Crop and vegetation monitoring with the aid of remote sensing

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***Abstract*—Satellite imagery assists us in monitoring the world around us but it was not always used like nowadays as before 1972 satellite imagery was utilized for military missions but the 'Land Remote Sensing Policy Act of 1992' which was a law that held the worth of remote sensing technology allowed certain companies to launch their own satellites and also sell the images produced by these satellites. After the release of this law, satellite imagery was used to observe the earth around us and other essential factors which without these factors, life would not be possible on Earth. Examples of such factors are the ocean, atmosphere, and the Earth's surface. In this research, we are going to address the use of satellite imagery on crops to help us monitor the crops planted in the designated fields and how certain crops were rotated around the fields over a period of time.[1]**

***Index Terms*—MCAST, IICT, LaTeX, Project, Paper**

I. Introduction

With the assistance of satellite imagery, farmers all around the world are able to monitor their crops and also their health by simply looking at a monitor instead of going around the fields and checking crop by crop which may waste a lot of valuable time, and may also help farmers plan much more where and how to plant the crops the years after. And when monitoring the designated fields over a period of time, a pattern may be noticed on how the planted crops develop over time, meaning that when time goes by a farmer will be able to manage the condition of the crops much better and precisely as with the help of this pattern, as farmers will be able to divide the development of a crop into stages. With the help of these stages, a farmer will know what needs to be done for the crop to develop as in every stage of it's life cycle, a crop needs maintenance and care. Therefore with this technology, a farmer can work much more efficiently than if he worked using traditional methods to monitor crops and their health. But satellite imagery does not tell the whole story as certain aspects will not be visible from the images. For example, a farmer would not know if a crop is being used as food for animals and insects as such. TO know such information, 1the farmer needs to physically go and check on the crops himself in order to determine such factors as the farmer must inspect the leaves, flowers, fruits or vegetables of the crop to see if there is any damage or holes left from insects and pests while they are consuming a part of the crop.

II. Literature Review

A. *Soil erosion and agricultural sustainability*

Soil erosion has always been always of a major concern since Plato and Aristotle , but recently soil erosion has been associated with the rise and fall of civilizations in middle eastern Greece. Many people blame the effects of deforestations and the lack of agricultural maintenance of land in upland environments.

In Reality , soil erosion is a very complex process which depends on factors such as the soil's properties, where the fields are located , the amount of rainfall in that location and also the vegetation in that specific environment. Thanks to soil erosion, a field will have less agricultural potential due to the loss of fertile soil within it.

The acceleration of soil loss and erosion has been acknowledged in modern industrial agriculture, as the U.S. Department of Agriculture(USDA) initiated the 'soil-Tolerance value' also known as T value. With this value we can calculate the acceptable amount of soil erosion within a certain environment. The maximum soil-Tolerance values have been established at a value of 5-12 tons of soil per year based on 1,200kg/m(cubed) which is equivalent to 0.4 -1 mm of mm loss per year. It is stated that only in highly erodible places that the soil-Tolerance value was exceeded but it was found out that the agricultural potential of a field with this soil-Tolerance value is only slightly threatened.

When looking at long-term effects of soil erosion , we can distinguish between floodplain agriculture and upland agriculture.In floodplain agriculture the floods replenish mineral soil while in upland agriculture the soils slowly start to thin out resulting in a loss of soil production which then leads to the soil erosion rates exceeding those of soil production.

As time goes by, Hillslope soils will find a balance between soil erosion and soil production which will result in the setting of a type of soil's characteristic thickness which depends on it's geological and climatic setting.

Soil erosion and production rates have been recognized that they vary quite drastically around the world due to local site factors such as the climate, soils , topography , geology and vegetation. Due to this, one may ask 'How representative are the span of environments covered by this data due to the drastically varying environmental factors?'. Below we can see the approximation of average global erosion rates showing how the data is spatially representative.

Table 2. Average global geologic erosion rates and global soil production rates reported in previous studies

Source	Rate, mm/yr
Global geologic erosion	
Montgomery and Brandon (39)	0.017
Wilkinson (49)	0.024
Wilkinson and McElroy (50)	0.016
Global soil production	
Wakatsuki and Rasyidin (51)	0.058
Troeh *et al.* (52)	0.083

In the 1900s it has been found that conventional agricultural methods increased soil erosion. Because of this there has been experimentation with conservation tillage and no-till agriculture, the process of tilling, also known as ploughing is the method where farmers loosen up the soil before planting the crop's seeds . in the past decades the no-tilling method has been adopted more than the conventional tilling method as it is found that tilling has a big contribution to soil erosion, therefore farmers nowadays insert the seeds directly into the soil with a dedicated drill without disturbing the soil's current state and structure which reduces soil runoff. It has been recognized that with the no-till method, soil erosion has been reduced quite drastically. As it has been recognized that in traditional tobacco cultivation, soil erosion has been reduced by rates of up to 90

With the data gathered we realize how in the future, soil loss and erosion will become a major issue for global agriculture with the use of upland farming methods, especially if rates of soil erosion exceed the rates of soil production as this means that fertile soil will continue to erode away leaving less and less soil where crops can be planted. [2]

B. Crop classification using multi-sensing and multitemporal Satellite Imagery with Machine Learning.

Remote sensing provides data about a certain target without the need of being close to it. This is done thanks to satellites and also aircraft which pick up usable data from our planet's surface using electromagnetic radiation, acoustic energy and also other types of remote sensors are available. These remote sensors are either passive or active. Active sensors send a stimulus to the target required and then waits for a response from the target while passive do not utilize the stimulus but they collect data which is sent by the target.

In this paper we can observe how machine learning algorithms are used on indices in order to classify crops. An example of such algorithms are linear and tree-based. This will be done by utilizing ground truth which has been given access from the National Agricultural Statistics Service(NASS) by the United States Department of Agriculture (USDA), which will grant access to 12 classification models with 10-fold cross validation methods which are able to differentiate 7 crop types.

When it comes to land usage detection using satellite imagery there is a lot that has been done , example of such work is the usage of a pixel-analysis upon a high resolution image in order to reveal vegetation. When it comes to refining accuracy specifically phenological patterns , which are extracted from the NDVI index are utilized for data aggregation , also using random forest as a classifier on multi-temporal images which provided an accuracy of 0.91 utilizing 4 different crop types. As it can be seen it is quite accurate but on order to utilize these procedures a model driven approach is required therefore limiting flexibility of the procedure.

Satellite images contain 4 characteristics which are:

a. Spatial resolution displays the amount of details per pixel.
b. Spectral resolution shows the amount of spectral bands from where the sensor collects the data.
c. Temporal resolution displays how many time the satellite revises the target currently being observed.
d. Radiometric resolution displays the number of data each pixel carries by displaying them in bits.

- The satellites used here are Sentinel- 2A and Sentinel-2B where the data provided by these 2 satellites is downloaded from the Sentinel Hub online service which supplies the data from the Sentinel satellites.

TABLE I. SPECTRAL BANDS OF SENTINEL-2 SATELLITES

Band name	***Resolution*** *(m per pixel)*	***Wavelength*** *(nm)*	***Bandwidth*** *(nm)*	***Purpose***
B01	60	443	20	Aerosol detection
B02 (Blue)	10	490	65	Blue
B03 (Green)	10	560	35	Green
B04 (Red)	10	665	30	Red
B05 (Red edge)	20	705	15	Classifying the vegetation
B06	20	740	15	Classifying the vegetation
B07	20	783	20	Classifying the vegetation
B08A	20	865	20	Classifying the vegetation
B08 – NIR (Near Infra-red)	10	842	115	Near infrared
B09	60	945	20	Detecting the water vapour
B10	60	1375	30	Cirrus cloud detection
B11	20	1610	90	Snow/ice/cloud discrimination
B12 – SWIR (Short-wave Infra-red)	20	2190	180	Snow/ice/cloud discrimination

The table above shows 13 different spectral bands out of sentinel 2 displaying their main characteristics. Than these bands are utilized for calculating 15 indices which are found in table II.

TABLE II. INDICES AND THEIR FORMULATION[6]

Name	***Formula***
ARI	$\frac{1.0}{B03} - \frac{1.0}{B05}$
ARVI	$\frac{B09 - B04 - y * (B04 - B02)}{B09 + B04 - y * (B04 - B02)}$
CHL-RED-EDGE	$\frac{B07^{-1}}{B05}$
EVI	$2{,}5 * \frac{B08 - B04}{B08 + 6 * B04 - 7.5 * B02 + 1}$
EVI2	$2{,}4 * \frac{B08 - B04}{B08 + B04 + 1{,}0}$
GNDVI	$\frac{B08 - B03}{B08 + B03}$
MCARI	$((B05 - B04) - 0.2 * (B05 - B03)) * \frac{B05}{B04}$
MSI	$\frac{B11}{B08}$
NBR	$\frac{B08 - B12}{B08 + B12}$
NDII	$\frac{B08 - B11}{B08 + B11}$
NDVI	$\frac{B08 - B04}{B08 + B04}$
NDWI	$\frac{B03 - B08}{B03 + B08}$
PSSR	$\frac{B08}{B04}$
SAVI	$\frac{B08 - B04}{B08 + B04 + L} * (1.0 + L)$
SIPI	$\frac{B08 - B01}{B08 - B04}$

In order to obtain and preprocess the satellite images taken by the satellites , first of all in a period of a year a series of satellite images are taken. Later those images with high cloud coverage are excluded as they do not provide a clear image of the crops therefore they are not usable, Later the remaining images are grouped into a group of images which are related to a certain area by using a temporal axis to average the pixel values on. The result is that each area now has a set of images containing the average index value for each pixel. Later these images are converted into a table showing a pixel with it's respective value of all the indices . When this table is processed it is later filtered again in order to show a list only the corresponding data for the selected crops only.

TABLE III. SELECTED CROPS FROM CDL DATABASE WITH THEIR RESPECTIVE ACCURACY SCORES IN CALIFORNIA, US

Crop type	***Recall***	***Precision***	***Kappa***
Rice	0.974	0.987	0.972
Grapes	0.983	0.983	0.983
Almonds	0.932	0.972	0.927
Walnuts	0.942	0.961	0.941
Pistachios	0.937	0.991	0.934
Avocado	0.999	0.969	0.999
Pomegranates	0.931	0.959	0.931

TABLE IV. EXCERPT FROM THE DATASET

ARI*	***EVI****	***NDVI****	***NDWI****	***…****	***CDL class***
1.63287	0. 13674	0.25313	-0.29978	…	Avocado
1.16493	0.23225	0.2702	-0.33484	…	Grapes

* Indices values are average values over a period of one year

**Three dots represent 11 other indices

Out of all the classification models the Random Forest model provided the most accurate results as it is clearly visible within the table below. Therefore this model is used in order to combine it with another dataset containing 5 new areas in California with all the 7 different crop types.

TABLE V. Performance of Machine Learning Models

Models	Accuracy	Kappa
Linear discriminant analysis	0.7209057	0.6743900
Penalized discriminant analysis	0.7209007	0.6743841
Random forest (mtry=2)	0.9036928	0.8876416
Random forest (mtry=8)*	**0.9046185**	**0.8887215**
Random forest (mtry=15)	0.8963673	0.8790952
K-nearest neighbors (k=5)	0.8926145	0.8747169
K-nearest neighbors (k=7)	0.8895372	0.8711267
K-nearest neighbors (k=9)	0.8859945	0.8669936
Support vector machines (linear)	0.7937203	0.7593403
Neural network (size=4, decay=0.01)	0.7307631	0.6858903
Neural network (size=4, decay=0.1)	0.7193195	0.6725394
Neural network (size=8, decay=0.01)	0.7765074	0.7392586

* Random forest achieves best results

In the table below it is clearly visible that Grapes superseded the majority of the other crops , while it is also clearly shown that it's precision when compared to others is a bit low, therefore further examination is done by including an extra area containing grapes and examining it very closely.

TABLE VII. Recall and Precision of Random Forest Model for Each Crop Type

Crop type	Recall	Precision
Rice	0.9093	0.9890
Grapes	0.9460	0.6925
Almonds	0.8547	0.8512
Walnuts	0.6812	0.8740
Pistachios	0.5957	0.8767
Avocado	0.9969	0.8821
Pomegranates	0.9124	0.8151

With the results acquired from machine learning it is quite clear that satellite imagery can be of great assistance for crop classification, as 7 different crop types have been identified with the average accuracy of 0.8420 therefore we can see that the accuracy for crop classification is easily achievable even though it is not perfect. [3]

C. Good Management Practices for Agricultural Crops: A Mini Review

When it comes to food security all around the world, it is mostly dependent on the production of agricultural crops and plants, therefore it is very important to increase the production of these crops.In developing countries, food mostly comes from these agricultural crops therefore for these countries it is even more essential that it's population manage their agricultural crops in the best ways as they mostly depend on it for them to be able to consume enough essential vitamins and nutrients for them to live a healthy life.

In order to maximize crop production there are several methods to do so, as long as these methods assist in decreasing problems and issues which are related to global crop production.Such methods which help to maximize crop production are crop rotation, the use of cover crops, proper water and irrigation management , pesticides and fertilizers and much more.

In order to maximize crop production one must make sure to utilize such methods not to only maximize crop production but by utilizing these methods when paying attention one will notice that soil quality will be enhanced , the conservation of the biodiversity within a certain environment will also be improved.

Now we will see some of the best methods in order to maximize crop production:

a. The use of cover crops Cover crops are crops which when they grow , they remain close to the ground. They are normally planted during the off-season in order to prepare the soil and also other factors within a field for planting the cash crops later on.

These cover crops play a major role in improving crop production as thanks to these crops , soil fertility is improved, soil erosion and runoff is reduced , they improve the quality of water being used by the crops.

They are also beneficial as they prevent soil compaction as they provide the required nitrogen levels in order to balance pH levels. They can also be used to divert certain pests to attack them instead of attacking the cash crops therefore assisting with the further maintenance of cash crops.

It is clearly visible that the use of cover crops is of great importance to maximize agricultural crop production and in fact it is recommended by many farmers as it is one of the best methods in order to maintain crops.

b. Crop rotation and intercropping

Crop rotation is the process of growing a type of crop in a certain season, and the season after on the same area , a different crop is planted .[5] While intercropping is the process of planting 2 types of crops at the same time within the same field in the same season.With these processes the soil becomes more fertile as the soil is not being exhausted by planting the same crop over and over again which results in depleting the soil from a certain nutrient .

Therefore since plants both release and absorb many different nutrients , when crop rotation is being done, the soil will have a good balance of essential nutrients within it making it more fertile and as a result of this the crop yield will be increased.It is recommended though that crop rotation is practiced when the land does not produce as much as it should.Thanks to crop rotation and intercropping soil erosion is also reduced as the soil will have crop coverage resulting in less runoff of the soil.

c. Pesticide and fertilizer

Pesticides are the last resort when it comes to protecting crops from pests which are a threat to crops.But when it comes to using natural fertilizers such as manure in order to nourish the soil in order to make it more fertile it is regarded as a safe practice.

A farmer must pay extra attention when it comes to choosing a pesticide as some pesticides might provide added harm to the environment around the crop that it is being sprayed on. When choosing a type of pesticide a farmer must consider many factors such as it's chemical solubility and also it's characteristics in order to make sure it does not harm the environment around.

If a farmer is not sure what to use when it comes to pesticides it is recommended that he consults with a specialist regarding agricultural practices as certain pesticides might contain characteristics which may be toxic to soil, other types of crops and vegetation and also water, and must also be given the required measurement in order to use the right amount of pesticide for his requirements.

One must also take into consideration that pesticides have an unhealthy impact on humans also therefore when applying pesticides a farmer is recommended to always wear a filtering mask in order to minimize pesticide intake .[6]

With the use of these practices a farmer ensures that crop production is at it's peek even though many characteristics for crops and also soil structure is different around the world, these practices will surely enhance food security from crops.[4]

III. Research Methodology

The aim of this project is to prove that with the assistance of satellite imagery , crop monitoring can be made much easier thanks to today's technology especially with the help of the copernicus mission and it's satellites. Especially with the help of the satellite Sentinel 2 , Which was specifically launched for agricultural monitoring purposes. While this also proves that satellite imagery does not help with monitoring agricultural crops and vegetation only but also other factors related to our planet with the aid of other satellites especially other Sentinel satellites.

A. Hypothesis

It is possible to monitor the crops being cultivated in fields using remote sensing.

To be able to address the hypothesis the current plan was created.

1. Determine the best satellite to utilize the prototype.
2. Locate the area where the NDVI index is going to be applied .
3. Plan the time period from where the timelapse starts until it finishes.
4. Download the required products of the country within the time period that was determined to be the best for a change in vegetation to be displayed.
5. Process the images required for the timelapses.
7. Create the 2 timelapses one containing the images which depict the area with it's natural colours and another timelapse with the same images of the area but are processed with the NDVI formula in order to display the amount of vegetation in a certain area.
8. Get the opinion of people within the agricultural field on whether or not these timelapses assist in crop monitoring.

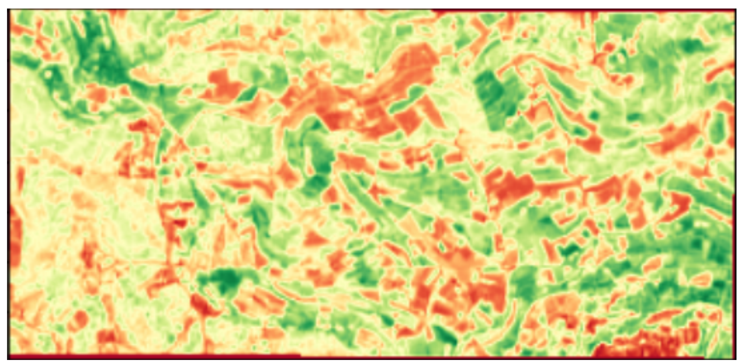
B. Research Questions

1. Which technology is best for proper crop monitoring?

In order to determine which technology is best suited for crop mapping and vegetation lots of research was done in order to use the best possible technology for this. It has been determined that the best technology is the Sentinel 2 satellite which is a part of the copernicus missions. This satellite has a multispectral sensor with 13 different bands to view our home planet's surface and the vegetation present on it.

Further research on Sentinel 2 shows us that this satellite can help us monitor crop growth, can show us the changing vegetation covering our land and the amount of vegetation present in a specific area while it also helps us to monitor our home planet's forests.[9]

This satellite was in fact primarily launched for agricultural purposes mostly and in fact when certain bands are combined they can show specific data on the map. For example if the bands B8 and B4 are combined and put into the formula (B8-B4)/(B8+B4) the NDVI index will be constructed which will show us the amount of vegetation in a specific place. The amount of vegetation is determined by colours for example the greener an area is , the more vegetation is contained within that area. While in areas depicted in red shows that there is not that much vegetation within that area. An example of this index is shown in the image below.



2. Which techniques are ideal for proper crop monitoring and identification?

When it comes to proper crop identification in the designated fields, The best way to find this out is by asking the farmer who maintains these fields who is most probably the person who planted these plants and crops who is the farmer you will gain the most knowledge about how crops are classified as the person who maintains these plants and trees does not only know what type of crops they are but also what they require to be able to grow out fruits, vegetables, flowers and many other things you get from crops and plants. He can also acknowledge you on when is their time to plant them, or when they need watering or maybe other essential needs which these crops require to keep growing and to live. Other essential questions which can be answered by the farmer are questions such as 'What type of fruits or vegetables do the crops grow?' or 'When is it time to harvest such crops?' All these questions are essential as their answer gives us a story of how the crops grow and live out until they die and what is needed for them such as the amount of water and sun in order to maintain a good life cycle with good harvesting potential for each crop or maybe how certain crops are created by breeding two different crops together in order to develop a new variety of a certain crop which may have qualities improved over the parent crops such as improved resistance to diseases and improved grain quality and many more improved qualities. Therefore as we can see a farmer with a good amount of experience has access to a healthy amount of information that is needed to maintain crops. Also if a person has a chance to observe the farmer when he is maintaining the crops ,one can learn first hand about crops and their principals as the farmer would explain how to identify a crop from it's leaves for example, while also explains how you can identify the crop from other factors also and how to determine whether a crop is healthy or not and what is needed to be done to improve the health of a crop. When the crops are identified they can be classified by having researched online and determine the several different categories and list the crops within the designated fields according to their respective category. Therefore by asking the farmer we can determine lots of factors which will assist us in being able to classify the crops into 7 categories. [8]

includes/pipeline.png

Fig. 1. Research Pipeline

IV. Findings & Discussion of Results

The prototype worked fine as it showed a good example of how the vegetation within the designated area which was the valley known as Chadwick lakes had changed within that time period . It was both clearly visible on the timelapse containing the images with the RGB bands therefore with the bands that show it's true colour and also the timelapse which had the images processed with the NDVI formula showing the amount of vegetation within the area. Showing that satellite imagery for crop and vegetation monitoring, it will surely aid farmers in monitoring their crops from a monitor within their homes due to the results obtained from the prototype, although it will not tell the whole story as it is clearly shown that so far the prototype only shows whether vegetation is present or not within a specific area. But when it comes to combining machine learning alogrithms with the different bands present in the Sentinel - 2 satellite , and using methods such as the Random Forest model , crops are able to be classified. Even though Accuracy is not Perfect . [3]

When the timelapses were shown to a farmer he stated that at first he could not acknowledge at what he is looking at but after some explaining he understood enough to get the concept of the timelapses. The farmer stated that it can prove to be helpful if the designated area was a bit smaller therefore he could easily identify the fields that belong to him but since the satellite image's pixels are 10 metres by 10 metres the images would not be clear at all. His complaint was that these images are not able to let him know of other essential factors related to the crop's needs such as for example if a crop needs watering or it will not let you know whether certain crops are being attacked by pests.

V. Conclusion

Satellite imagery has come a long way since it started and lots of work is being done in order to improve it's use for monitoring the world around us. When it comes to satellite imagery for crop monitoring it still has a long way to go in order to rely totally on satellite imagery without inspecting the crops physically. But if we improve the accuracy and also the methods to remove cloud cover it will be far more practical than other crop monitoring method as one can monitor their crops from the comfort of their own home knowing exactly what is needed to be done for their crops to be healthy.

When working on the prototype I have found out that remote sensing for very small areas is not feasible as My designated field is about 2 acres and I tried capturing it but due to the pixels being 10 metres squared , the satellite image became very pixelated therefore it makes it very difficult for crops to be identified and monitored for other factors.

There still was success with the prototype as it displayed a huge change within the time period in the amount of vegetation cover therefore it gave us a clear view of what was happening to crops and vegetation in this area within the time period of 4 months. But when it came to processing these images there still were some downsides.

One downside was that when viewing the list of products on scihub.copernicus, most products did not have the whole area of Malta within them but only half of it and by coincidence the edge of the image of most of these products went over the designated area therefore it left a part of this area without being visible therefore these products were of no use to be able to build the prototype therefore it limited the selection of products.

Another downside when it comes to crop classification using satellite imagery is the problem related to cloud cover in a certain area as when satellite images of the designated areas are taken and cloud cover is present it will not be clear as clouds are in the way of the designated target making it even harder for vegetation cover to be visible. But there are several methods to reduce cloud cover from within satellite images. But when it came to the prototype , in order to limit the cloud cover, from within scihub.copernicus only products which had between 0 to 5 percent of cloud cover were included and as a result of this a very limited selection of products was listed in order to use within the prototype therefore the timelapse did not have a huge variety of satellite images, just enough to show how the vegetation in the designated area evolves within that time period.

In the future to further add with this research , when building a prototype A larger time period should be utilized to further see how vegetation changes and cloud cover should be set to 10 percent and not 5 as only very few products were displayed in scihub.copernicus. Even though the cloud cover would be more, if the designated area is not covered with clouds, that product is beneficial to the prototype. And lastly this prototype should be combined with machine learning algorithms to extract further data out of the vegetation as by doing this, crops would be able to be classified into 7 different crop types as it was shown in one of the literature reviews [3].

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