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Understanding Crop Practices and Patterns Using Remote Sensing Technologies

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Abstract – In the last twenty years, scholars have employed remote sensing techniques for a diverse range of agricultural applications. These include the estimation of crop acreage, discrimination between different crops, assessment of soil moisture and crop condition, estimation of crop yield, implementation of precision agriculture practices, conducting soil surveys, managing agricultural water resources, and providing agro-meteorological and agro advisory services. The improved satellite data accessibility at improved geographical, spectral, and temporal resolutions has facilitated the emergence of novel applications in agriculture and contributed to economic expansion. One notable example is the usage of satellite data in insurance, enabling enhanced risk management strategies in the agricultural sector. Nevertheless, the effective use of satellite data in this perception necessitates a combination of technical proficiency about their limitations and capabilities, as well as a comprehension of their effects on the efficacy of risk mitigation initiatives. Given the potential lack of precision in agronomic terminology within the remote sensing literature, we provide a comprehensive categorization of prevalent agricultural practices, accompanied with detailed elucidations. Two key approaches that were identified are crop rotation and crop succession.

Keywords – Remote Sensing, Crop Practices, Crop Succession, Crop Patterns, Sequential Cropping, Normalized Difference Vegetation Index.

I. INTRODUCTION

According to a scholarly source, the projected global population by the year 2050 is around 9.7 billion individuals. In order to adequately address future food requirements, it is essential to focus on augmenting crop production, minimizing food wastage, and altering consumption patterns. In order to meet the demands of the projected population growth by 2050, it is imperative to achieve a substantial increase of 70 percent in agricultural yield. Consequently, it becomes necessary to reassess and modify our strategies and policies appropriately. Several initiatives have been developed to enhance agricultural productivity, including the 2030 Agenda for Sustainable Development, and Good Agricultural Practices (GAPs) [1]. In order to effectively reduce the reliance on external inputs such as fertilizers and pesticides, while simultaneously increasing crop productivity without expanding agricultural area and exacerbating the depletion of natural resources, it is advisable to adopt ecological cropping practices as the preferred techniques and policies.

Certain agricultural practices, such as the use of certain crop rotation schemes, have the potential to expedite the progression of sustainable intensification. The cultivation of annual crops follows a specific sequence and arrangement within a designated area. Cropping patterns are influenced by several factors, including agricultural policy, socioeconomic and environmental circumstances, water availability, and crop management strategies. Cropping patterns undergo continuous evolution throughout time and across different geographical locations due to the influence of many elements. The inclusion of this data is vital for the purpose of land management planning and conducting evaluations on food security. Therefore, it is crucial for policymakers, farmers, and agronomists to have regular updates on these shifts in cropping patterns.

Cropping patterns are hardly referenced in agricultural statistics, which primarily focus on specific attributes of particular plots of land, like their dimensions, crop kind, and developmental stage. The main sources of data are household surveys and cadastral surveys of agricultural land. Moreover, the collection of such data is often limited to a specific location and seldom encompasses vast geographical areas. The aforementioned approaches for acquiring information are characterized by their labor-intensive nature, extensive time requirements, substantial financial investments, and limited frequency of implementation. The accuracy and reliability of agricultural data, including field size, crop condition, and yield estimates, as reported by farmers, were shown to be significantly compromised. The presence of these challenges makes the task of gathering precise data on agricultural land and comprehending cropping patterns within a specific locality or over a broader geographic region arduous. Consequently, there exists a deficiency in understanding the techniques used in agricultural production in other nations. The extent of remote sensing surpasses that of traditional surveys, enabling the acquisition of field data on a regional and global scale. The use of multi-source remotely sensed data for the estimation and monitoring of farmland information has the potential to enhance understanding of the agricultural landscape. Nevertheless, a comprehensive evaluation of the application of remote sensing in mapping yearly crop trends is still lacking.

The significance of cropping activities has been widely acknowledged by the global society, leading to the formulation of the ideology and recommendations for the FAO (Food and Agriculture Organization) and GAP. The GAP aims to effectively oversee and enhance natural environments, while concurrently producing secure and nourishing agricultural goods, both food and non-food in nature. To attain this objective, the proposals put forward endorse the implementation of improved water and soil management practices at the farm level, as well as the enhancement of crop and fodder production techniques. Additionally, the recommendations emphasize the need of effective insect and disease control measures, as well as the management of energy and waste in agricultural operations. The phenomenon of global food production poses challenges to the ability of particular nations and their inhabitants to exercise influence over the food supply. Hence, it is important to possess the capability to monitor and verify the use of exclusively secure agricultural methodologies. This phenomenon will result in an augmented need for geographical data.

Remote sensing has shown to be quite valuable in tracking agricultural operations. The continuous expansion of civilian satellites, equipped with diverse sensors, enables the recording and monitoring of changes in the spatial and temporal attributes of land surfaces resulting from human activities. Nevertheless, while doing an extensive examination of the existing body of literature, it becomes apparent that a mere 10% of scholarly works pertaining to remote sensing and agriculture effectively delve into the subject matter of crop management.

There is a pressing need for an updated assessment of the potential of remote sensing in cropping systems characterizing and mapping, considering the substantial importance of this field of study. Consequently, an examination was conducted on the existing literature pertaining to remote sensing data and its use in the provision of spatial information on agricultural practices. It is worth mentioning the lack of discourse pertaining to the remote sensing-based mapping of crop types, since this subject has been extensively addressed in prior scholarly studies. The present study will go in accordance with the following outline. Section II presents a discussion of the typology of cropping practices. Section III and Section IV present a review of crop succession and cropping pattern, respectively. Lastly, Section V draws a conclusion to the article, including remarks for future research.

II. TYPOLOGY OF THE CROPPING PRACTICES

The precise definitions of certain agronomic terms lack a widely agreed-upon consensus. The abuse of specialist agronomic language in remote sensing literature is sometimes seen. In order to mitigate any potential ambiguity, it is essential to establish precise definitions for certain agronomic terms that will be used in this study. These definitions will be based on widely accepted interpretations within the field of agronomy, adhering rigorously to established agronomic conventions.

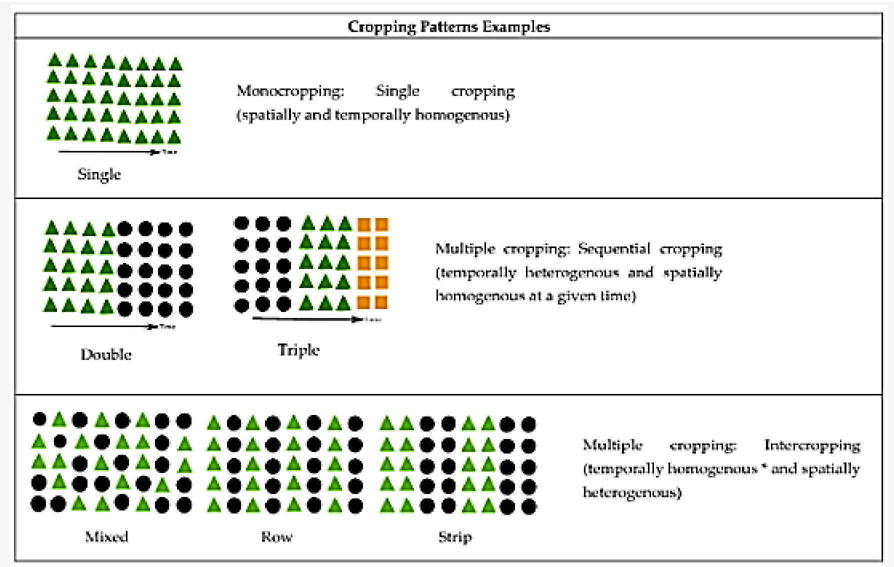

Fig 1. Several Agricultural Rotations and Provides Examples

The rotations in **Fig. 1** rotations are characterized by homogeneity, when all crops are simultaneously in an active developmental stage. The elements of a cropping system are commonly denoted as "cropping practices" within the context of this study. The word "cropping system" refers to the comprehensive strategy used by a farm for the purpose of field management over an extended period. This encompasses the selection and sequencing of crops cultivated, along with any specialized techniques implemented. Each component of the cropping system exhibits distinct cropping techniques, which may be outlined as follows: A crop management system comprises three essential components: (1) a temporal element that outlines the sequential arrangement of fallows or crops over successive years, known as "crop succession"; (2) an element, which defines the annual pattern and spatial distribution of fallows and crops within a specific land area, known as "cropping pattern"; and (3) a crop management element, which encompasses the various approaches, such as soil tillage or irrigation, employed on a given parcel of land.

Sequential cropping is a fundamental kind of multicropping, whereby two distinct crops are farmed consecutively and then harvested. Nevertheless, the majority of multicrops include the practice of cultivating many species on a single parcel of land, with the development these species cycles overlapping to some extent throughout the cultivation process. Multicrops may be categorized as either intercrops, which are limited to agroforestry or a single planting season, which involves a permanent component such as shrubs or trees occupying a piece of the land across several growing seasons. The cropping systems outlined in **Table 1** encompass a spectrum of approaches, varying from the straightforward and homogeneous nature of monocrops, where a single plant species is cultivated in consecutive rows over multiple seasons, to the intricate and diverse nature of agroforestry, where a multitude of plant species coexist within and across growing seasons. In the context of these intricate systems, it is common practice to cultivate high-value growing crops such as oil palm (Elaeis guineensis), cocoa (Theobroma cacoa), rubber (Hevea brasiliensis), and coconut (Cocos nucifera) alongside annual species, so establishing dual canopy crops. The region exhibits a coexistence of long-lived canopy plants with a shorter-lived crop, therefore establishing a complementary relationship. It is therefore plausible that these gardens have a multifunctional and multiseasonal nature, including not just culinary crops but also include woody plants.

Table 1. Different approaches to crop production

Systems	Definitions	Remarks
Alley cropping	Hedgerow agroforestry may be classified as a specific category within the broader area of agroforestry, whereby the deliberate planting of trees and shrubs is undertaken inside cultivated fields.	Row planting is a commonly used technique for the cultivation of woody plants, whereby the spacing between rows is determined by the specific species being planted and the characteristics of the surrounding terrain. The method of combining hedgerows with intercropping is sometimes referred to as "hedgerow intercropping."
Agroforestry	Mixed-use landscapes include a combination of herbaceous plants, which may consist of both annual and perennial crops, pastures, and/or animals, together with woody perennials such as shrubs and trees.	Agroforestry systems have the potential to provide a variety of goods and services from a single woody component. These include but are not limited to shelter, shade, soil or water conservation, and animal habitat.
Relay cropping	Intercropping is a widely used agricultural technique characterized by the cultivation of a secondary crop during the ongoing growth period of the primary crop, prior to its full maturation and subsequent harvest.	The temporal duration of the overlap is sufficiently limited to result in little interspecies contact. As a result of the timely sowing and safeguarding of the first crop, the subsequent crop stands to gain advantages in terms of more advantageous soil moisture conditions. The practice of cultivating a subsequent crop prior to the completion of the harvest of the first crop serves to distribute labor efforts and enhance the feasibility of the harvesting process.
Strip intercrop	The cultivation of intercrops involves the practice of cultivating separate rows for each species.	The width of the strips inside each block is sufficient to allow some plants to function as if they were components of a unified crop.
Row intercrop	Various plant species are strategically arranged in alternating blocks inside straight rows to create intercrops.	The many species within distinct rows engage in interactions with one another, whereas intra-row competition takes place among individuals of the same species. It is feasible to engage in the cultivation, application of fertilizers, and reaping of various plant species.
Mixed-species plantations	Mixed-species plantations may be classified as a kind of polyculture.	When a planter need additional yield from a secondary species, they may choose to cultivate these crops as either replacement or additive intercrops, without compromising the output of the main crop.

Intercropping	The practice of cultivating many annual crops on a piece of land during 1 planting season.	Intercropping systems can exhibit two distinct patterns: replacement intercrop and additive intercrop. In the former, each plant of a particular species within the sole crop is substituted with one plant of a single or multiple species. In the latter, more plants of a single or multiple species are introduced to an established population of sole crops.
Multicropping	The phenomenon of many species coexisting within the same geographical area, whereby some aspects of their distinct life cycles intersect.	Inter-species plant interactions may manifest when plants of different species are in close proximity to one other, often seen throughout different stages of their growth and development.
Sequential cropping	The phases of cultivation of different crops do not overlap.	Following the completion of the first harvest in the rainy season, it is common practice to cultivate a subsequent crop. The potential consequences for future harvests arise from any enduring effects on the nitrogen reservoir, weed population, and the prevalence of pests and diseases. Ideally, a minimum duration of 180-200 days would be desirable for its development. The second cycle of crop development is often characterized by its vulnerability, mostly because to the limited availability of moisture.
Sole crop	Plants belonging to the same species that have been intentionally grown in close proximity.	Plants at similar stages of development engage in mutual interactions. The crop's temporal and geographical needs may be fulfilled by the implementation of integrated management strategies, including the coordination of inputs, control measures, and irrigation practices. The automation of a task is a viable possibility.
Ratooning	The practice of allowing the leftover stumps of a crop to regenerate leads to a second harvest.	Second crop that requires less resources and grows more quickly than consecutive cropping. Second-crop yields are notoriously low and unstable, often as a result of the spread of pests and diseases. only sorghum, rice, millet, and pigeonpea may be grown.
Monocropping	The phenomenon of cultivating identical plant species on a certain piece of land consecutively across several years.	Pests, diseases, and weeds have the potential to persist through consecutive growing seasons, so presenting a significant hazard to agricultural crops.

The cropping system encompasses all essential components for the prosperous growth of crops and the balanced interaction between plants and their environment. Within this system, the cropping pattern is a fundamental element that is inseparable from the whole of the system. This phenomenon may be attributed to the use of various cropping strategies, such as cropping patterns, which serve to elucidate several aspects within a cropping system. Irrigation, tillage practices, harvest procedures, crop selection, and fallow periods are all illustrative instances of cropping techniques. Efficient and effective management of cropping systems at the field level necessitates the control of pests and diseases, maintenance of soil nutrients, conservation of water, and use of optimal cropping patterns.

Hence, there exists a strong interconnection between agricultural yield and the level of land use. Improper management and the adoption of unfavorable cropping patterns may lead to diminished agricultural output and degradation of natural resources. These negative outcomes can be attributed to the adverse impacts on water consumption, soil health, greenhouse gas emissions (GHG), and regional climate. Cropping patterns are of paramount importance within a cropping system, as they serve as a key factor in enhancing crop yield in a sustainable manner and ensuring food security.

The deliberate arrangement of spatial elements inside a cropping pattern distinguishes it from other patterns. Monocropping, which involves the cultivation of a single crop in a specific field annually, and multiple cropping, which entails the cultivation of various crops in the same field within a single year, are the two prevailing approaches. In industrialized nations, large-scale agricultural operations often prioritize the cultivation of a single crop, but small-scale farms in poor countries have long depended on the practice of multiple cropping.

The following chapters exclusively provide a comprehensive account of the agricultural techniques that were examined via the use of satellite images. Additionally, the text references certain pastoral approaches used in the management of their production. Our intention was not to create an exhaustive compilation of studies, but rather to give a selection of evidence that we consider to be typical of the extant literature.

III. CROP SUCCESSION

Crop succession is commonly known as a recurrent pattern of years characterized by alternating periods of crop cultivation and fallow periods. Hence, several types of agricultural succession may be seen, such as crop rotation, fallowing and monoculture, which involves the alternating cultivation and fallow periods. Given the distinct impacts of these three crop succession methods on food production and resource management, it is essential to differentiate among them.

In the context of agricultural production planning, it is often observed that the cultivation of multiple crops in rapid succession on a single plot of land is not feasible. Failure to occur in this regard would result in a decrease in the soil's fertility, rendering crops more susceptible to infestations and illnesses. Nevertheless, it is possible that there exists a recommended sequence for the cultivation of agricultural produce. In the aforementioned instances, it is essential to assert that certain prerequisites for crop rotation must be satisfied. In some regions, the consecutive cultivation of cotton may result in the proliferation of pests due to the presence of residual seeds.

Similarly, the continuous cultivation of sorghum may give rise to challenges associated with the weed striga, while the successive cultivation of potatoes may lead to the presence of nematodes in the soil. The practice of intercropping soybeans with cereals is recommended for the purpose of restoring soil fertility. The restoration of soil fertility may be facilitated by the natural process of plant regrowth during a designated period of land fallow. For example, after the harvest of cereal crops such as maize, it is advisable to implement a period of fallow. On the other hand, using a rotational grazing system for cattle and agricultural purposes might potentially provide advantageous outcomes. The temporal interval between plantings is mostly dictated by the requirements of the subsequent crop in the succession.

Soybeans, maize, and fallow are crop rotation cycles that may be used consecutively within a given agricultural plot. It is customary to implement a crop rotation scheme that maintains a somewhat consistent allocation of land for each crop on an annual basis. Personnel at agricultural experimental stations, such as those employed in the field of agriculture, may suggest a limited number of cycles for crop rotation. The Gezira plan in Sudan is an illustrative case that employs an 8-year rotation cycle integrating fallow-fallow-sorghum-fallow-cotton-fallow-fallow. The Gezira rotation system has been substituted by the implementation of a 4-course cycle including the cultivation of groundnuts (or sorghum), wheat, cotton, and fallow periods. This shift in agricultural practice has been facilitated by the advent of insecticides, herbicides, and mechanized farming techniques.

The implications of crop succession requirements on agricultural production planning are notably significant. The analysis of historical land usage is of utmost importance, as is the need to guarantee that future production plans facilitate the implementation of highly productive strategies. While it is true that considering these elements may be achieved by the implementation of a recommended crop rotation cycle, the consequent inflexibility in choosing production methods for future years is seen unfavorable.

Crop Rotation and Monocropping

Crop rotation is a highly efficient approach to soil management that effectively mitigates the occurrence of pests and diseases, facilitates the removal of excessive nutrients from soil, and mitigate the issue of nutrient deficiency. The use of crop rotation is crucial for low-input agricultural systems, while intensive farming operations tend to rely on monocropping as a more prevalent practice, mostly owing to their greater access to abundant resources. In the practice of crop rotation, the selection of successive crop species is not arbitrary, but rather follows established standards. For example, it is advisable to rotate a nitrogen-deficient cross with nitrogen-fixing crops, and to substitute low-biomass crops with crops composed of high biomass.

The use of annual crop type maps enables a direct assessment of monocropping and crop rotation practices via the extraction of the chronological succession of types of cross at a scale of individual fields for a period beyond two years. In order to examine the relationship between market prices and the corn-soybean rotation dynamic, Zahran, Saeed, and Elazizy [2] conducted a study using 10 years of yearly remote sensing cross categorization retrieved from the USDA (United States Agricultural Department) National Agriculture Statistics Services. Accurate crop type maps of the Kiev region in Ukraine were constructed by utilizing an integration of neural networks on radar and optical image time series collected from 2013 to 2015. A map was then created by the Bilotserkivskiy district, delineating regions where the cultivation of illicit crops such as winter rapeseed, winter wheat, maize and sunflower had persisted for a minimum duration of two to three years in identical locations [3].

Zhou, Wang, He, and Shan [4] constructed the Representative Crop Rotation by integrating and examining mappings of major agricultural cross that are sold on the commodity market in the United States. These maps are generated on a yearly basis by the USDA using remote sensing data. The use of the Edit Distance (RECRUIT) algorithm for the purpose of selecting representative crop rotations. The process of transforming land-use dataset into cross rotations histories may seem straightforward in theory. However, Potapov et al. [5] highlighted that the presence of misclassifications in categorization might significantly impact the results. In light of this, it has been suggested that a matrix of land use modifications from one year to another, which include either illogical disallowances or exceptionally uncommon occurrences, be used to identify potential errors in classification. The investigation of techniques for improving the identification of crop types via the limitation of classification models may also include the usage of a priori information about localized rotation patterns.

Crop-Fallow Fallowing/Rotation

The term "fallow" is used to refer to agricultural land that has been unused for a period of one year or more prior to being cultivated again. Approximately 28% (equivalent to approximately 4.35 million square kilometers) of the global agricultural areas are intentionally left uncultivated, with the purpose of facilitating the restoration of natural resources like water and soil subsequent to their use. To ensure well-informed decision-making about matters such as the choice between agricultural intensification and expanding farmland area, as well as the allocation of valuable on-farm water resources, it is essential to possess current and comprehensive understanding of the quantity, frequency, and duration of fallow land. The majority of contemporary assessments pertaining to land use and land cover tend to aggregate cultivated and fallowed fields into a unified category. Mapping fallow land poses significant challenges owing to the extensive range of fallow treatments now used. Various factors such as climate and soil conditions, cropping practices, crop failure, and natural regeneration might contribute to the resemblance of a fallow field to an actively farmed field or the surrounding ecosystem.

Notwithstanding these challenges, there are instances of methodologies used to characterize fallow land via the utilization of remote sensing data. The process of characterizing fallow land is often carried out in three sequential steps: (1) the identification and delineation of cultivated land areas; (2) the identification and delineation of temporary periods of non-cultivation within the cultivated land areas using satellite imagery collected over time; and (3) the analysis of several years of fallow maps to determine the frequency of fallowing, referred to as the fallow age. In their study conducted in Niger, Doiron, Legagneux, Gauthier, and Lévesque [6] devised a categorization methodology that relied on several phenological attributes of the vegetation, such as the Normalized Difference Vegetation Index (NDVI), amplitude, and decline rate. These characteristics were tracked using the MODerate-resolution Imaging Spectroradiometer (MODIS). In their study, Forkuor, Conrad, Thiel, Landmann, and Barry [7] provided evidence to support the need of including a masking technique to differentiate non-agricultural regions from agricultural fields as a critical pre-processing measure. **Fig. 2** presents the data that suggest a higher NDVI value in fallowed fields compared to unmanured planted areas, and further indicates a more pronounced reduction in NDVI in the former.

Yan et al. [8] conducted a study in which they used a NDVI time series obtained from Landsat dataset, supplemented by the MODIS dataset and ground data gathered on a monthly basis, to track land fallowing in the California Central Valley. The researchers used a decision-tree approach to allocate land-use classifications to each field. This included evaluating a collection of phenological parameters obtained from time series of the NDVI, as well as comparing land-use modifications to prior years. The categorization technique yielded an accuracy rate over 85%. Bassa, Chamorro, José-María, Blanco-Moreno, and Sans [9] observed that the predominant errors were associated with field boundaries or partial plantings, along with misidentifications of recently established permanent agricultural fields as young fallow areas.

The FANTA (Fallow-land based on Neighborhood and Temporal Anomalies) technique was developed and implemented by Wallace, Thenkabail, Rodriguez, and Brown [10] in order to address the constraints associated with collecting ground data in the aforementioned region. This algorithm effectively and consistently delineates the status of farmland (whether it is fallowed or cropped) with producer and user precision surpassing 75%. The FANTA technique examines the correlation between the present pixel greenness in an agricultural setting and its historical greenness, as well as the greenness of the remaining refined pixels within a certain geographic region. While FANTA demonstrated efficacy in the cultivation of yearly row crops, the research faced a similar challenge as Wallace, Thenkabail, Rodriguez, and Brown [11] when applying it to perennial crops.

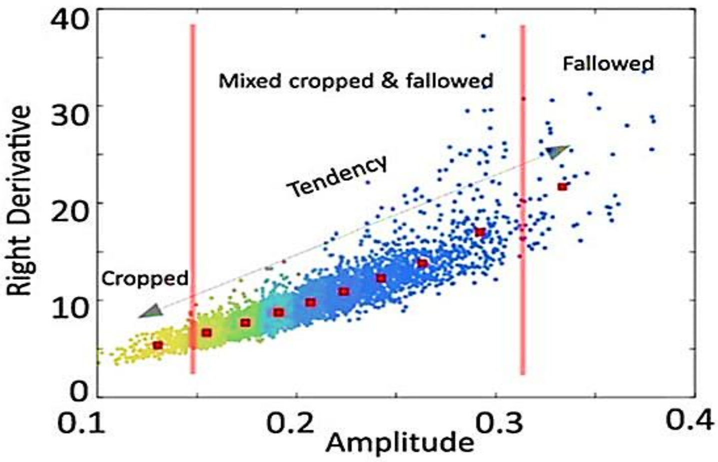

Fig 2. Scatter Plots Derived from The Study Conducted by Friendly and Denis [12], Illustrating the Observed Phenological Differences Between Farmed Land Without Manure Application and Fallowed Land in Niger.

These changes were assessed using the MODIS NDVI. Following the conclusion of the rainy season, the fallowed fields exhibited a more pronounced amplitude and a more rapid drop in comparison to the cultivated areas that were not subjected to manure application.

The aforementioned examples demonstrate that there is a tendency to confuse fallows with the neighboring crops, especially perennial crops, or the natural flora. This confusion is seen across several geographical regions because to variations in temperature, soil conditions, and agricultural practices. Hence, in many regions around the world, there persists a deficiency of dependable mechanisms for monitoring cultivated, fallow, and uncultivated land. An area that warrants further investigation is to the use of systematically obtained and processed satellite imagery for the purpose of monitoring the long-term evolution of vegetation on a consistent land parcel.

IV. CROPPING PATTERN

The term "cropping pattern" refers to the annual pattern and spatial prearrangement of cross, or pasture and crops, within a designated area of land. In contrast to the practice of single cropping, multiple cropping involves the cultivation of two or more separate crops simultaneously.

Single Cropping

The term " single cropping" alludes to the spatial configuration of crops during the practice of single cropping. The primary emphasis of remote sensing research lies in the cartographic representation of the spatial distribution of arboreal agricultural commodities, such as vineyards and orchards. The investigation of annual crop row orientation has been limited to a few studies.

Tree Crop Planting Pattern

The mapping of tree crops alongside annual crops is seldom conducted because to the disparities in their respective production techniques, despite the fact that tree crops are often found in agricultural landscapes. Understanding the geographical location and agricultural practices associated with landscape ecology studies and economic surveys is beneficial. Support subsidies for certain tree crops, like nut groves, and vineyards, are delivered under the ECAP (European Common Agricultural Policy) for designated tree planting density and plot size. Consequently, remote sensing has emerged as a valuable instrument serving several objectives, such as subsidy regulation. Initially, its use was focused on generating a comprehensive map delineating the locations of perennial crop cultivation.

The wide range of variations in the characteristics of the item being studied, including plant arrangement, density, and structure, presents an issue for optical remote sensing due to its geographical variety and diversity. approaches for mapping vineyards and orchards routinely have been advanced using a textural approach. These approaches use several structural metrics, such as indices retrieved from autocorrelograms, co-occurrence matrix, frequential analysis, and Markov random fields. Yao, Son, Ma, and Rossi [13] shown a high level of accuracy (92 percent) in the identification of cover crops and assessment of olive tree surface by the use of multispectral photography. Yan et al. [14] elucidated the utilization of Geographic Information Systems (GIS) and models to differentiate between orchards and alternative land uses in their investigation on nut crop and fruit management techniques. Regrettably, the accurate identification of tree crop species has not been attained without a vital degree of competence in the field.

The predominant area of interest in remote sensing research pertaining to planting patterns for tree crops has been centered on wine grapes. Olive and nut orchards have been somewhat neglected in terms of research and development. Nevertheless, the majority of writers have underscored the need of acquiring high spatial resolution photographs, namely those with metric and sub-metric resolution, in order to effectively identify and analyze the cropping structure within a given field. The ability to differentiate between various cropping systems, such as pergola vs basic row, in massive vineyards may be attributed to the use of decametric resolution pictures obtained from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) with a longitudinal resolution of 15 m. Unmanned Aerial Vehicles (UAVs) and Unmanned Aerial Systems (ULAs), which operate autonomously without human pilots, were used to capture aerial photographs of the utmost quality.

Manoharan, Gajendran, Padmanabhan, Vignesh, Rajesh, and Bhuvaneshwaran [15] utilized high spatial resolution images obtained through the use of an Unmanned Aerial Vehicle (UAV) to showcase the efficacy of a straightforward co-occurrence matrix-oriented indices and local Fourier analysis in the identification of vineyards and the characterization of intra-area cropping sequences, such as pergola systems and simple row. Additionally, the study successfully determined the orientation and scale of rows and inter-rows within the vineyards. In a similar vein, Lv et al. [16] used a textural algorithm based on variograms to discern between olive orchards, woodlands, and other forms of vegetation. In a more comprehensive context, Onufriienko and Taranenko [17] utilized wavelet analysis of the texture of images to differentiate between tree crops with periodic, directed, and varied sizes. Raja [18] have proposed the use of wavelet decomposition for the purpose of enhancing the identification and characterization of vineyards, particularly in relation to their cropping patterns and row orientation. A considerable number of studies in the academic literature have explored the use of three-dimensional (3D) methodologies for characterizing the structure of tree crops, mostly using Light Detection and Ranging (LiDAR) technology. However, several scholars argue that LiDAR technologies provide more relevance as a tool for mapping tree crowns and extracting structural information.

Numerous research have focused on the assessment of tree crown health, including physical delineation of trees and utilizing imagery with spatial resolutions below one meter. In the domain of automated tree top delineation, several methodologies and algorithms have been devised by Zhen, Quackenbush, and Zhang [19]. These include techniques such as valley-following and local maximum filtering. It is worth noting that the effectiveness of tree identification is often contingent upon the high spatial resolution of sub-meter imagery. While the primary purpose of these algorithms is to locate trees in deep forest areas, they also demonstrate effective performance in less intricate situations such as fruit orchards.

The software known as CLUstering Assessment (CLUAS) was developed by García-Torres, Peña-Barragán, Gómez-Candón, López-Granados, and Jurado-Expósito [20] with the aim of offering environmental parameters and quantitative agronomical indicators for olive groves. These parameters include the count of olive trees, the dimensions of individual trees, the proportion of soil sheltered by trees, and the latent throughput determined through density computations. In order to get accurate outcomes in the search for trees, the utilization of hyperspectral and/or unmanned aerial vehicle (UAV) technology is essential. The potential of high-resolution stereo photographs for generating surface and elevation models of trees is evident. However, their effectiveness is contingent upon the presence of sufficient distinction between the crown of the trees and its instantaneous surroundings, ensuring accurate stereo pairs matching.

Multiple Cropping

Sequential Cropping

This refers to the practice of cultivating and harvesting many crops in rapid succession during a single growing season. It is possible to get many harvests within a single year in places that receive sufficient rainfall and have a prolonged period without frost. The fundamental economic incentive for adopting successive cropping systems lies in the rapid enhancement of land productivity. Nevertheless, there are other factors that may also be associated with sequential cropping, outside from ecological crop management practices. For example, a considerable number of farmers choose to cultivate an additional crop subsequent to the conclusion of the rainy period in order to initiate the use of no-till activities. It has been suggested that farmers have the potential to enhance their crop yields via the use of measures aimed at mitigating the erosion-induced loss of chemical compounds and organic matter, as well as promoting water retention in the soil. The proliferation of Asiatic rust soybean illness within Southern Amazon field was facilitated by the extensive use of the monoculture of soy. However, the implementation of sequential cropping has potential as a strategy to mitigate this issue. One additional advantage of double cropping is its potential to mitigate land use changes, namely the occurrence of tropical deforestation resulting from agricultural expansion.

The precise observation of phenological cycles and the documentation of seasonal fluctuations and crop schedules in sequential cropping structures see **Fig. 3** rely on the use of remote sensing-based techniques that provide high temporal resolution time series data for the characterization of sequential multiple cropping. This requires a significant degree of specialized expertise about region-specific farming practices) and NDVI.

The use of MODIS data has facilitated the mapping of sequential multiple cropping in numerous agricultural regions characterized by extensive areas, such as the China, Brazil, and United States. Shammi and Meng [21] conducted an assessment of the efficacy of EVI and NDVI time series in the classification of crops and cropping systems across the Kansas Great Plains. Subsequently, the researchers used this data to generate a map. Vu Dang, Truong Thi Thu, Dong Thi Ha, and Nguyen Mai [22] used Fourier and wavelet analytic techniques to map the double (winter wheat-cotton, winter wheat-rice, and winter wheat-maize) and single (maize or cotton) cropping systems in Northern and Central China. Lu, Kuenzer, Wang, Guo, and Li [23] have used vegetation index of the MODIS time series to examine the potential for differentiating between single-cropping systems (specifically soybean) and double-cropping models (involving soybean-cotton or soybean-maize). Subsequently, comprehensive regional mappings of these models spanning the whole Mato Grosso state were generated, drawing upon the aforementioned research studies.

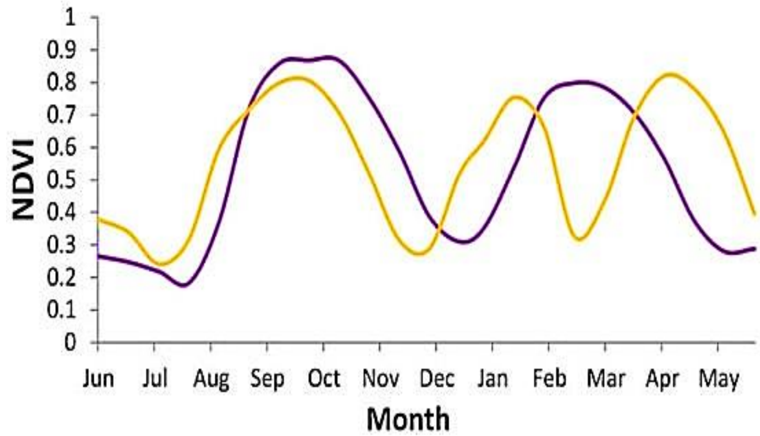

Fig 3. An Instance of The Smoothed Time Series NDVI Profiles Retrieved from MODIS For Both Consecutive Double-Cropping and Triple-Cropping Systems

The presented profiles in **Fig. 3** illustrate the intensification tactics used in South Asia, which include the cultivation of two consecutive cycles of rice inside a single growing season (shown by the purple line). Additionally, a brief development cycle of the grain legume crops is integrated between 2 cycles of rice (represented by the orange line).

In the context of these research, it is common practice to apply pre-processing techniques to Vegetation Index (VI) time series in order to mitigate the potential misclassification resulting from noisy dataset. Whereas MODIS VI data consists of composite figures, it is worth noting that tropical regions with a pronounced wet season may nonetheless have low noise VI values. In order to rectify these results, a range of smoothing procedures might be used, along with the utilization of wavelet analysis. The majority of research use supervised classification techniques, whereby reference data, often obtained from ground observations, is used for training purposes. Unsupervised classification procedures are somewhat less prevalent, although they have shown promising outcomes via the use of hyperclustering algorithms. Clustering methodologies do not need the use of ground data, which may be laborious and demanding in terms of time and resources, particularly when data acquisition has to be conducted twice over the span of a growing season across extensive regions. However, the process of categorizing the ultimate classes is contingent upon possessing sufficient information about the agricultural practices specific to the local and regional contexts. This knowledge enables the establishment of connections between various phenological cycles and crop calendars, eventually facilitating the identification of different kinds of crops.

The primary concern in categorization is to the significant intra-class diversity seen within consecutive cropping systems. Diverse crop calendars can be attributed to variations in regional climatic conditions, occasional climatic anomalies (e.g., prolonged dry seasons leading to late sowing), as well as logistical considerations, like the extended sowing season required for large-scale farming operations. Various methodologies are used to categorize satellite time series in order to tackle this problem. Time series data may undergo processing to extract various characteristics. For instance, Roy [24] generated 36 parameters based on the MODIS VI time series, such as standard deviation, amplitude, median, mean, maximum and minimum of NDVI and EVI for both yearly wet and dry seasons. These features were then used for classification purposes. In the study, the scientists conducted a search to determine the optimal dates within a time series, which would provide the highest separability detachment between the six distinct EVI profiles modules of cropping models.

Novel methodologies, such as wavelet analysis or Fourier analysis, issue a fresh approach to representing picture time series, enabling a more detailed examination of vegetation phenology. However, it should be noted that these strategies rely on a decrease in dimensionality, which always results in a loss of information. In order to tackle this matter, novel methodologies, such as the use of Dynamic Time Warping (DTW) methods including temporal weight, were effectively examined for the purpose of categorizing land cover categories, encompassing both double and single cropping models. This classification was achieved by the application of shape matching algorithms using MODIS EVI time series data. In their study, Bailly, Arvor, Chapel, and Tavenard [25] used a Dense Bag of Temporal SIFT Words methodology to describe vegetation index time series. This technique entails encoding the time series as a collection of local characteristics, including peaks and steady growth patterns. Subsequently, the aforementioned characteristics were used to construct histograms that depict patterns associated with novel representations of time series data. These histograms were then subjected to classification using conventional machine learning algorithms, like the support vector machine (SVM).

The potentials of Synthetic Aperture Radar (SAR) imaging used to monitor different cropping models was assessed via complementary investigations. Several studies have provided evidence of the capability of ENVISAT Advanced SAR time series in determining triple- cropped, double- cropped, and single-cropped rice fields within the Mekong Delta River. The study conducted by Phan, Le Toan, and Bouvet [26] shown that the identification of a substantial rise in backscatter during the first stages of the rice growth cycle facilitated the timely generation of rice maps in the early part of the season. Nevertheless, the aforementioned research was constrained by the inadequate frequency of SAR data collecting. Temporal averaging and the Angle of Incidence Normalization approaches were used to integrate acquisition from different years and tracks. The aforementioned constraint has been obsolete as a result of the deployment of the Sentinel-1 sensor of SAR, which offers a denser time series characterized by a consistently maintained the angle of incidence.

Intercropping/Agroforestry

Remote sensing research often does not prioritize the investigation of intercropping. This phenomenon may be attributed to the intra-field variability infra-metric scale in varied crop grounds. Agroforestry models, which will be thoroughly examined in subsequent sections, may be regarded as the only exception.

Agroforestry involves the deliberate cultivation and maintenance of plants, trees, and even animals in close proximity to one other. This creative approach to land management yields benefits to the economy, society, and the environment. The incorporation of farm trees and agricultural field contributes to the enhancement of food security, health, environmental sustainability, and income, even in highly industrialized nations. The practice of agroforestry has been shown to have several beneficial effects on food production. These include the promotion of higher fertility, the mitigation of soil erosion, the improvement of water quality, and the substantial sequestration of carbon.

The monitoring of agroforestry systems via remote sensing is challenging due to the geographical heterogeneity and intricate nature of these cropping systems. Agroforestry encompasses a diverse range of cropping patterns, which span from the systematic intercropping of many crop types to the haphazard arrangement of numerous tree species of varying sizes under a closed canopy. The extensive range of agroforestry systems presents a considerable challenge in distinguishing them just based on their spectral signature. Previous studies have employed the spectral response of Landsat TM as the sole criterion for classifying agroforestry systems. However, this approach has been limited to scenarios where the focus is on a singular tree species, such as monoculture rubber tree cultivation or exclusive implementation of poplar-based agroforestry systems within the examined region.

Lamanda, Malézieux, and Martin [27] proposed a methodology for assessing the complexity and structure of agroforestry systems based on coconuts in Melanesia. This approach included leveraging in-field observations as a means of interpretation, and specifically presented a Canopy Closure Index retrieved from monogram of Quickbird imagery. To establish a comprehensive understanding of the agroforestry cropping pattern and its applications, it is important to differentiate the constituent elements of the pattern, namely trees, rows, and stripes. As a result, it is necessary for photographs obtained from suppliers such as Ikonos, Geoeye, Quickbird, Worldview, and Pleiades to possess a minimum spatial resolution of 1 meter. Bhaskaran, Paramananda, and Ramnarayan [28] conducted a study where they showcased the ability of pixel-oriented Ikonos image classifications to differentiate between intercrops (coffee and banana), monocrops (such as eucalyptus and mango), and crops that are grown alongside Uganda’s shading trees (albizias coffee). This distinction was achieved by integrating Haralick textural indices that are linked to radiometric profiles. The study conducted by Ozturk and Colkesen showcased the effectiveness of a WorldView2 image classification method in distinguishing between various planting structures and levels of heterogeneity in cocoa-oriented agroforestry models in Cameroon. This approach utilized multiscale dissections and the combined utilization of spectral and textural indices.

V. CONCLUSION AND FUTURE PROSPECTS

The significance of agriculture in sustaining human existence lies in its ability to generate critical resources such as food, clothing, fuel, and raw materials. In the present day, the need to perform this purpose arises in light of the pressing concerns surrounding environmental sustainability and climate change. Additionally, the task is compounded by the historical context of a population that is now at an unprecedented level and continues to grow gradually. Moreover, it is essential to ensure that agricultural practices remain economically viable, so enabling the provision of sustenance and employment opportunities. Remote sensing has the ability to assist in the adaptive development of agricultural practices by providing consistent and replicable data on crop quality at various scales and for diverse stakeholders. This may contribute to addressing the significant challenge at hand. A comprehensive examination of the available literature reveals that the remote sensing society has mostly focused its efforts on the identification and categorization of agricultural activities. The methodology and data sources employed in these attempts encompass a wide range, albeit predominantly confined to case studies. The challenge arises when attempting to capture and describe agricultural operations at the level of individual plots across broad regions due to the lack of suitable satellite datasets, specifically those that provide a comprehensive time series of radar and optical resolution pictures in the decametric range.

The enhancement of research efforts in this field, along with the advancement of training programs for the upcoming generation of satellites equipped with LiDAR and hyperspectral sensors, should be supported by the growing accessibility of remote sensing data. Specifically, the availability of free European Sentinel-1 constellations dataset and Sentinel-2 constellations dataset that is best for tracking small- and medium-sized fields, and the introduction of new approaches of data processing, like deep learning and data mining, contribute to this endeavor. In anticipation of forthcoming advancements in satellite sensors, it is imperative for researchers to explore the optimal utilization of current satellite technologies. This can be achieved through the integration of data from multiple satellite sensors, such as optical and radar sensors with varying resolutions, in conjunction with other sources of information, including expert knowledge and census data. The objective is to generate comprehensive maps delineating homogeneous land units. Hence, it is expected that remote sensing will play a vital duty in sustainability management of these complex models via the enhancement of spatial understanding of cropping systems and agricultural practices.

CRediT Author Statement

The author reviewed the results and approved the final version of the manuscript.

Data Availability

The datasets generated during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interests

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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