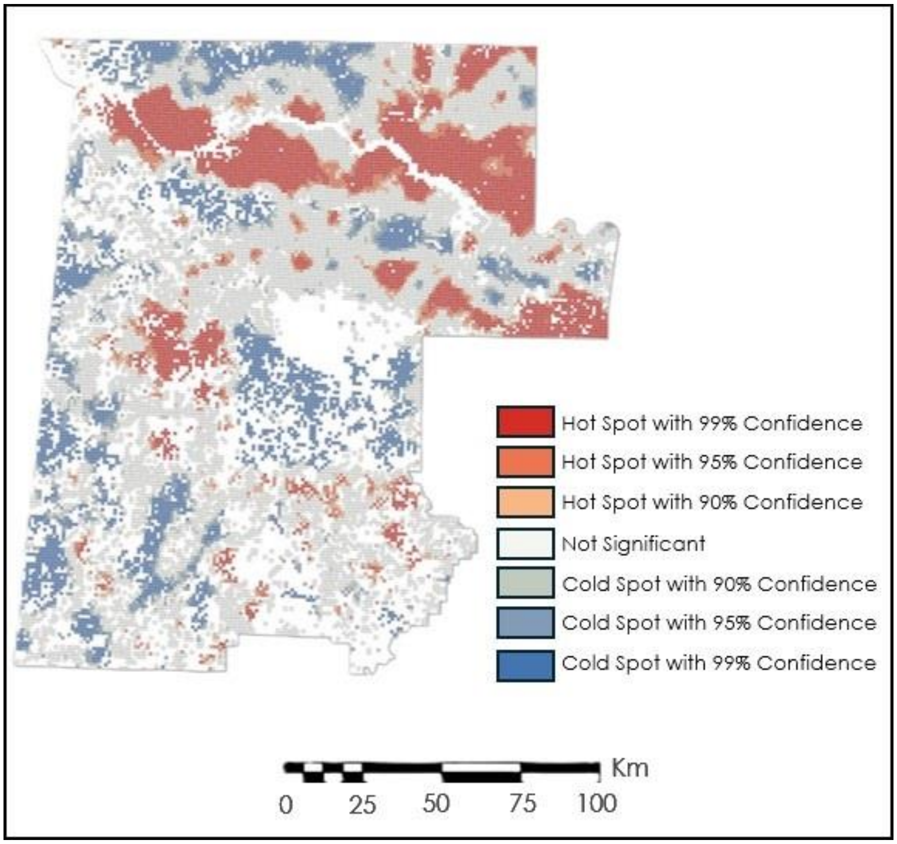

Figure 7. A hotspot analysis of areas retaining high amounts of water displayed on a 1km grid (2023).

4.1.3 Winter and Cover Crop Adoption Rate Compared to Water Retention

We continued comparing our winter and cover crop and water retention data by viewing the two results through a bivariate choropleth map aggregated to a 10 kilometer grid (Figure 8; Figure A3). We found that as indicated by the previous figures, the cropland along the Tennessee River contains a high density of winter and cover crops as well as a high average water retention. Other parts of the study area, such as the east and southwestern regions, had medium or high percentages of winter or cover crops, but low average water retention. We visually found areas with high average water retention but low winter and cover crop adoption rates to be an uncommon occurrence within the study area.

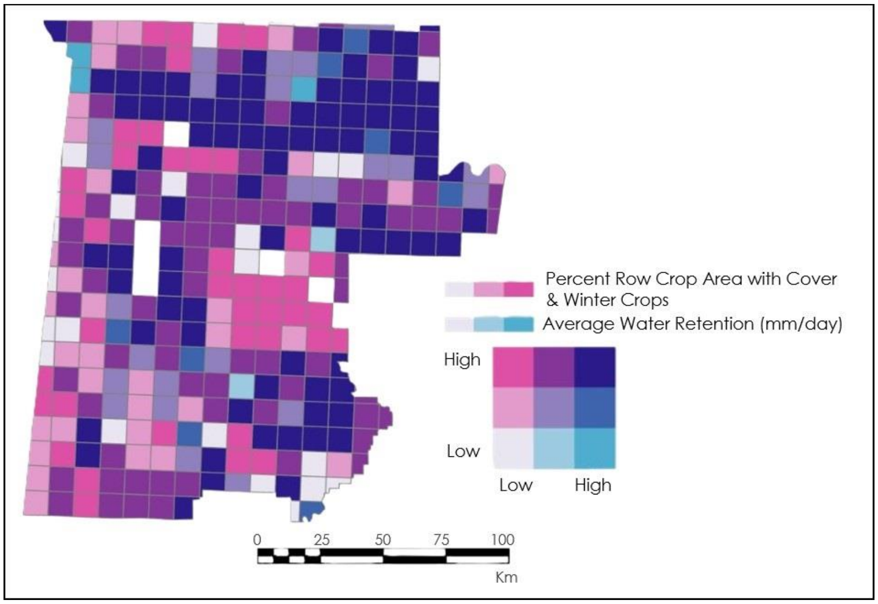

Figure 8. Bivariate analysis of percentage winter and cover crop adoption and average water retention displayed on a 10 km grid (2023).

4.2 Errors & Uncertainties

Using the Cropland Data Layer as an input contributed to certain errors. The USDA reports an average accuracy of about 80% for the Cropland Data Layer (National Agricultural Statistics Service, 2024). Many random pixels appear outside of fields and many fields have missing pixels. This resulted in a highly erroneous crop field mask, and subsequently error pixels in the winter and cover crop mask which affects the percent area of winter and cover crops.

When identifying cover crops using Earth observations, it is difficult to differentiate them from weeds that are spectrally similar. There were additional factors when it came to weed growth in late winter and early spring, conflicting with the winter and cover crop growth period. Winter weed emergence increases with higher soil temperatures (Werle et al., 2014) and is more of a concern in warmer regions such as the South. Similar studies have taken place in the Midwest and East Coast which have a much colder climate than Alabama (Hively et al., 2015; Kc et al., 2021). Considering weeds often compete with crops for water (Kelton et al., 2015), there are multifactorial distinctions to winter and cover crops regarding water retention benefits, and we were unable to differentiate the two based on maximum NDVI alone. Kc et al. (2021) outlines a more complex approach that considers continuous NDVI throughout the winter season and a cover crop's phenology which may be capable of addressing this issue. Additionally, there was potential for error when visually identifying whether fields were green or not. While clear cases of greenery, such as fields with winter or cover crop growth were straightforward to classify, borderline cases were more challenging to categorize (Figure 9). For example, fields that were only partially green, made classification difficult and increased the likelihood of potential human error. Misclassification of these fields directly impacted the NDVI threshold calculations used to train and validate the model, potentially affecting the accuracy of our winter and cover crop map.

Figure 9. Clear and unclear cases when classifying green fields (Source: Planet Explorer).

Furthermore, it is important to note discrepancies in the curve number method for calculating runoff and water retention (Berhanun& Bisrat, 2018). Developed in 1956, the curve number method is debated in the scientific community for its accuracy, particularly when applied at a national scale without local calibration (Soulis, 2021). Curve numbers often overestimate infiltration compared to in situ measurements in conservation practices (Bonta & Shipitalo, 2013). This highlights the need for locally derived curve numbers when replicating the methodologies from this project. Lastly, we calculated water retention using only three parameters: 4 basic soil groups, 2 land cover classes, and precipitation. Water retention, infiltration, and other index calculations can be optimized by incorporating additional parameters such as soil hydro conductivity, particle size, or by considering other moisture indicators like long-term rootzone soil moisture data and evapotranspiration. Implementing this approach likely requires additional field-scale data. Nevertheless, the curve number method demonstrated its utility as a simple and feasible approach for this project considering data availability.

5. Conclusions

5.1 Interpretation of Results

Overall, we found that winter and cover crops were adopted across row crop fields in our study area (21.6%), with some counties showing higher adoption rates such as Colbert County. Additionally, fields with winter and cover crops showed increased water retention especially during farming off-seasons. Finally, our findings suggest that water retention can be enhanced by winter and cover crops, providing a strategy for drought mitigation. These results will help our partners better understand where winter and cover crops are being utilized and areas that can benefit from agricultural drought resistance for the purpose of communicating this information to the greater agricultural community of Alabama.

5.2 Feasibility & Partner Implementation

Ultimately, our results indicated that the use of NASA Earth observation data was a largely feasible and scalable approach for monitoring winter and cover crop implementation and efficacy. We effectively accomplished our two objectives: We harnessed HLS and Landsat 5 TM to classify and map winter and cover crop coverage with minimal error (7%) and leveraged IMERG precipitation data to quantify soil water retention and compare soil water retention within respective classes to estimate the impact of winter and cover crops. The spatial and temporal resolutions of Landsat 5 TM and HLS were suitable to achieve our objectives, even when aggressively masking cloud cover, because we only required the maximum NDVI from multiple months. Consistent with previous studies of this kind, NDVI demonstrated reliability in determining the presence of vegetation in the winter season. Lastly, the temporal resolution of IMERG precipitation data (millimeters per day) was more than acceptable for our second objective because we averaged this value over the winter season.

However, there were a few factors that limited the spatial extent. We were bounded by the availability of producer-reported ground truth points of fields that certainly had cover crops. Because we were manually identifying points for NDVI calculation, we had to restrict the scale of our study area due to time constraints of the term; therefore, we worked with our partner to concentrate on the Northwest SET of Alabama. The process of randomly generating points and calculating an NDVI threshold would have to be repeated for other regions of Alabama, because there are likely differences in NDVI thresholds across the state. In the future, our partner would like to repeat the methodology for other SET regions of Alabama. Alabama Drought Reach should consider creating a reliable database of ground-truth points that identify farms where cover crops are used to greatly improve the accuracy of the NDVI threshold calculation and allow for increased scalability.

Despite this, Alabama Drought Reach can use the results from this project to assess economic and environmental impacts of increased water retention during drought periods. All Earth observations, ancillary data, and software used in this project, are publicly available apart from Planet Explorer. Alabama Drought Reach could substitute the need for high resolution satellite imagery with ground-truth validation points. While our partner's use of remote sensing for this purpose is limited, they are familiar with ArcGIS Pro and could conceivably implement our methods to address winter and cover crop monitoring needs throughout the state of Alabama. Analyzing the winter and cover crop map and water retention package could serve as a useful tool for promoting the use of winter and cover crops. For these reasons, Alabama Drought Reach can effectively replicate this methodology and explore these results to support their mission of prioritizing research in mitigation and strategic planning for drought.

6. Acknowledgements

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7. Glossary

Cash crop – a crop produced for its commercial value rather than for use by the grower
Cover crop – a single species or a mix of grasses, legumes, or forbs grown primarily to provide seasonal cover and related benefits
Cropland Data Layer – an annual raster, geo-referenced, crop-specific land cover data layer produced by the USDA National Agricultural Statistics Service
Curve Number (CN) – a hydrological parameter ranging from 30 to 100 for predicting runoff due to rainfall, where a lower curve number indicates more permeable soil
Earth observations – satellites and sensors that collect information about the Earth's physical, chemical, and biological systems over space and time
GPM – Global Precipitation Measurement
IMERG – Integrated Multi-satellite Retrievals for Global Precipitation Measurement

NDVI – Normalized Difference Vegetation Index, a widely used metric for quantifying the health and density of vegetation using sensor data calculated using Red and Near-Infrared data
Northwest Strategic Extension Team (SET) – an Alabama Extension administrative region with similar environmental qualities and agricultural activities; includes the counties of Colbert, Fayette, Franklin, Marion, Morgan, Lamar, Lauderdale, Lawrence, Limestone, Walker, and Winston
OLI – Operational Land Imager
Row crop – a crop that can be planted in rows wide enough to allow it to be tilled or cultivated by agricultural machinery (examples include corn, cotton, sorghum, soybeans, potato, and sunflower)
Runoff (Q) – the water draining away from the surface of an area of land
Spatial Resolution – the dimensions of the area on the ground represented by a single cell in a raster or pixel in an image; the size of a pixel, or its spatial resolution, affects the level of detail represented in an image
Temporal Resolution – the frequency or rate at which images are captured over the same geographic location
TM – Thematic Mapper
Water Retention (F) – water content in soil after runoff begins
Winter crop – a crop fall-sown for growth during the winter, maturing in the spring, and harvested for sale

8. References

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9. Appendices

Appendix A: *Additional Statistical Results*

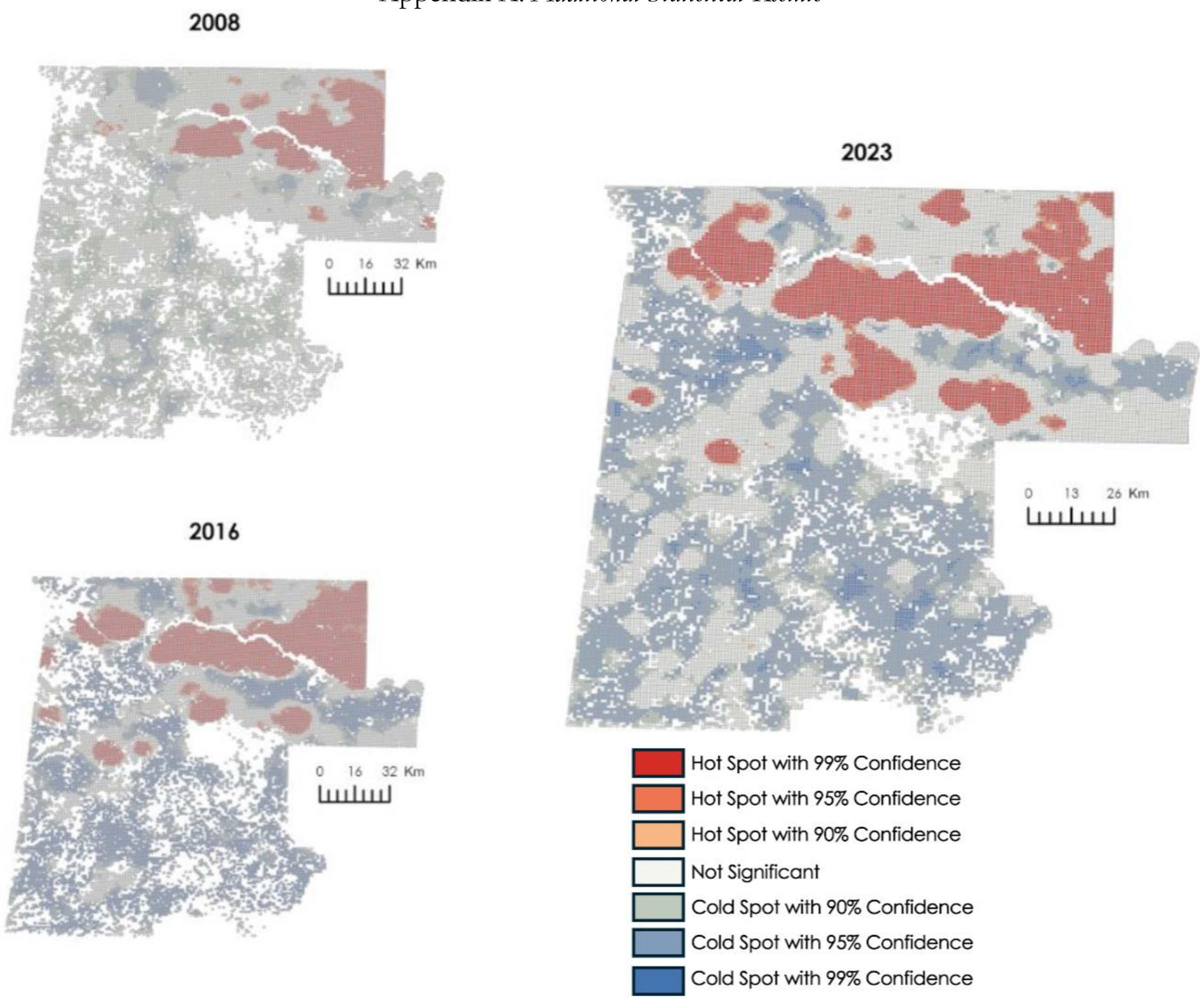

Figure A1. A hotspot analysis of areas with high winter and cover crop adoption displayed on a 1 km grid.

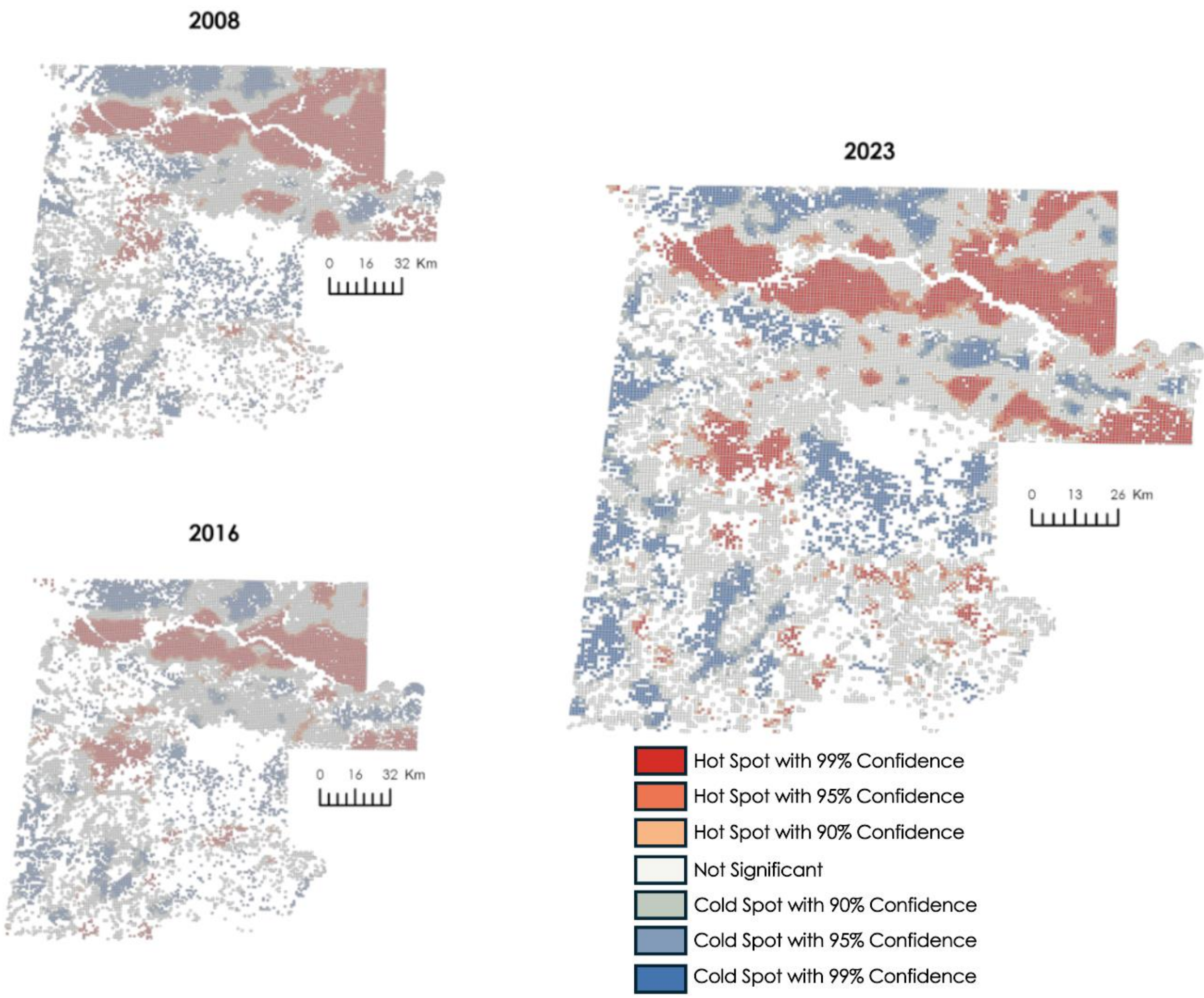

Figure A2. A hotspot analysis of areas retaining high amounts of water displayed on a 1 km grid.

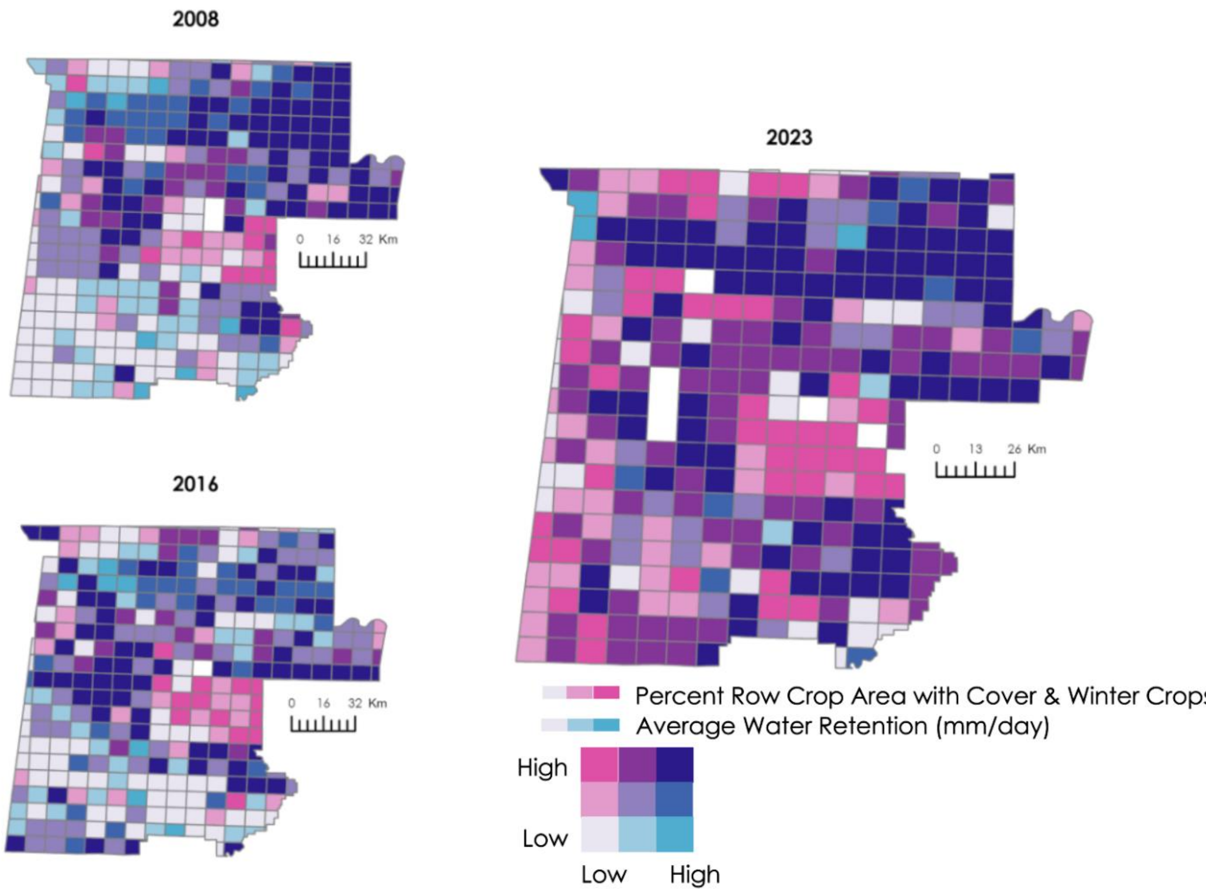

Figure A3. Bivariate analysis of percentage winter and cover crop adoption and average water retention displayed on a 10 km grid.