LEAF AREA INDEX (LAI) MAP CREATION EXERCISE REPORT

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INTRODUCTION

Leaf Area Index (LAI) serves as a crucial biophysical parameter for crop analysis, facilitating the detection of water stress, biomass estimation, and identification of crop growth stages. While remote sensing methods are effective for early growth stages, they often encounter challenges during reproductive stages due to canopy closure. This report presents an exploration of two methods for estimating LAI in maize crops utilizing top-of-canopy RGB images collected via a hexacopter throughout the growing season. First method uses R programming and the second uses QGIS to process data related to leaf area index (LAI), vegetation leaf area density function (VLADF), green canopy cover (GCC), and crop height at different time points (21 Nov 2018, 12 Dec 2018, 7 Jan 2019, and 25 Jan 2019) for a crop field.

METHODOLOGY

The research employed two distinct approaches for LAI estimation:

Empirical Approach: The method utilized RGB images to estimate canopy height, green-canopy cover, and a 'vertical leaf area distribution factor' (VLADF) derived from allometric relations (utilizing crop height from RGB images and days after sowing). The empirical model trained a linear function with these inputs against Licor canopy analyzer LAI values. This approach yielded promising results during the Rabi (post-monsoon) seasons of 2018–19 and 2019–20, exhibiting R^2 values of 0.84 and 0.77, and RMSE values of 0.36 and 0.45 respectively, when compared with Licor LAI values. However, its accuracy significantly dropped (R^2 of 0.56 and RMSE of 1.34) when evaluated against true LAI values obtained from manual leaf area measurements.

Refined Conceptual Model: In response to the limitations of the empirical approach, a refined model was developed. This model incorporated VLADF, green-canopy cover estimates from RGB images, and field-measured top leaf angle. The output from this conceptual model demonstrated improved performance, achieving an R^2 of approximately 0.6 and RMSE of 0.73 when compared against true LAI values. Notably, this model remained unaffected by canopy closure during the reproductive stage of the crop.

IMPLEMENTATION IN R AND QGIS

The implementation of these methods involved the utilization of R for data preprocessing, statistical analysis, and model training. QGIS was employed for spatial analysis and visualization of the derived LAI maps. The RGB images collected via drones were processed to extract relevant parameters such as canopy height, green-canopy cover, and VLADF. These parameters were then utilized in the development and validation of the empirical and conceptual models for LAI estimation.

R programming: The code written in R and is focused on analyzing and visualizing data related to leaf area index (LAI), vegetation leaf area density function (VLADF), green canopy cover (GCC), and crop height at different time points (21 Nov 2018, 12 Dec 2018, 7 Jan 2019, and 25 Jan 2019) for a crop field. Here's a summary of the code:

Setup and Data Loading

- The code starts by setting the working directory and loading various required packages for spatial data analysis, plotting, and data manipulation.
- It defines several helper functions for reading and processing shapefile data, performing spatial intersections, adding lookup table data, and calculating LAI values.
- A lookup table (LookupTable.xlsx) is loaded, containing information about leaf angle, VLADF, and days after sowing (DAS) for different crop heights.

Data Processing

- For each of the four time points (21 Nov 2018, 12 Dec 2018, 7 Jan 2019, and 25 Jan 2019), the code reads three shapefiles containing information about canopy cover, DAS, and crop height.
- These shapefiles are intersected using the func.intersect function, and the resulting spatial object is enriched with data from the lookup table using the func.lookup function.
- The LAI values are calculated for each spatial object using the func.lai function, which considers VLADF, leaf angle, and canopy cover.
- The mean LAI values for each time point are calculated.

Visualization and Analysis

- Box plots and violin plots are generated for LAI, VLADF, GCC, and crop height, allowing for visual comparison of their distributions across the different time points.
- Histograms and spatial maps are created to visualize the distribution and spatial patterns of LAI for each time point.
- Correlation matrices are computed and visualized as heatmaps for each time point, showing the relationships between VLADF, leaf angle, LAI, and crop height.
- A Hovmöller plot is generated to visualize the spatial and temporal patterns of LAI.

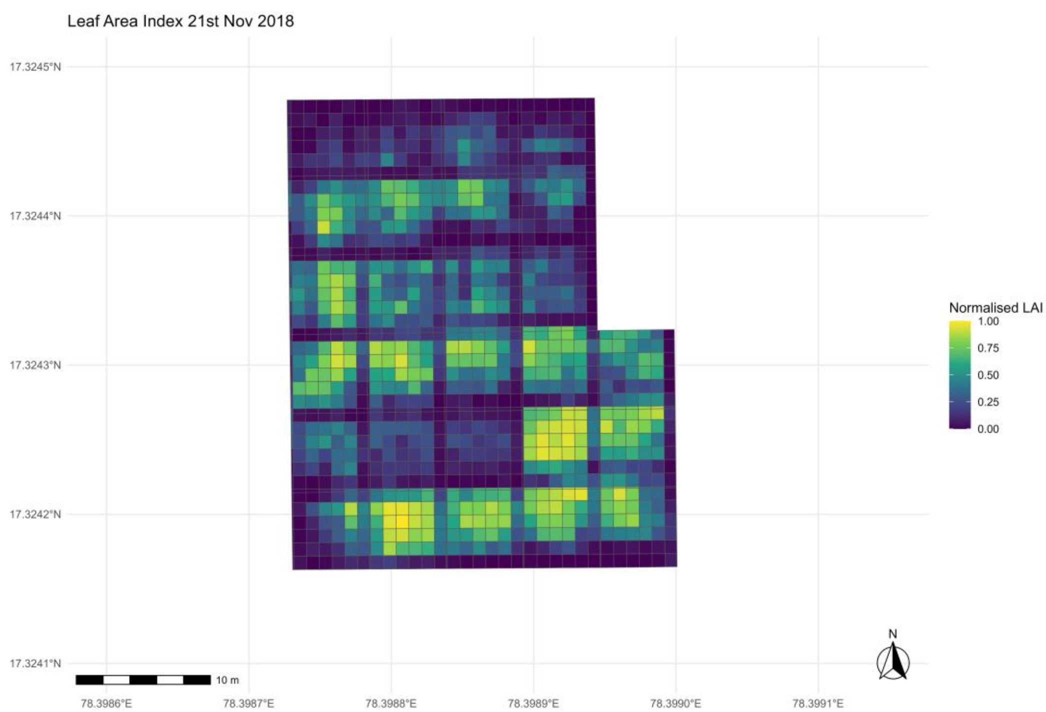
- Individual plot performance is assessed by calculating the mean LAI for each plot and visualizing it using bar plots and stacked bar plots.
- A map is created with plot IDs labeled for the 7 Jan 2019 time point.

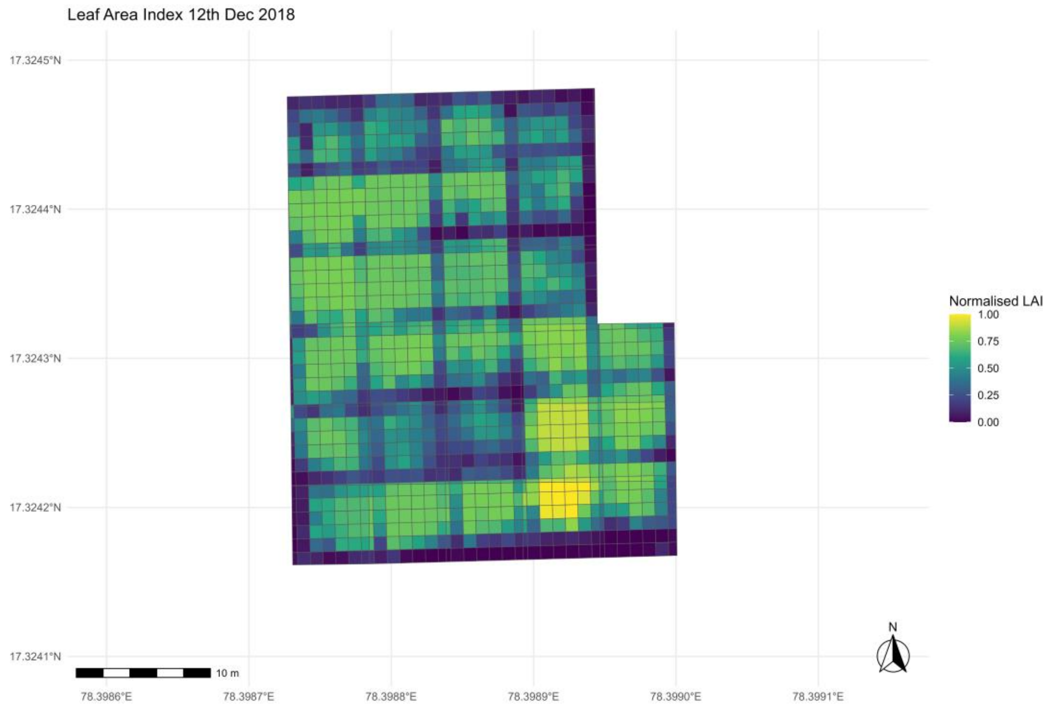
Helper Functions

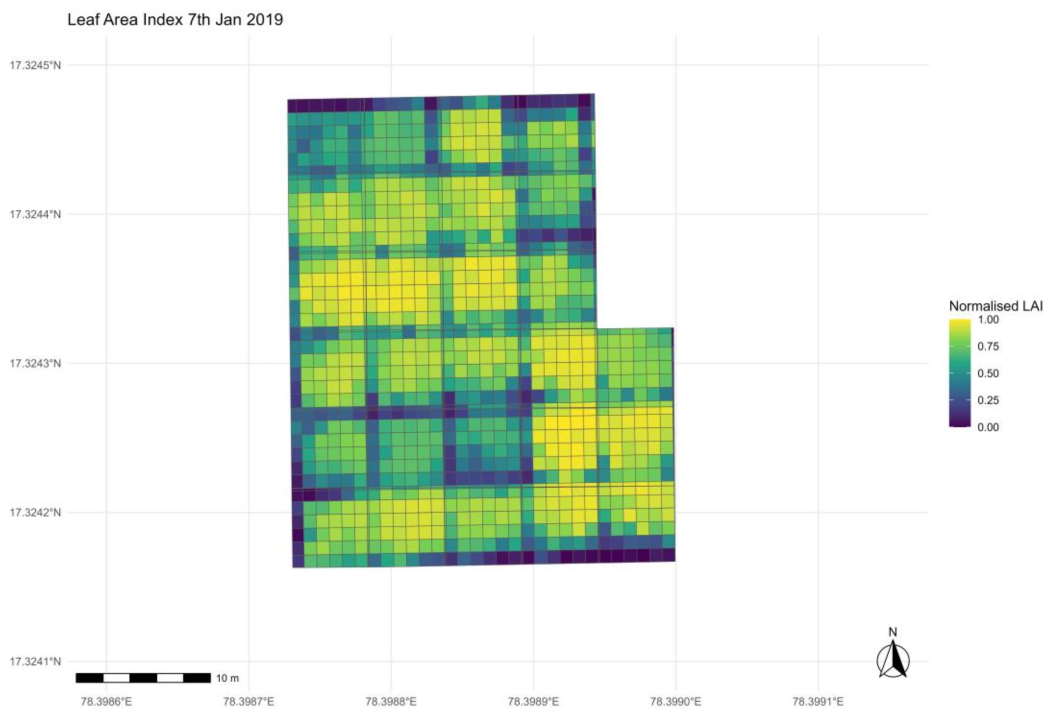
Several helper functions are defined for tasks such as saving plots in A4 format, creating histogram plots, generating spatial maps, and computing correlation matrices and heatmaps.

Overall, this code performs a comprehensive analysis of spatial and temporal patterns in LAI, VLADF, GCC, and crop height, using a combination of data processing, visualization, and statistical techniques. The analysis aims to understand the relationships between these variables and their dynamics over time, potentially aiding in crop monitoring and management.

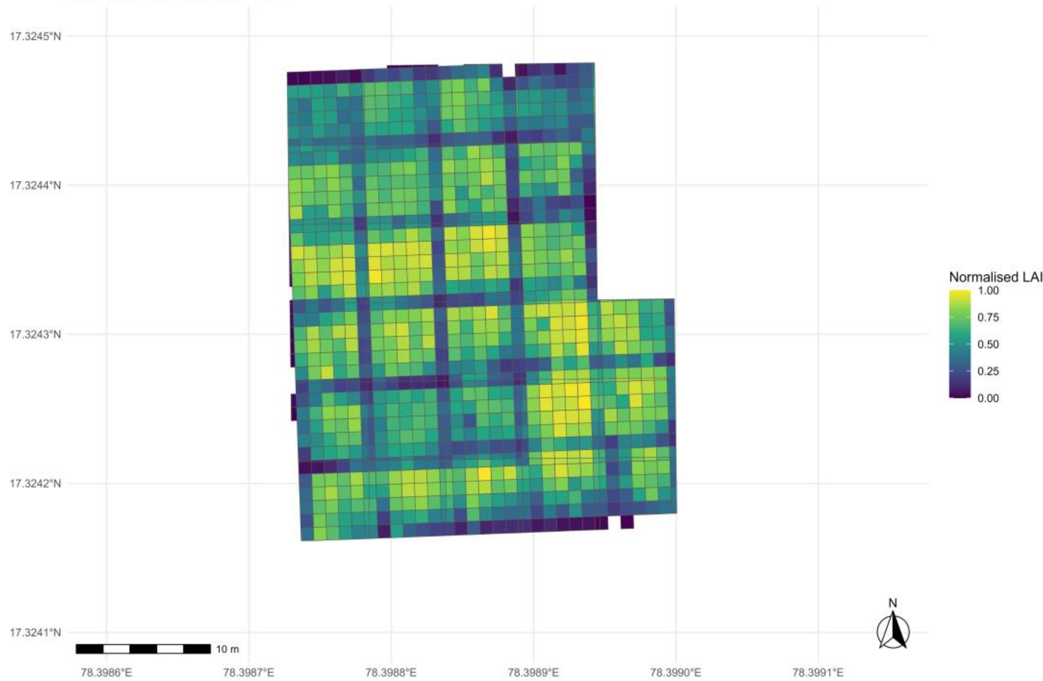
Results of R programming for LAI Mapping



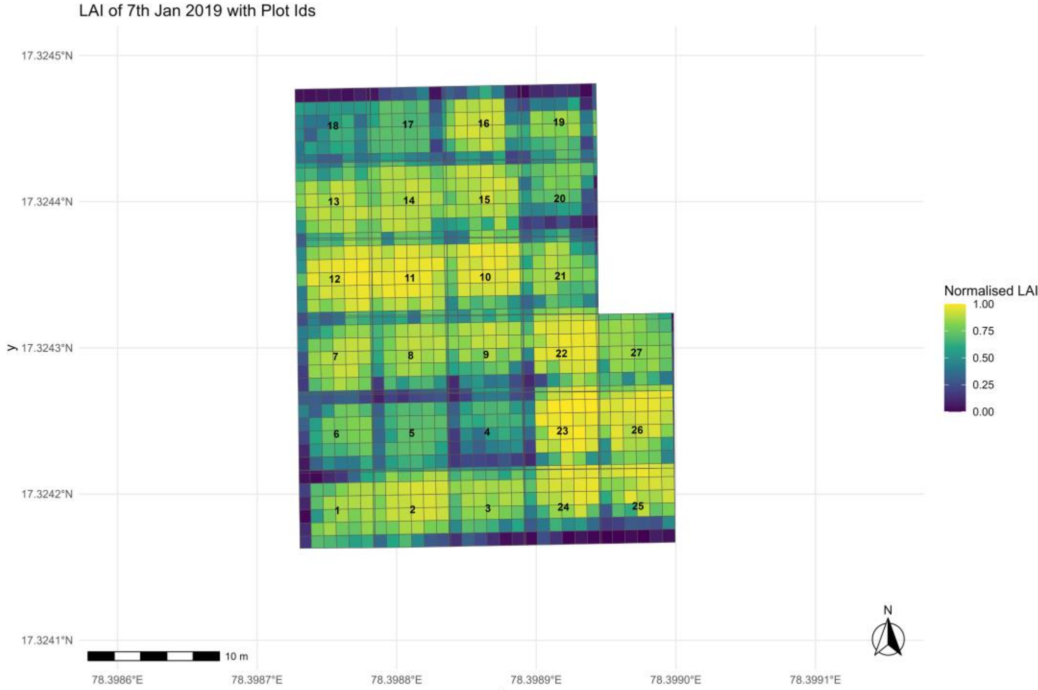

Leaf Area Index 12th Dec 2018
17.3245°N
17.3244°N
17.3243°N
17.3242°N
17.3241°N
78.3986°E
78.3987°E
78.3988°E
78.3989°E
78.3990°E
78.3991°E
10 m
N
Normalised LAI
1.00
0.75
0.50
0.25
0.00

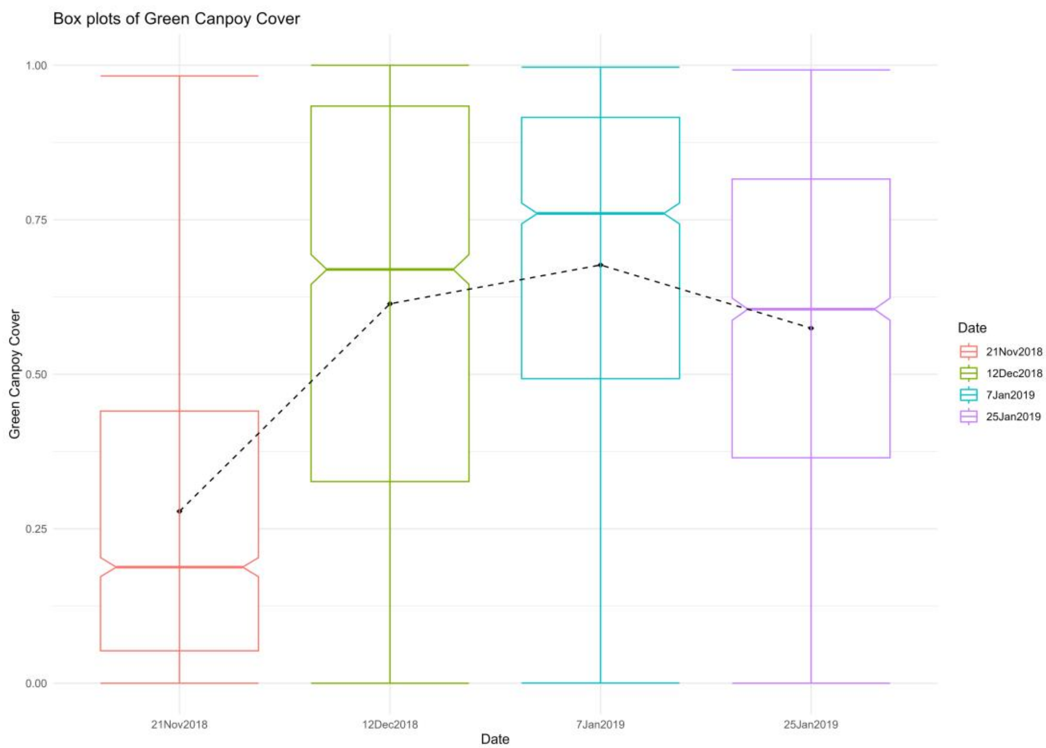

Leaf Area Index 7th Jan 2019
17.3245°N
17.3244°N
17.3243°N
17.3242°N
17.3241°N
78.3986°E
78.3987°E
78.3988°E
78.3989°E
78.3990°E
78.3991°E
10 m
N
Normalised LAI
1.00
0.75
0.50
0.25
0.00

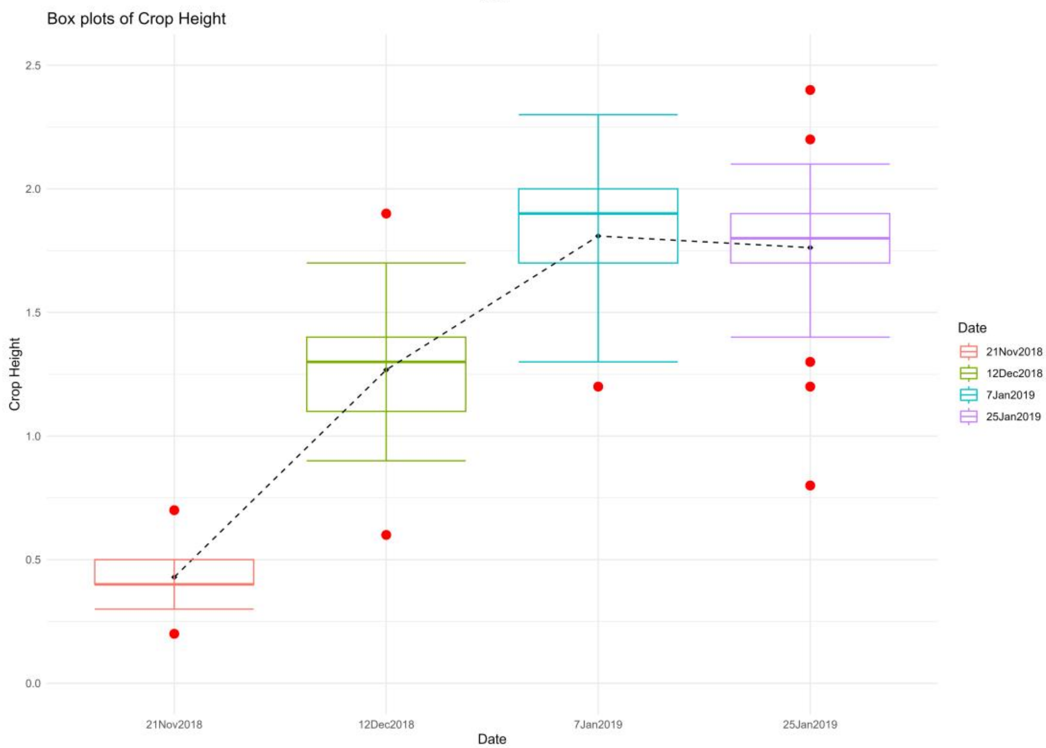
Leaf Area Index 25th Jan 2019

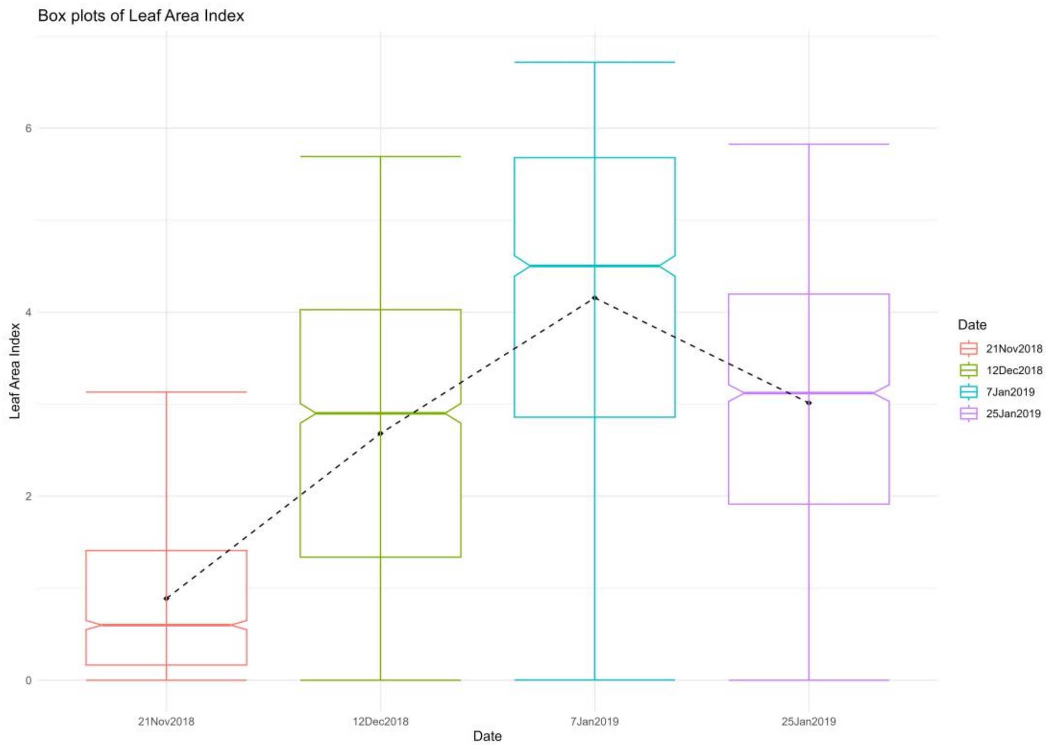


LAI of 7th Jan 2019 with Plot Ids

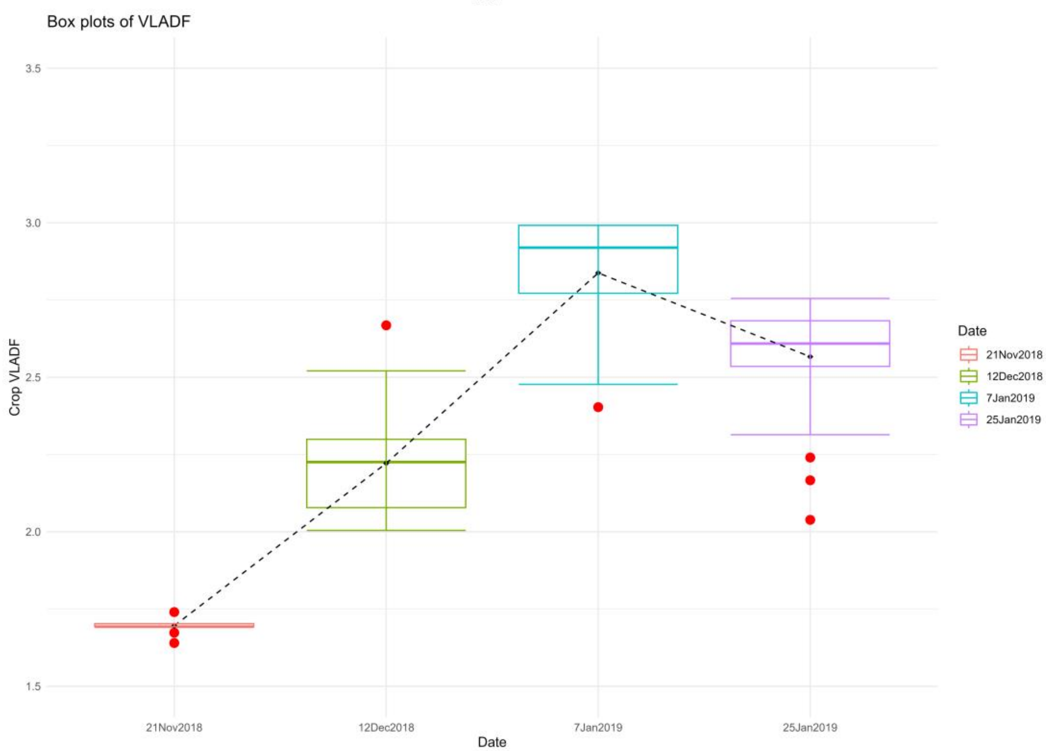



Box plots of Green Canpoy Cover
Green Canpoy Cover
1.00
0.75
0.50
0.25
0.00
21Nov2018
12Dec2018
7Jan2019
25Jan2019
Date
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019

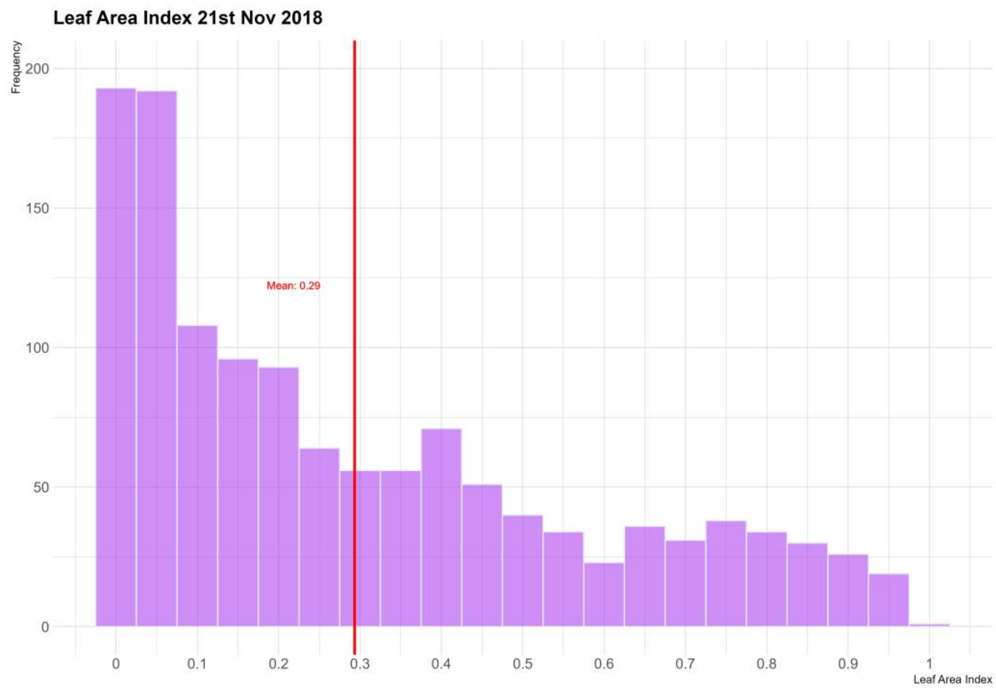

Box plots of Crop Height
Crop Height
2.5
2.0
1.5
1.0
0.5
0.0
21Nov2018
12Dec2018
7Jan2019
25Jan2019
Date
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019

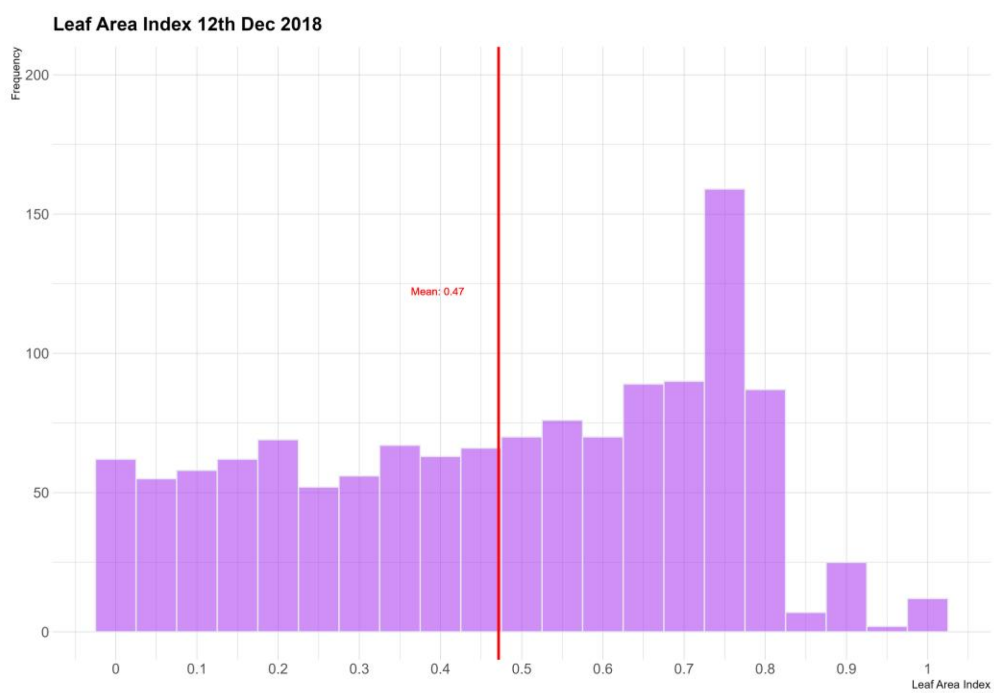


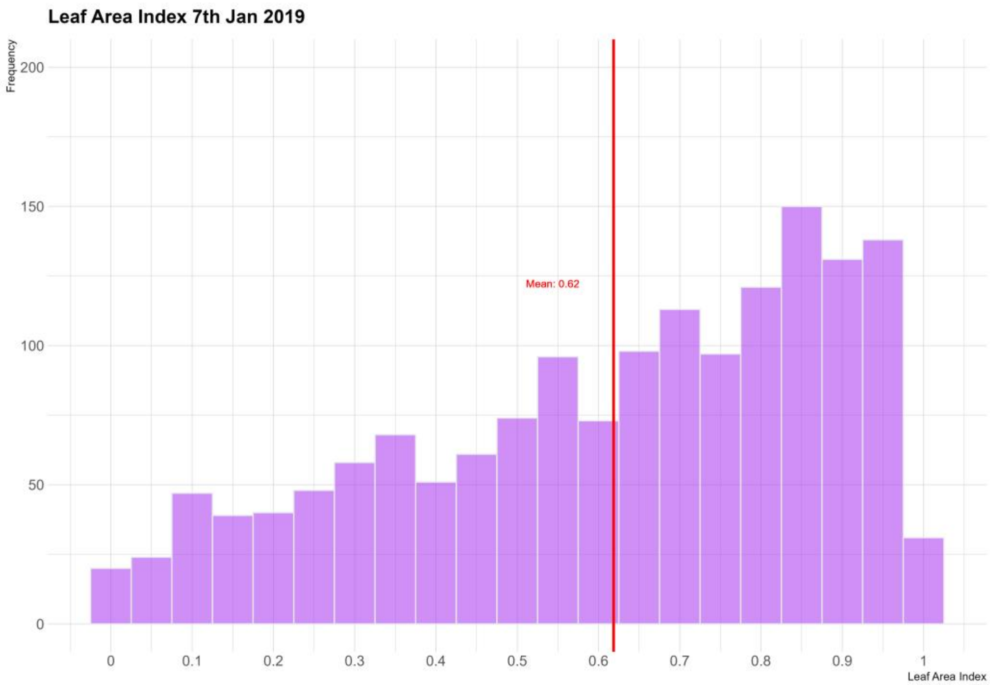
Box plots of Leaf Area Index
Leaf Area Index
0
2
4
6
21Nov2018
12Dec2018
7Jan2019
25Jan2019
Date
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019



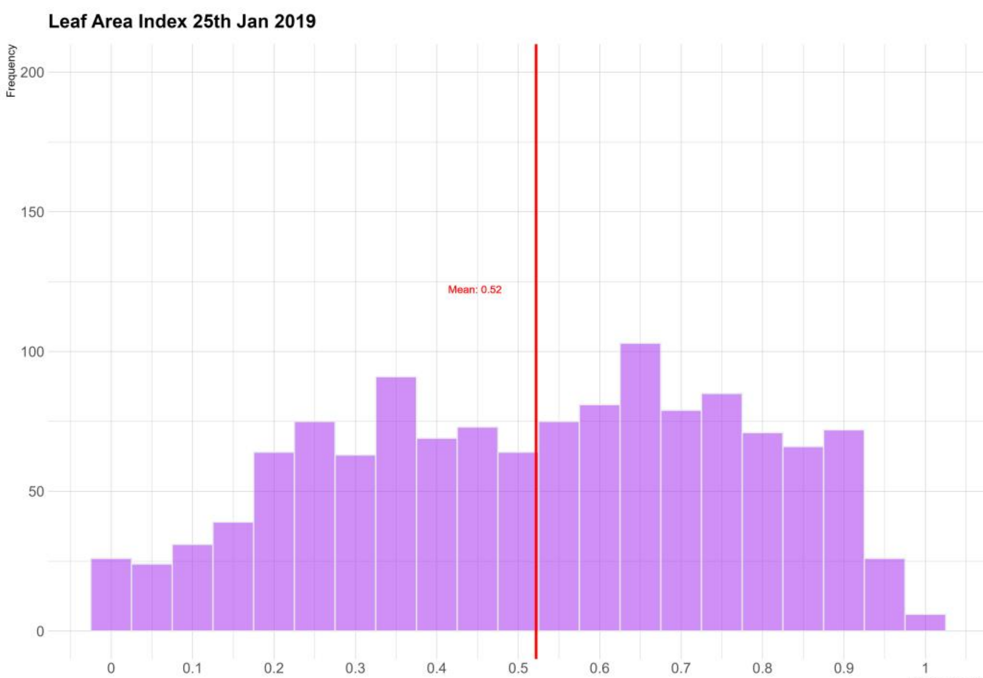
Box plots of VLADF
Crop VLADF
1.5
2.0
2.5
3.0
3.5
21Nov2018
12Dec2018
7Jan2019
25Jan2019
Date
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019


Leaf Area Index 21st Nov 2018
Frequency
200
150
100
50
0
Mean: 0.29
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Leaf Area Index

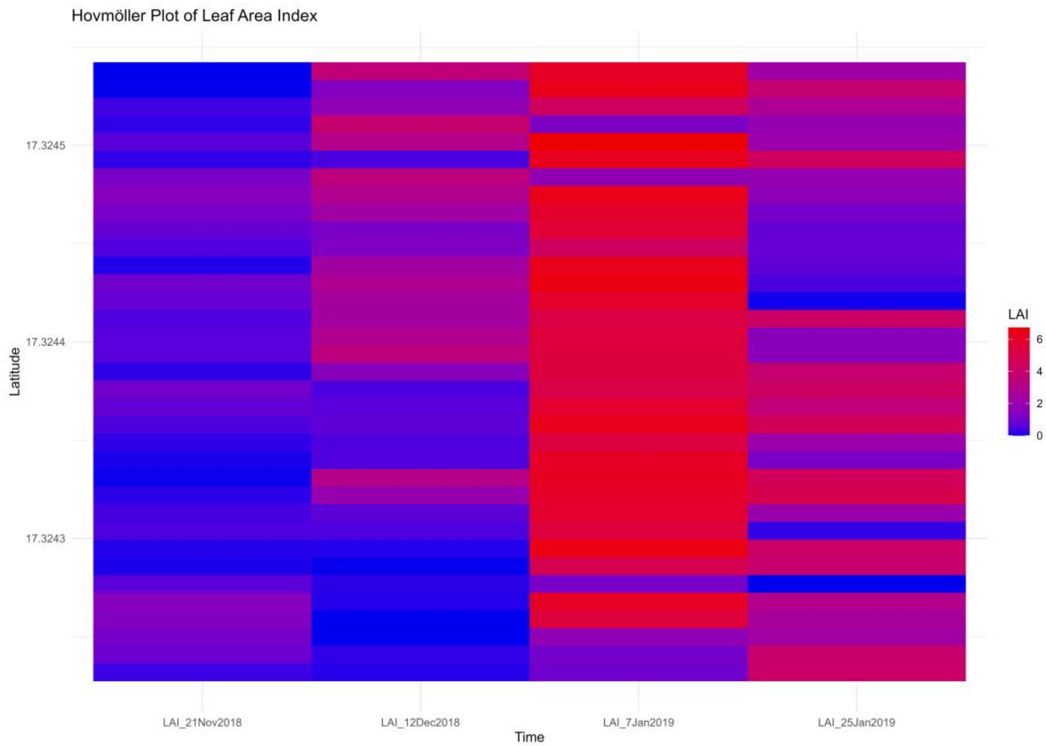

Leaf Area Index 12th Dec 2018
Frequency
200
150
100
50
0
Mean: 0.47
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Leaf Area Index

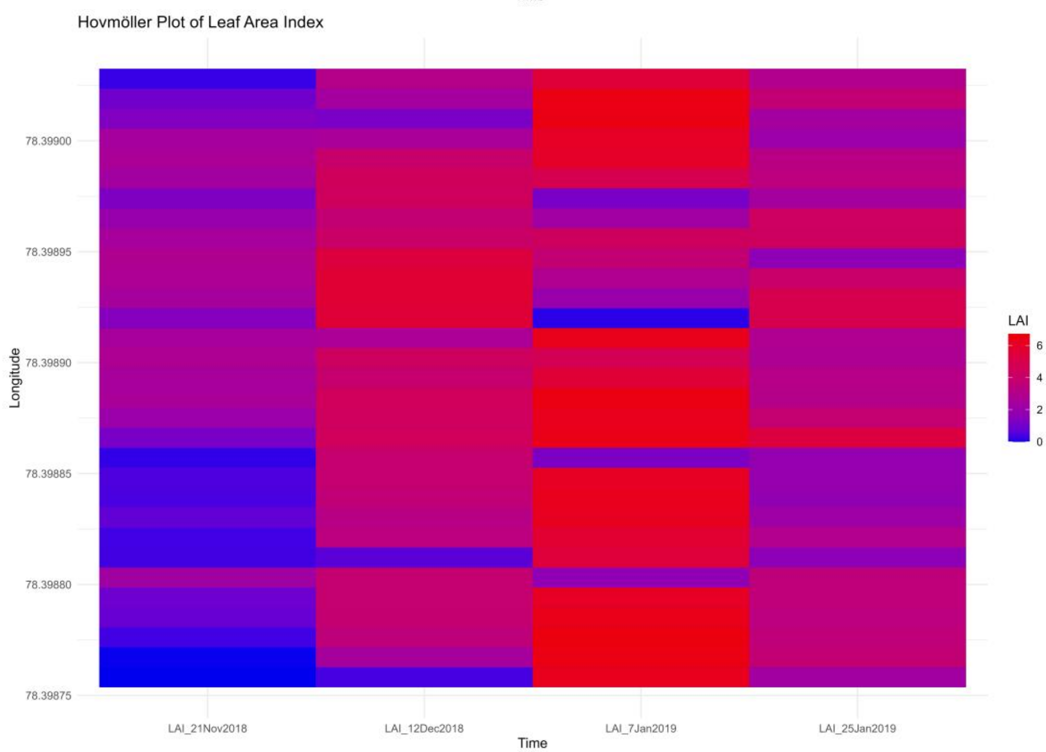


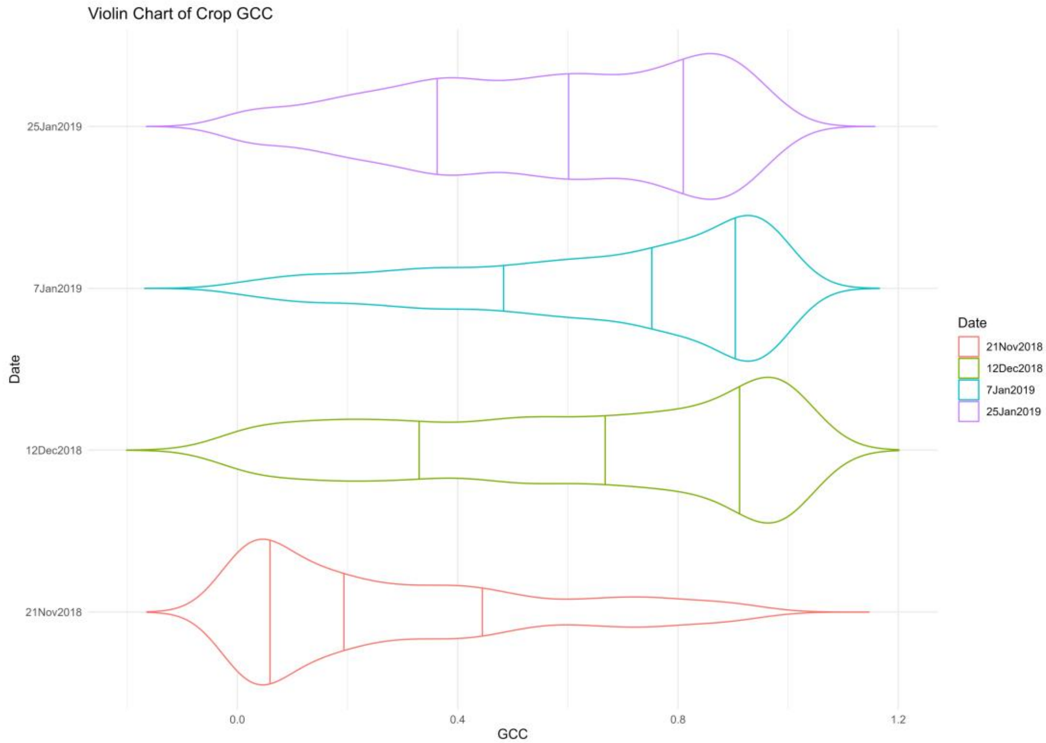
Leaf Area Index 7th Jan 2019
Frequency
200
150
100
50
0
Mean: 0.62
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Leaf Area Index

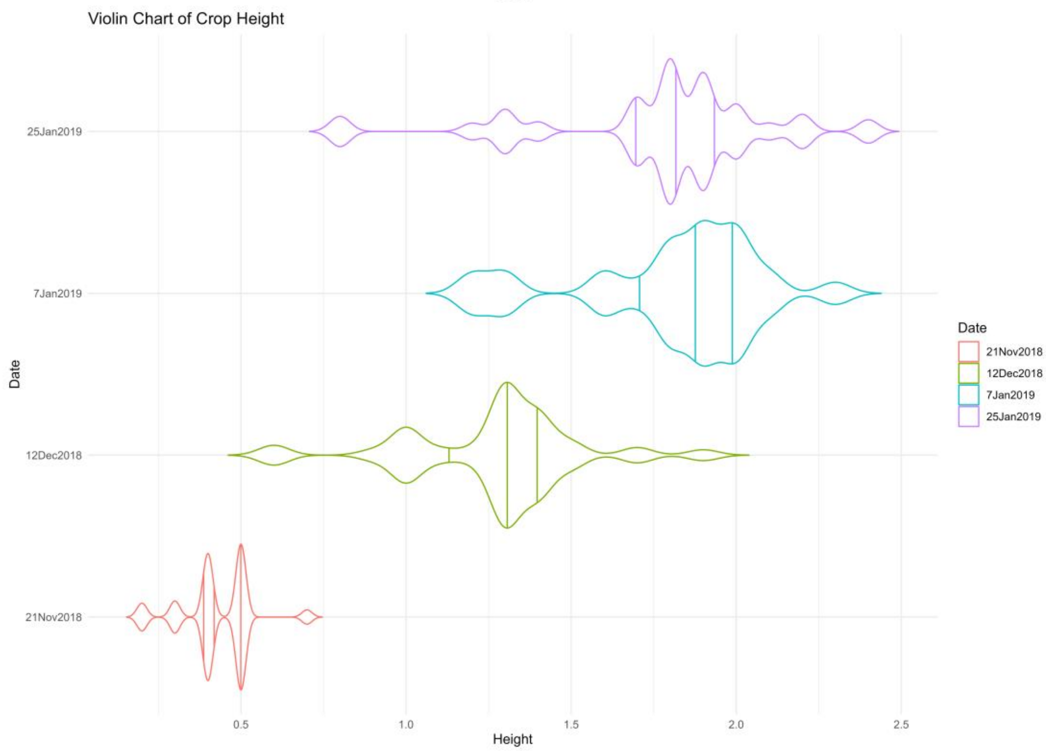


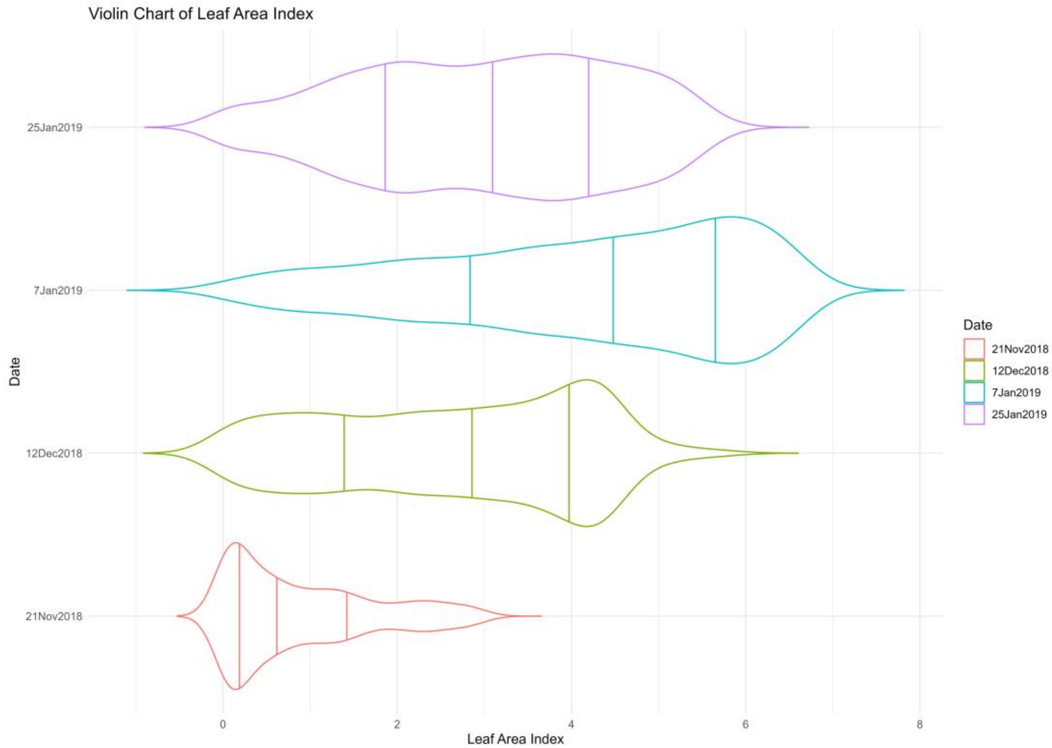
Leaf Area Index 25th Jan 2019
Frequency
200
150
100
50
0
Mean: 0.52
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Leaf Area Index


Hovmöller Plot of Leaf Area Index
17.3245
17.3244
17.3243
Latitude
LAI
6
4
2
0
LAI_21Nov2018
LAI_12Dec2018
LAI_7Jan2019
LAI_25Jan2019
Time

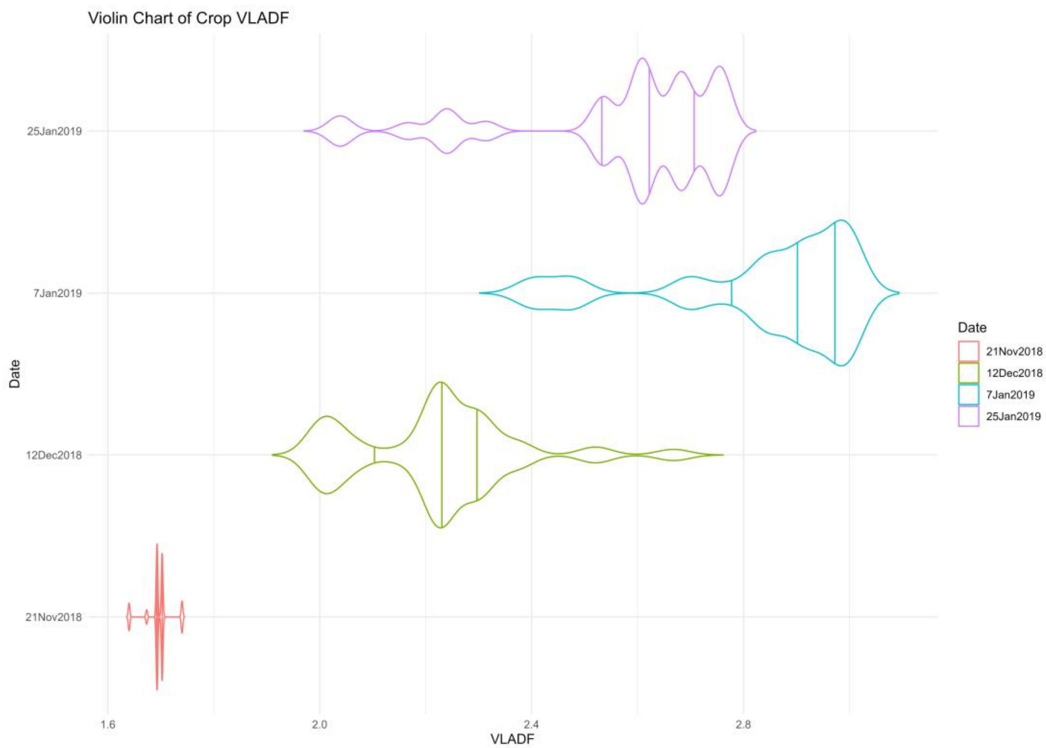

Hovmöller Plot of Leaf Area Index
78.39900
78.39895
78.39890
78.39885
78.39880
78.39875
Longitude
LAI
6
4
2
0
LAI_21Nov2018
LAI_12Dec2018
LAI_7Jan2019
LAI_25Jan2019
Time


Violin Chart of Crop GCC
25Jan2019
7Jan2019
12Dec2018
21Nov2018
Date
0.0
0.4
0.8
1.2
GCC
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019

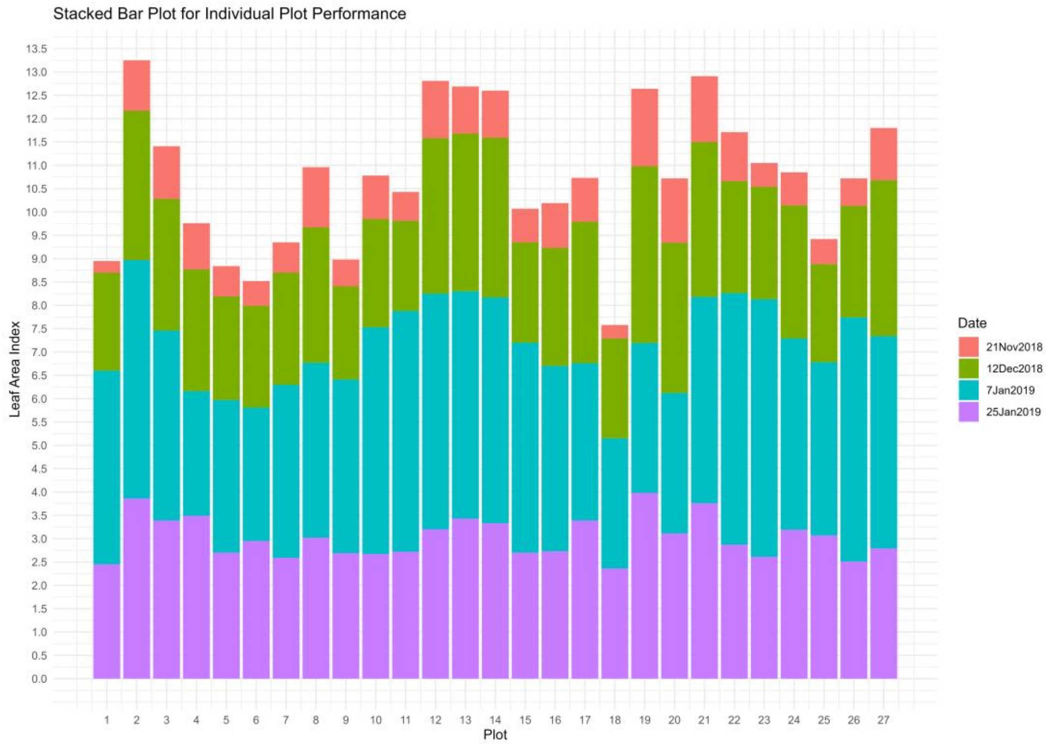

Violin Chart of Crop Height
25Jan2019
7Jan2019
12Dec2018
21Nov2018
Date
0.5
1.0
1.5
2.0
2.5
Height
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019



Violin Chart of Leaf Area Index
25Jan2019
7Jan2019
12Dec2018
21Nov2018
Date
0
2
4
6
8
Leaf Area Index
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019



Violin Chart of Crop VLADF
25Jan2019
7Jan2019
12Dec2018
21Nov2018
Date
1.6
2.0
2.4
2.8
VLADF
Date
21Nov2018
12Dec2018
7Jan2019
25Jan2019



Result

The overall trend is -

7 Jan 2019 is the most vigorous day for the crops.

21 Nov 2018 is the least vigorous day for the crops.

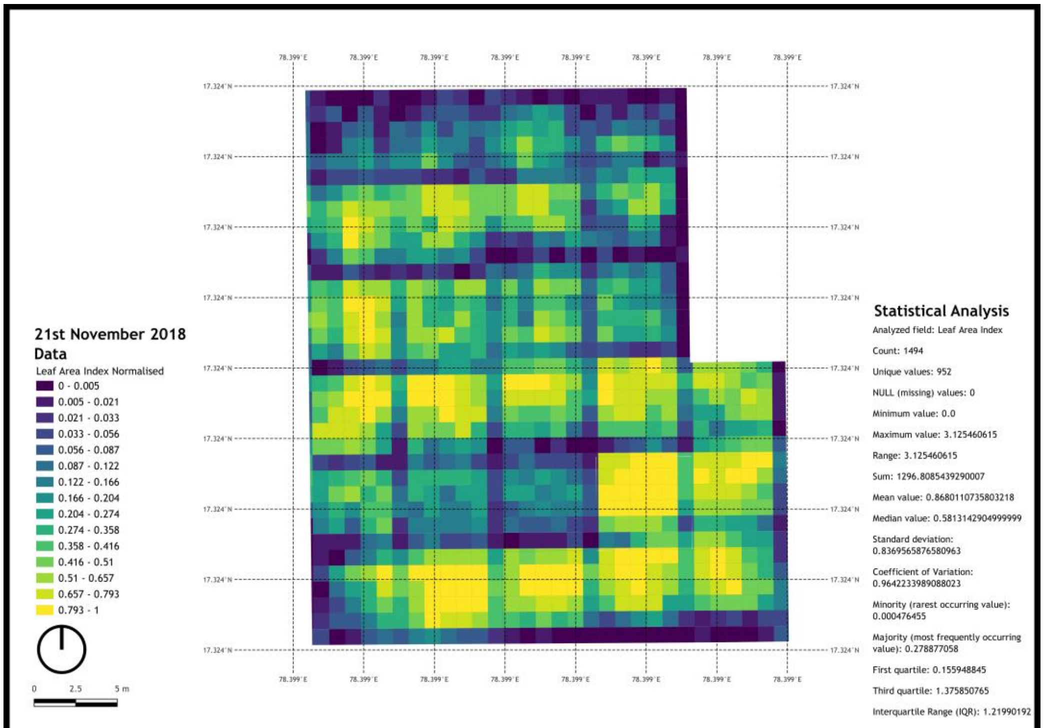
The activity increases till 7 Jan 2019 later falling

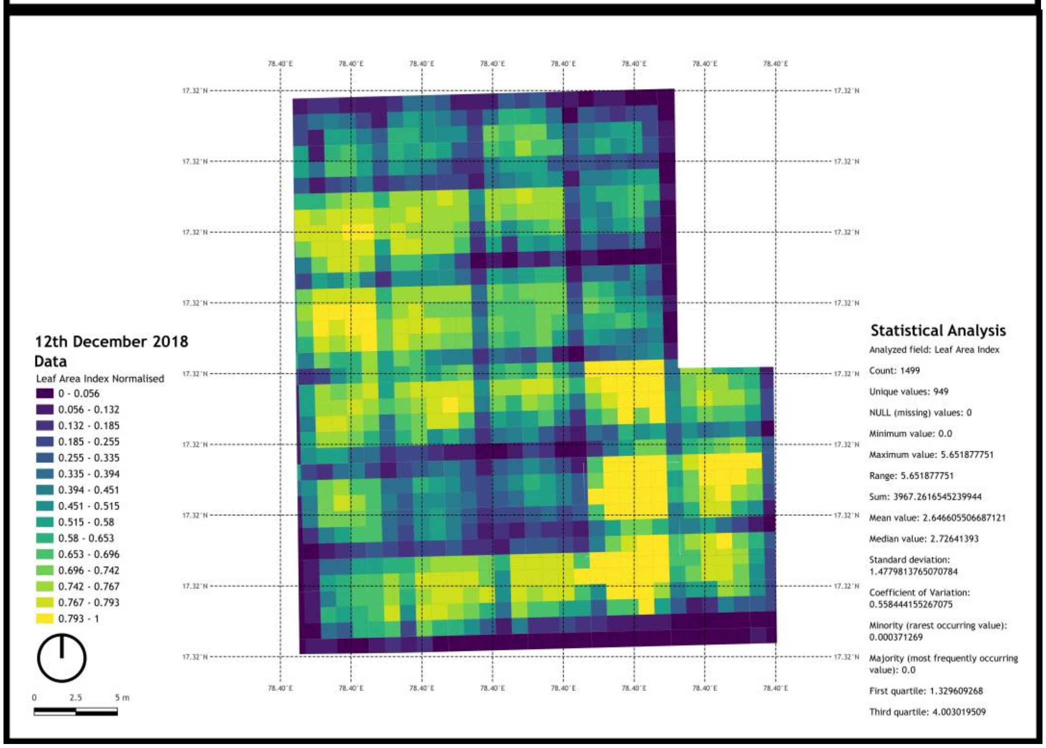
For individual plots -

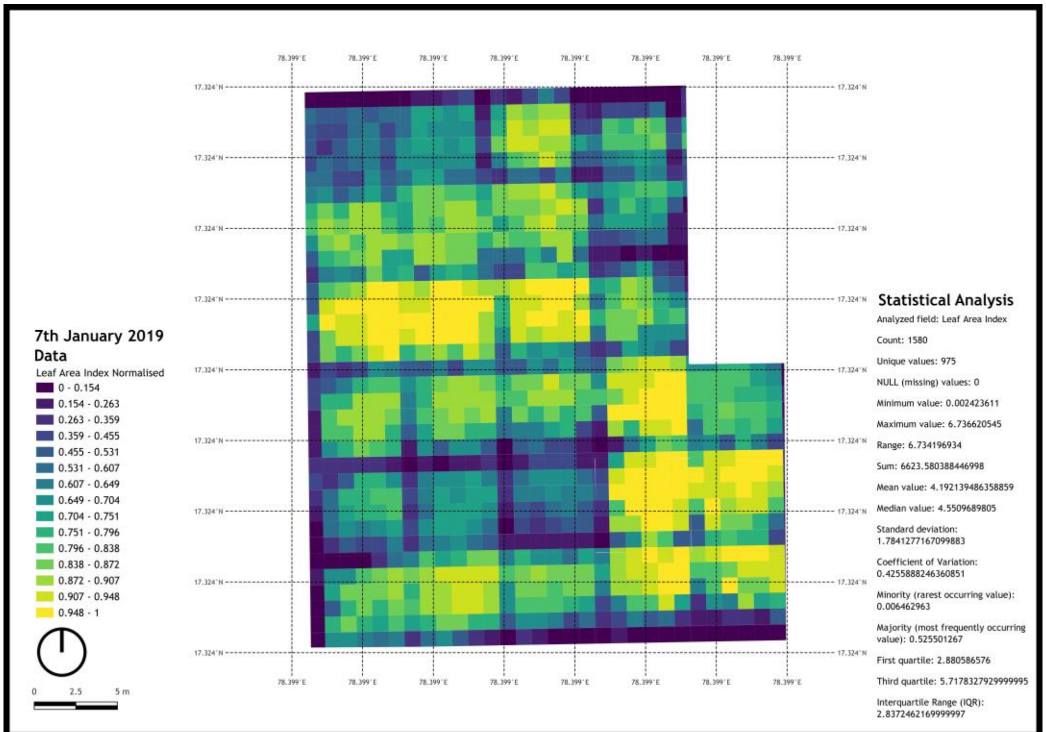
Overall plots 2, 12, 13, 19, and 21 are the most productive as their cumulative LAI for the is over 12.

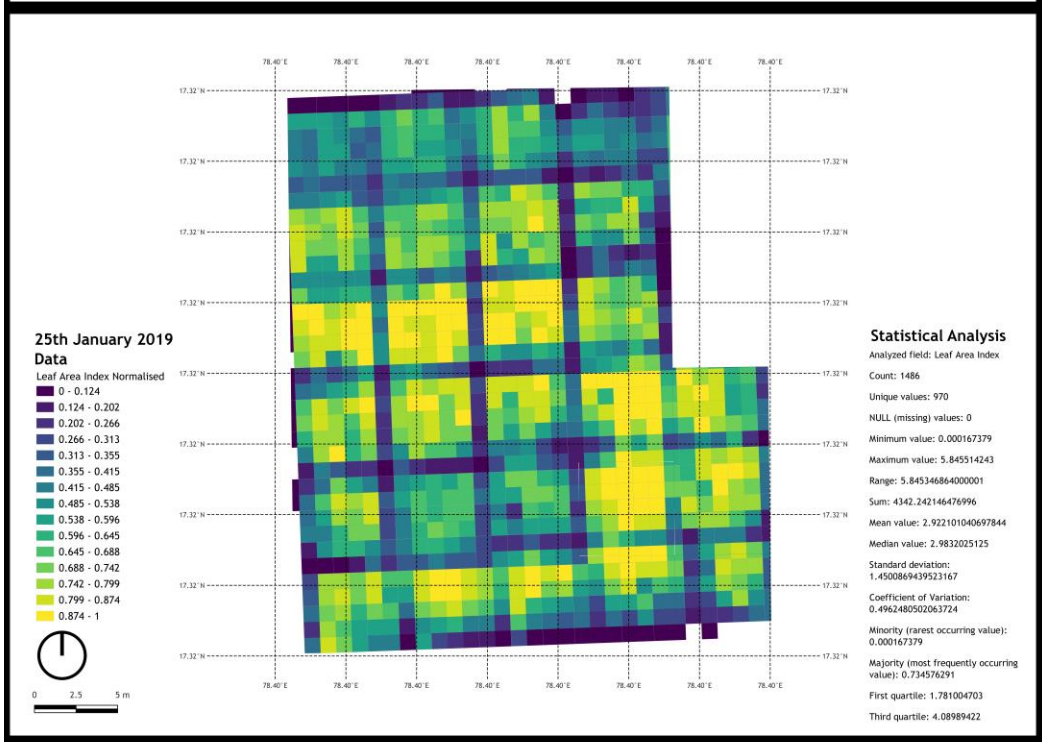
Overall plot 18 is the least productive.

Results of QGIS LAI Mapping


78.399°E
17.324°N
21st November 2018
Data
Leaf Area Index Normalised
0 - 0.005
0.005 - 0.021
0.021 - 0.033
0.033 - 0.056
0.056 - 0.087
0.087 - 0.122
0.122 - 0.166
0.166 - 0.204
0.204 - 0.274
0.274 - 0.358
0.358 - 0.416
0.416 - 0.51
0.51 - 0.657
0.657 - 0.793
0.793 - 1
0
2.5
5 m
Statistical Analysis
Analyzed field: Leaf Area Index
Count: 1494
Unique values: 952
NULL (missing) values: 0
Minimum value: 0.0
Maximum value: 3.125460615
Range: 3.125460615
Sum: 1296.8085439290007
Mean value: 0.8680110735803218
Median value: 0.5813142904999999
Standard deviation: 0.8369565876580963
Coefficient of Variation: 0.9642233989088023
Minority (rarest occurring value): 0.000476455
Majority (most frequently occurring value): 0.278877058
First quartile: 0.155948845
Third quartile: 1.375850765
Interquartile Range (IQR): 1.21990192


78.40°E
17.32°N
12th December 2018
Data
Leaf Area Index Normalised
0 - 0.056
0.056 - 0.132
0.132 - 0.185
0.185 - 0.255
0.255 - 0.335
0.335 - 0.394
0.394 - 0.451
0.451 - 0.515
0.515 - 0.58
0.58 - 0.653
0.653 - 0.696
0.696 - 0.742
0.742 - 0.767
0.767 - 0.793
0.793 - 1
0
2.5
5 m
Statistical Analysis
Analyzed field: Leaf Area Index
Count: 1499
Unique values: 949
NULL (missing) values: 0
Minimum value: 0.0
Maximum value: 5.651877751
Range: 5.651877751
Sum: 3967.2616545239944
Mean value: 2.646605506687121
Median value: 2.72641393
Standard deviation: 1.4779813765070784
Coefficient of Variation: 0.558444155267075
Minority (rarest occurring value): 0.000371269
Majority (most frequently occurring value): 0.0
First quartile: 1.329609268
Third quartile: 4.003019509


7th January 2019
Data
Leaf Area Index Normalised
0 - 0.154
0.154 - 0.263
0.263 - 0.359
0.359 - 0.455
0.455 - 0.531
0.531 - 0.607
0.607 - 0.649
0.649 - 0.704
0.704 - 0.751
0.751 - 0.796
0.796 - 0.838
0.838 - 0.872
0.872 - 0.907
0.907 - 0.948
0.948 - 1
0 2.5 5 m
Statistical Analysis
Analyzed field: Leaf Area Index
Count: 1580
Unique values: 975
NULL (missing) values: 0
Minimum value: 0.002423611
Maximum value: 6.736620545
Range: 6.734196934
Sum: 6623.580388446998
Mean value: 4.192139486358859
Median value: 4.5509689805
Standard deviation: 1.7841277167099883
Coefficient of Variation: 0.4255888246360851
Minority (rarest occurring value): 0.006462963
Majority (most frequently occurring value): 0.525501267
First quartile: 2.880586576
Third quartile: 5.7178327929999995
Interquartile Range (IQR): 2.8372462169999997


25th January 2019
Data
Leaf Area Index Normalised
0 - 0.124
0.124 - 0.202
0.202 - 0.266
0.266 - 0.313
0.313 - 0.355
0.355 - 0.415
0.415 - 0.485
0.485 - 0.538
0.538 - 0.596
0.596 - 0.645
0.645 - 0.688
0.688 - 0.742
0.742 - 0.799
0.799 - 0.874
0.874 - 1
0 2.5 5 m
Statistical Analysis
Analyzed field: Leaf Area Index
Count: 1486
Unique values: 970
NULL (missing) values: 0
Minimum value: 0.000167379
Maximum value: 5.845514243
Range: 5.845346864000001
Sum: 4342.242146476996
Mean value: 2.922101040697844
Median value: 2.9832025125
Standard deviation: 1.4500869439523167
Coefficient of Variation: 0.4962480502063724
Minority (rarest occurring value): 0.000167379
Majority (most frequently occurring value): 0.734576291
First quartile: 1.781004703
Third quartile: 4.08989422

IMPLEMENTATION IN R AND QGIS

The implementation of LAI mapping methods involved the utilization of R for data preprocessing, statistical analysis, and model training. QGIS was employed for spatial analysis and visualization of the derived LAI maps. The RGB images collected via drones were processed to extract relevant parameters such as canopy height, green-canopy cover, and VLADF. These parameters were then utilized in the development and validation of the empirical and conceptual models for LAI estimation.

CONCLUSION

In conclusion, this study highlights the challenges associated with LAI estimation in maize crops, particularly during reproductive stages. While traditional empirical methods based on remote sensing data show promise, they often suffer from inaccuracies when compared against true LAI values. The introduction of a refined conceptual model, incorporating additional parameters and field measurements, offers a viable alternative with improved accuracy and resilience to canopy closure effects. The integration of drone-based RGB imagery with advanced modeling techniques presents a valuable tool for monitoring and managing crop growth dynamics, contributing to enhanced agricultural productivity and sustainability.

REFERENCES

Raj, Rahul, Jeffrey P. Walker, Rohit Pingale, Rohit Nandan, Balaji Naik, and Adinarayana Jagarlapudi. ‘Leaf Area Index Estimation Using Top-of-Canopy Airborne RGB Images’. *International Journal of Applied Earth Observation and Geoinformation* 96 (1 April 2021): 102282. https://doi.org/10.1016/j.jag.2020.102282.