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A Normalised Difference Vegetation Index Model for Maize Crop Performance Monitoring and Cropland Area Mapping in Sudan Ecological Zone of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The monitoring and mapping of crops remotely are critical for easy identification of stressed crop, prompt response to part of the crop field that requires immediate attention and the potential harvest as well as for agricultural field management. Optical remote sensing offers one of the most attractive options for vegetation indices evaluation and some optical remote sensing data are readily available free for this application, especially, Sentinel-2A, which is equipped with a multispectral sensor (MSI), which enables calculation of some vegetation indices and assessment

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of vegetation health and status. However, serious attention has not been given to the potential of vegetation indices calculated from MSI data in the developing countries, Nigeria inclusive. Thus, the study therefore calculated the time series NDVI for the length of the growing season for the selected crops (Maize) and geometrically calculated area of the farm plot size. In this study. The study used the Normalized Difference Vegetation Index and Supervised Image classification technique for the crop health assessment and cropland area mapping for maize. The result showed the mean, standard deviation, range, minimum and maximum NDVI values for all the farm plots over the growing season from planting period to the harvesting period for the selected crop. The average NDVI value in May which marks the onset of the growing season for maize in the study area ranges from 0.044 to 0.148. In July, which represents the period of the grain filing stage ranges from 0.136 to 0.348 and in August, which is the maturity stage for harvest ranges from 0.110 to 0.450. Also, it was observed that cropland area is 194.973269 Square Km. It is therefore evident that the results of our NDVI analysis and cropland area mapping are good insights into solving national agricultural planning problems and agricultural resources allocation for effective agricultural practices for national food security. Our results showed that vegetation indices had the greatest contributions in identifying specific crop types and crop conditions during the growing season.

Keywords: Crop performance; NDVI; Sentinel-2; cropland area.

1. INTRODUCTION

The monitoring and mapping of crops remotely are critical for easy identification of stressed crop, prompt response to part of the crop field that requires immediate attention and the potential harvest as well as for agricultural field management. Optical remote sensing offers one of the most attractive options for vegetation indices evaluation and some optical remote sensing data are readily available free for this application, especially, Sentinel-2A, which is equipped with a multispectral sensor (MSI), offers some vegetation indices calculated to assess vegetation status.

A Normalised Difference Vegetation Index (NDVI) of a crop or a plant estimated regularly over the growing season periods of a crop can reveal a lot about the changes in that crop conditions [1,2,3]. In other words, we can use NDVI to evaluate plant health remotely. The Normalized Difference Vegetation Index (NDVI) measures the greenness and the density of the vegetation captured in a satellite image [4]. Healthy vegetation is characterized by a spectral reflectance curve in which the value is positive and this can be discovered by calculating the difference between two bands – visible red and near-infrared [5,6,7]. NDVI is that difference expressed as a number ranging from -1 to 1. A sudden drop in the NDVI values may be a symptom of crop health deterioration.

The value drop can also correspond to normal changes, such as the time of harvesting, which is why NDVI should be counter-checked against other available data. Correct NDVI values interpretation can help agronomists raise healthier yields, save money on fertilizers, and take a better care of the environment. The input data for NDVI are multispectral satellite Image containing Near Infrared band and Red band.

Satellite imagery, is Earth observation imagery. They are images of the Earth, collected by imaging satellites or Unmanned Ariel Vehicle (UAV) called drones, and these pictures form wide or narrow areas for observation. In Nigeria, the agency responsible for taking a wide satellite imagery area is the National Space Research and Development Agency (NASRDA). However, small-area imagery can come from UAV. The images include crops, livestock, building, water bodies, and any object on Earth. The Convolutional Neural Network (CNN) algorithm model can filter and classify these images and estimate the Area covered by each object. Similarly, the CNN algorithm focuses on crops through their chlorophyll contents and data collected through ground truthing and those for crop output for the Area under consideration.

Time series of normalized-difference-vegetation-index (NDVI), derived from the satellite data, have been used for crop yield predictions since the 1980's [1,8,9,10]. Most of the studies that related NDVI measurements to crop yield have been concentrated on staple crops such as wheat maize and rice [7,8,11]. Many researchers have also found that NDVI variables are very good at grain yield predictors. Although the inter-annual variability of NDVI (probably due to

unexpected weather conditions or disasters) can reveal crop yield fluctuations; however, remotely sensed NDVI cannot detect those human-induced factors that increased some crop yield.

1.1 Statement of Research Problem

There has been a loss of significant maize yield to pest, disease and climate as a result of a lack of accurate, timely and first-hand information about the crop condition on the farm. The manual survey is laborious and time-consuming. Remote Sensing technology through Normalized Difference Vegetation Index model provides a better alternative to crop monitoring during the growing season especially when a large area is involved for crop optimum yield. Hence, this study.

1.2 The Aim of the Study

The study aims to use satellite imagery to estimate the Normalized Difference Vegetation index for maize crop monitoring in Sudan Ecological Zone of Nigeria.

1.3 The Objectives of the Study are to

a. Map the cropland area for the study area.
b. Generate the NDVI to monitor the performance of the maize crop from the Earth Observation Satellite Image in sudan ecological zone of Nigeria.
c. Document the technical details of the algorithm for future reference by other users and replications for other crops.

2. METHODOLOGY

2.1 Study Area

The study area lies between latitude 11° 8^1 4.034^{11} to 11º 53^1 16.372^{11} and longitude 7º 21^1 51.831^{11} to 8º 10^1 48.902^{11}. This contains the three states; Kano, Kaduna and Kastina and the selected LGAs in these three States are the six LGAs that lie interface between these three States where they share boundary. These selected LGAs include; Kudan, Markafi, Danja, Rogo Kafur and Karaye. The study area has an area of approximately 3828.49 km^2.

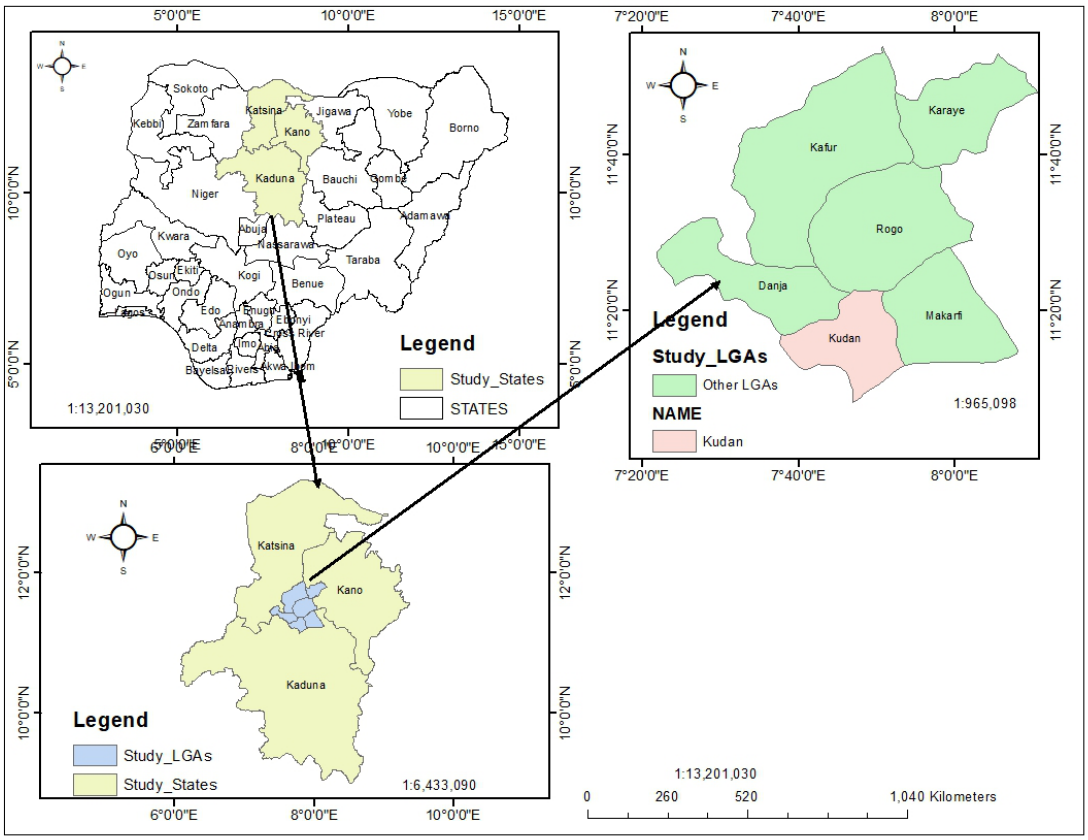


Fig. 1. Study area map

2.2 Data Types and Sources

Primary and secondary data were used for the study.

2.3 Primary Data

These include the use of questionnaires loaded into ODK apps to seek information from the farmers about the conditions of their farm and their agronomic practices. The GPS coordinates of the perimeter of their farm's plots were also collected using Germine GPS receiver. The perimeter coordinates of 1080 farms were collected with the aid of handheld Globe Positioning System Receiver from six local governments (Rogo, kudan, markafi, Ranja) that lies interface between the three selected states, (Kano, Kaduna and Kastina) in Nigeria. The name of the farmer, the planted crop and phone number were documented for follow-up and yield harvest weighing and documentation as one of the major input in the yield estimate model.

2.4 Secondary Data

Satellite Images were acquired for NDVI Analysis. These include Sentinel satellite 2A and 2B and landsat 8 and Landsat 9 satellite image acquired for the study area from the planting period, may 2022 to the period of harvesting, September, 2022.

1.Sentinel satellite image: Sentinel-2 is an Earth observation mission from the Copernicus Programme that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters. The mission is currently a constellation with two satellites, Sentinel-2A and Sentinel-2B with the two images having a revist period of 5 days and 10days as single constellation. The mission supports a broad range of services and applications such as agricultural monitoring, emergency management, land cover classification or water quality.

2.5 Landsat Satellite Image

Since one of the major limitations of the optical remote sensor is cloud cover, we decided to acquire landsat satellite images with 30m spatial resolution that are closer to the needed date of sentinel data and are relatively free from cloud cover as a replacement for date of sentinel data that are affected by cloud. The landsat8 and landsat 9 with path 189 and row 52 and sentinel with upper right and lower left coordinates 12 N, 7E and 11 30’18.84” N and 7 48’19.64” E respectively were acquired. Table 1 below shows the acquired Sentinel and Landsat Satellite Image that were used for the study.

Table 1. Satellite Data Acquisition for the Study with dates

S/N	Satellite Image Date	Satellite Image Type	Revisit Period
1	02/05/2022	Sentinel 2A	5 days with 2B
2	07/05/2022	Sentinel 2B	5 days with 2A
3	22/05/2022	Sentinel 2A	5 days with 2B
4	27/05/2022	sentinel 2B	5 days with 2A
5	03/05/2022	Landsat 8 (OLI)	8 days with landsat 9
6	11/05/2022	Landsat 9 (OLI)	8 days with landsat 8
7	19/05/2022	Landsat 8 (OLI)	8 days with landsat 9
8	27/05/2022	Landsat 9 (OLI)	8 days with landsat 8
9	01/06/2022	Sentinel 2A	5 days with 2B
10	04/06/2022	Landsat 8 (OLI)	8 days with landsat 9
11	12/06/2022	Landsat 9 (OLI)	8 days with landsat 8
12	20/06/2022	Landsat 8 (OLI)	8 days with landsat 9
13	28/06/2022	Landsat 9 (OLI)	8 days with landsat 8
14	06/07/2022	Landsat 8 (OLI)	8 days with landsat 9
15	14/07/2022	Landsat 9 (OLI)	8 days with landsat 8
16	22/07/2022	Landsat 8 (OLI)	8 days with landsat 9
17	07/08/2022	Landsat 8 (OLI)	8 days with landsat 9
18	05/08/2022	sentinel 2A	5 days with 2B
19	10/08/2022	Sentinel 2B	5 days with 2A
20	30/08/2022	sentinel 2A	5 days with 2B
21	08/09/2022	Landsat 8 (OLI)	8 days with landsat 9
22	24/09/2022	Landsat 8 (OLI)	8 days with landsat 9

3. DATA ANALYSIS

The perimeter coordinates of all the farm plots were plotted as points and these were used to digitize all the farm plots as polygon using geographic information system platform. For accuracy purposes, the GPS coordinates of the perimeters of each plot taken on the field were labelled in Excel as A1, B1, C1, D1 to An, Bn, Cn, Dn. This means plot one was labelled as A1, B1, C1, D1 to plot 1080 which was labelled as A1080, B1080, C1080, D1080.

3.1 Normalized Difference Vegetation Index (NDVI) Analysis

Since one of the objectives of the study is to generate the indices that simplify Ag-statistics estimation, we therefore analysed the time series Normalised Difference Vegetation Index (NDVI) value per farm plot from planting period to harvest period.

The Normalized Difference Vegetation Index (NDVI) for the entire study area was calculated using the NDVI algorithm.

The following equation was used.

$$NDVI = \frac{\text{NIR} - \text{RED}}{NIR + RED}$$

NIR = Near infrared band of the satellite image
RED = RED band of the satellite image

In sentinel satellite image, band 8 represents Near Inrared (NIR) while band 4 represents RED. Therefore, NDVI calculation for sentinel data = band 8 - band 4/ band 8 - band 4 and for landsat data, NDVI = (band 5 - band 4)/(band 5 - band 4). This implies that NIR for landsat correspond to band 5 while RED corresponds to band 4. For the generation of average NDVI for farm plots, all the digitized farm plot polygons were overlaid on the NDVI layer for the selected LGAs and the average NDVI was generated for each plot for maize, using the zonal statistics tool within Geographic Information System Platform.

4. RESULTS AND DISCUSSION

The study showed the time series NDVI for the length of the growing season for the selected crops (Maize) and the geometrically calculated area of the farm plot size. The study revealed the NDVI statistics for maize from may, 2022 (day of planting period) to September 2022 (Day of harvesting period). These statistics include the mean, standard deviation, range, minimum and maximum NDVI values for all the farm plots over the growing season from the planting period to the harvesting period for the selected crops. The average NDVI value in May which marks the onset of the growing season for maize in the study area ranges from 0.044 to 0.148. In july, which represents the period of the grain filing stage ranges from 0.136 to 0.348 and in August, which is the maturity stage for harvest ranges from 0.110 to 0.450. These approaches assume that measures of the photosynthetic capacity from spectral-vegetation indices are directly related to crop yield. This assumption is used because many of the conditions that affect crop growth, development and ultimately yield could be captured through spectra measurements such as the NDVI [12].

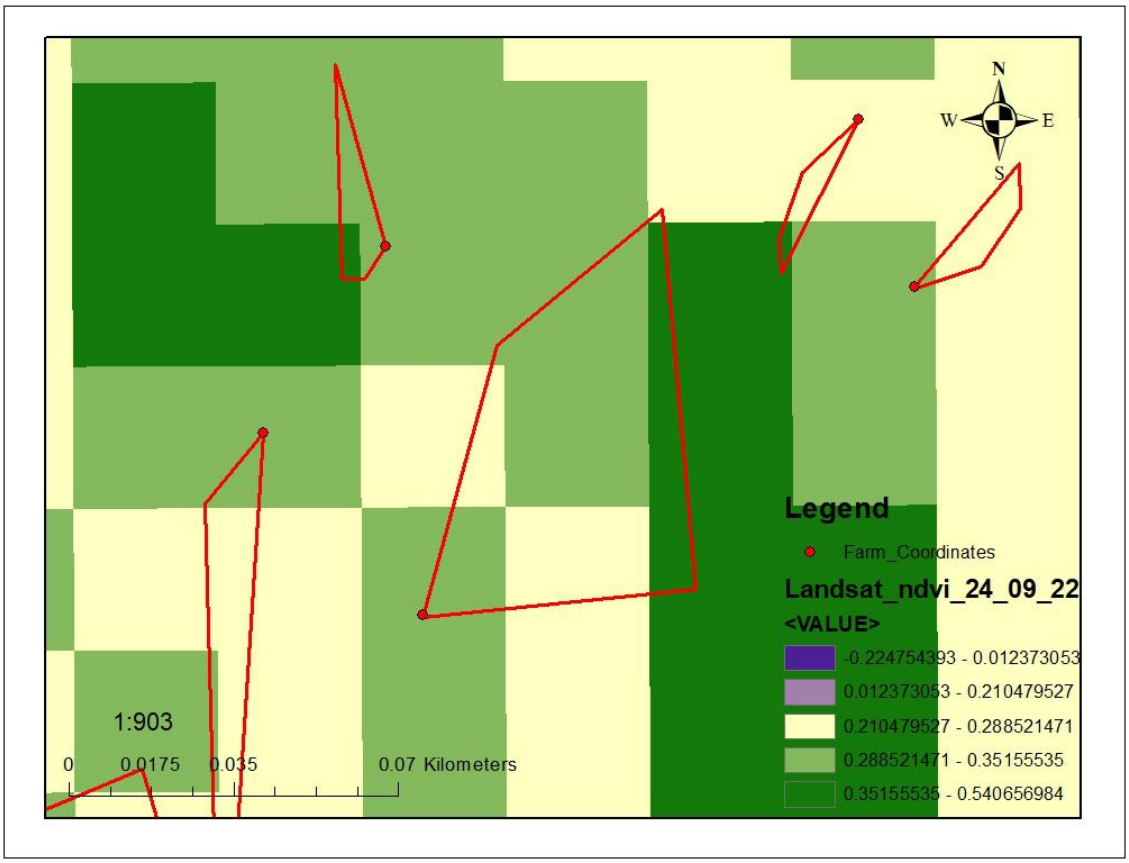
The supervised classification of the satellite image for land use landcover reveals that the cropland area for the cultivation of arable crops in the selected six LGAs is 194.973269 square Kilometer. These areas are found mostly along rivers network and near the dam area; the area with sufficient water for farming. This cropland area and other landcover classes are documented in the Table 2. The Fig. 2 is the map showing the area for arable crop farming otherwise known as cropland area in the study area.

4.1 Limitation to the Generation of the NDVI Statistical Values for all the farm Plots

The total number of farm plots selected for the study and whose coordinates were collected are 327 plots for the the selected crops. The zonal statistics tool within Geographic Information System platform was able to generate the NDVI statistical values for plots whose sizes are greater than the pixel size of each of the two satellite images used for the study. Landsat image has 30m by 30m spatial resolution while sentinel image has 10m by 10m spatial resolution. This means that a single pixel of Landsat satellite image measures 30m x30m as a square pixel and sentinel measures 10m x 10m as a square pixel. NDVI values were not generated for many farm plot that is not big enough to accommodate minimum of a single pixel within it. The area of some farm plots are less than 30 meter by 30 meter in size. For that reason, the Zonal statistics tool could not generate NDVI statistics for those plots. This

accounts for variations in the number of plots whose NDVI were generated. For, Sentinel image, between 250 to 327 plots were generated for the selected crop. This number becomes lesser for Landsat images because of its lower spatial resolution (30m X30m) which does not allow NDVI statistical values generation from zonal statistics for many farm plots smaller than the image pixel size of 30m by 30m as some of the farm plots sizes are lesser than 30m by 30m in area. It should be noted that for the successful generation of average NDVI for a polygon using zonal statistics, minimum of a pixel or more must fall within the polygon that represents farm plots. This is not the case for some plots in some of our plots. see Picture 1 below.

The bigger farm plot at the centre contains more than one pixel and average NDVI value can be calculated for it using zonal statistics, other surrounding pixels were omitted from the calculation automatically by the GIS platform tool used.



Picture 1. Farm plots overlay on the landsat Pixel of 30m by 30m resolution

Table 2. Landuse landcover for mapping for cropland area and other land cover estimation

Landuse Landcover classes	Area in Square Kilometer
Cropland Area	194.973269
Vegetation Area	901.76134
Grassland Area	200.8880
waterbody coverage	48.1059
Bareland Area	2417.4291
Settlement Area	64.8444
Total	3828.0021

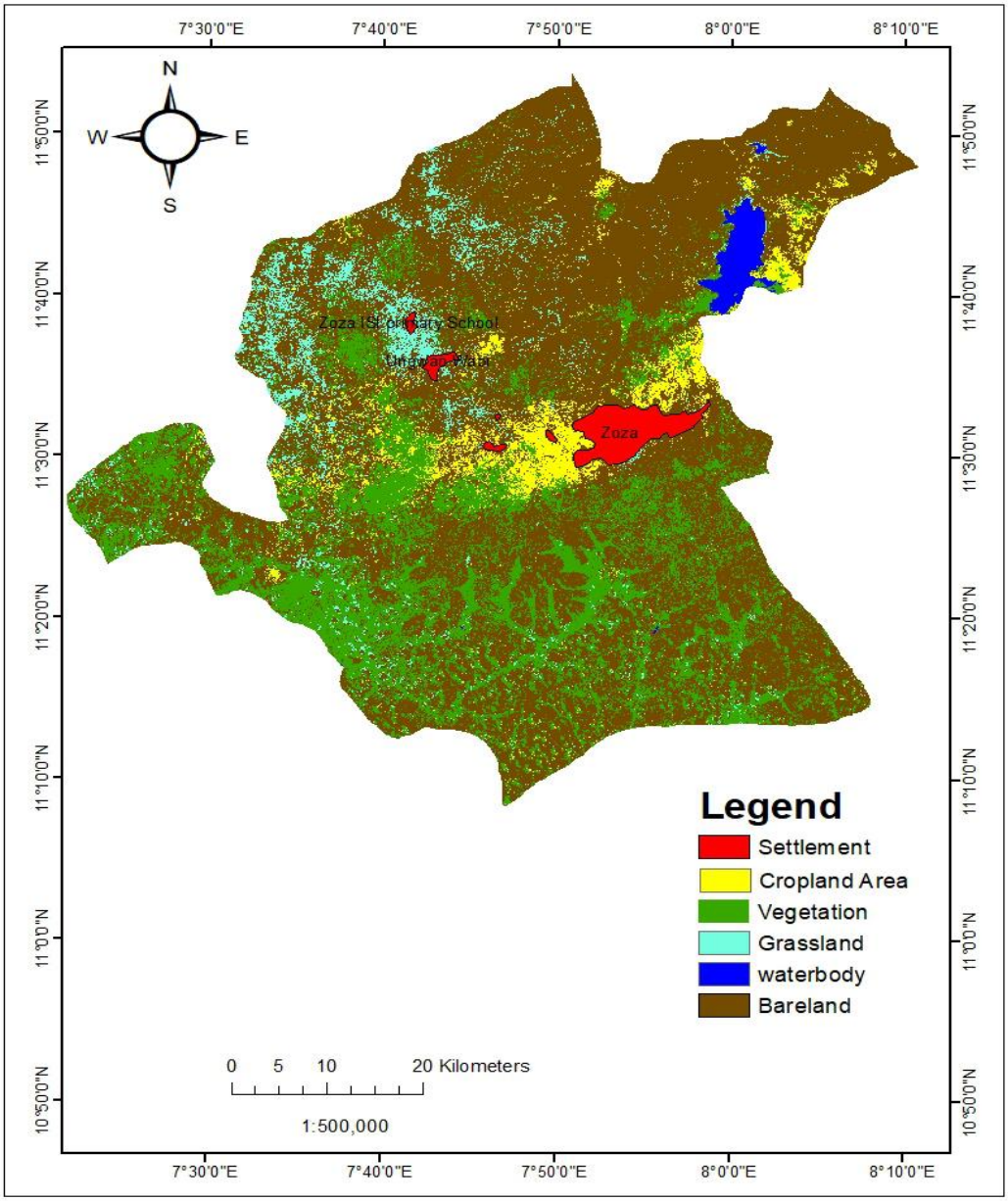


Fig. 2. Landcover area showing cropland area (July, 2022)

5. CONCLUSION

The study has successfully demonstrated the capability of NDVI model for crop monitoring and has given a guide into the calculation of cropland area quantification and yield value estimation from the field. It is therefore evident that the results of our NDVI analysis and cropland area mapping are good insights into solving national agricultural planning problems and agricultural resources allocation for effective agricultural practices for national food security.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Ndvi for 7th august 2022 of the growing season for maize plots

PLOT_ID	MEAN	PLOT AREA	MIN	MAX	STD
A1	0.13926321268	899.45436458600	0.13926321268	0.13926321268	0.00000000000
A10	0.14174300432	899.45436458600	0.14174300432	0.14174300432	0.00000000000
A100	0.14147070795	1798.90872917000	0.14143371582	0.14150770009	0.00003699213
A1004	0.15140222013	1798.90872917000	0.15069462359	0.15210981667	0.00070759654
A101	0.15392306447	899.45436458600	0.15392306447	0.15392306447	0.00000000000
A1015	0.15600873530	2698.36309376000	0.15571418405	0.15635313094	0.00026321934
A1016	0.15649241209	899.45436458600	0.15649241209	0.15649241209	0.00000000000
A1018	0.14662317187	1798.90872917000	0.14513364434	0.14811269939	0.00148952752
A102	0.14855803549	899.45436458600	0.14855803549	0.14855803549	0.00000000000
A104	0.17707353830	899.45436458600	0.17707353830	0.17707353830	0.00000000000
A105	0.14678984880	899.45436458600	0.14678984880	0.14678984880	0.00000000000
A1054	0.16403548420	1798.90872917000	0.16340593994	0.16466502845	0.00062954426
A106	0.17948380609	2698.36309376000	0.17912340164	0.17987716198	0.00030860224
A108	0.20109967887	899.45436458600	0.20109967887	0.20109967887	0.00000000000
A110	0.17892807722	899.45436458600	0.17892807722	0.17892807722	0.00000000000
A113	0.18790673465	1798.90872917000	0.18659539521	0.18921807408	0.00131133944
A116	0.18698866665	899.45436458600	0.18698866665	0.18698866665	0.00000000000
A118	0.17366736382	1798.90872917000	0.17335635424	0.17397837341	0.00031100959
A119	0.17950771749	899.45436458600	0.17950771749	0.17950771749	0.00000000000
A12	0.16886410117	1798.90872917000	0.16823667288	0.16949152947	0.00062742829
A121	0.10782401264	1798.90872917000	0.10758144409	0.10806658119	0.00024256855
A132	0.10544826835	899.45436458600	0.10544826835	0.10544826835	0.00000000000
A140	0.11193363369	899.45436458600	0.11193363369	0.11193363369	0.00000000000
A144	0.11425574124	899.45436458600	0.11425574124	0.11425574124	0.00000000000
A146	0.11532562971	899.45436458600	0.11532562971	0.11532562971	0.00000000000
A148	0.11176078767	899.45436458600	0.11176078767	0.11176078767	0.00000000000
A151	0.10083807260	899.45436458600	0.10083807260	0.10083807260	0.00000000000
A152	0.10238801688	899.45436458600	0.10238801688	0.10238801688	0.00000000000
A154	0.09897122532	899.45436458600	0.09897122532	0.09897122532	0.00000000000
A157	0.10220589489	899.45436458600	0.10220589489	0.10220589489	0.00000000000
A162	0.10598595440	899.45436458600	0.10598595440	0.10598595440	0.00000000000
A164	0.11186741293	899.45436458600	0.11186741293	0.11186741293	0.00000000000
A176	0.26767274737	899.45436458600	0.26767274737	0.26767274737	0.00000000000
A18	0.29449737072	899.45436458600	0.29449737072	0.29449737072	0.00000000000
A181	0.25789234042	899.45436458600	0.25789234042	0.25789234042	0.00000000000
A184	0.25644972920	899.45436458600	0.25644972920	0.25644972920	0.00000000000
A185	0.29445992410	1798.90872917000	0.28795376420	0.30096608400	0.00650615990
A188	0.26397818327	1798.90872917000	0.24644234777	0.28151401877	0.01753583550
A190	0.34810924530	1798.90872917000	0.33905982971	0.35715866089	0.00904941559
A2	0.24329774082	899.45436458600	0.24329774082	0.24329774082	0.00000000000
A20	0.24682566524	899.45436458600	0.24682566524	0.24682566524	0.00000000000
A209	0.29401591420	899.45436458600	0.29401591420	0.29401591420	0.00000000000
A215	0.24356879294	899.45436458600	0.24356879294	0.24356879294	0.00000000000
A217	0.17863185704	1798.90872917000	0.17798496783	0.17927874625	0.00064688921
A218	0.19077120721	899.45436458600	0.19077120721	0.19077120721	0.00000000000
A219	0.10654556751	899.45436458600	0.10654556751	0.10654556751	0.00000000000
A220	0.10603779554	899.45436458600	0.10603779554	0.10603779554	0.00000000000
A221	0.10836653411	899.45436458600	0.10836653411	0.10836653411	0.00000000000
A225	0.11195071042	899.45436458600	0.11195071042	0.11195071042	0.00000000000
A228	0.22399620712	1798.90872917000	0.22185736895	0.22613504529	0.00213883817
A23	0.23622027040	899.45436458600	0.23622027040	0.23622027040	0.00000000000
A231	0.23511219025	899.45436458600	0.23511219025	0.23511219025	0.00000000000
A245	0.19331499189	1798.90872917000	0.19316601753	0.19346396625	0.00014897436
A248	0.17721877992	899.45436458600	0.17721877992	0.17721877992	0.00000000000
A251	0.15826086700	899.45436458600	0.15826086700	0.15826086700	0.00000000000
A256	0.16633579135	1798.90872917000	0.16501593590	0.16765564680	0.00131985545
A258	0.15447002649	899.45436458600	0.15447002649	0.15447002649	0.00000000000
A26	0.16038756073	899.45436458600	0.16038756073	0.16038756073	0.00000000000
A269	0.09009949863	899.45436458600	0.09009949863	0.09009949863	0.00000000000
A27	0.09234933555	899.45436458600	0.09234933555	0.09234933555	0.00000000000
A271	0.09415970370	1798.90872917000	0.09317588061	0.09514352679	0.00098382309
A276	0.10242915899	899.45436458600	0.10242915899	0.10242915899	0.00000000000

A29	0.08196467906	899.45436458600	0.08196467906	0.08196467906	0.00000000000
A292	0.09002025425	2698.36309376000	0.08784449846	0.09203518927	0.00171461752
A294	0.08624095097	1798.90872917000	0.08597712219	0.08650477976	0.00026382878
A295	0.08964888752	899.45436458600	0.08964888752	0.08964888752	0.00000000000
A30	0.08888144791	899.45436458600	0.08888144791	0.08888144791	0.00000000000
A300	0.08501851559	899.45436458600	0.08501851559	0.08501851559	0.00000000000
A32	0.27638876438	1798.90872917000	0.26802679896	0.28475072980	0.00836196542
A327	0.30194437504	899.45436458600	0.30194437504	0.30194437504	0.00000000000
A331	0.31330499053	899.45436458600	0.31330499053	0.31330499053	0.00000000000
A34	0.29405852159	2698.36309376000	0.28264573216	0.30070057511	0.00810614085
A340	0.36071750522	899.45436458600	0.36071750522	0.36071750522	0.00000000000
A381	0.07819567248	1798.90872917000	0.07801472396	0.07837662101	0.00018094853
A382	0.33115391433	1798.90872917000	0.32762527466	0.33468255401	0.00352863967
A385	0.38100486994	899.45436458600	0.38100486994	0.38100486994	0.00000000000
A386	0.40484187007	1798.90872917000	0.39630633593	0.41337740421	0.00853553414
A387	0.37113589048	1798.90872917000	0.35873800516	0.38353377581	0.01239788532
A39	0.29695444306	2698.36309376000	0.29027596116	0.30070137978	0.00473411774
A391	0.35257643461	899.45436458600	0.35257643461	0.35257643461	0.00000000000
A394	0.38493388891	899.45436458600	0.38493388891	0.38493388891	0.00000000000
A4	0.18325544894	899.45436458600	0.18325544894	0.18325544894	0.00000000000
A42	0.24878650904	899.45436458600	0.24878650904	0.24878650904	0.00000000000
A421	0.20501488447	899.45436458600	0.20501488447	0.20501488447	0.00000000000
A436	0.30056828260	899.45436458600	0.30056828260	0.30056828260	0.00000000000
A441	0.31433460116	899.45436458600	0.31433460116	0.31433460116	0.00000000000
A445	0.27231067419	899.45436458600	0.27231067419	0.27231067419	0.00000000000
A448	0.23684750497	899.45436458600	0.23684750497	0.23684750497	0.00000000000
A452	0.22307588160	899.45436458600	0.22307588160	0.22307588160	0.00000000000
A453	0.22624179721	899.45436458600	0.22624179721	0.22624179721	0.00000000000
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A476	0.26294896007	899.45436458600	0.26294896007	0.26294896007	0.00000000000
A478	0.25524854660	899.45436458600	0.25524854660	0.25524854660	0.00000000000
A487	0.26445463300	899.45436458600	0.26445463300	0.26445463300	0.00000000000
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A52	0.26778364182	899.45436458600	0.26778364182	0.26778364182	0.00000000000
A520	0.19216413796	899.45436458600	0.19216413796	0.19216413796	0.00000000000
A522	0.19325169921	899.45436458600	0.19325169921	0.19325169921	0.00000000000
A523	0.19342701137	899.45436458600	0.19342701137	0.19342701137	0.00000000000
A531	0.15197736025	1798.90872917000	0.15156042576	0.15239429474	0.00041693449
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A627	0.28207546473	899.45436458600	0.28207546473	0.28207546473	0.00000000000
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A675	0.16921453923	1798.90872917000	0.16802397370	0.17040510476	0.00119056553

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