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Yield prediction in field crops through satellite and remote sensing

Laxman Navi, Kushal, Gangadhar K and Santosh Araganji

Abstract

The global population is expected to reach 9.7 billion by 2050, necessitating a 60% increase in food production from current levels to meet the nutritional requirements of billions. The most substantial population growth is anticipated in developing countries, where individuals grapple with significant challenges such as socio-economic issues, food insecurity, and poverty. Thereby, today's agriculture sector needs to produce higher yields and food grain production. Under changing climatic conditions, predicting the crop yield before harvest is crucial for handling natural disasters, ensuring food availability, predicting prices, fighting poverty etc., for policy planners and decision makers it helps to determine the levels of imports or exports needed for the food grains in a country (Noureldin *et al.*, 2013). Remote sensing is a novel technology in which its data can be used to estimate crop yield. It furnishes data on crop cultivation and its surroundings, enabling the estimation of crop production. The utilization of remote sensing satellite data and crop simulation models is crucial for monitoring and managing crops, particularly in the context of food security measures.

Keywords: Remote sensing, yield prediction, satellite and sustainable agriculture

Introduction

Over the past century, the world's population has experienced a fourfold increase. In 1915, the global population stood at 1.8 billion individuals. As of November 15th, 2022, the latest estimate from the UN indicates that the world's population has reached a significant milestone of 8 billion people, with projections anticipating an increase to approximately 9.7 billion by the year 2050 (Anon., 2022) [1]. The increase in population, combined with rising incomes in developing countries that result in changes in dietary habits, such as a heightened preference for protein and meat consumption, is fueling a rise in the global demand for food. Projections suggest that food demand is poised to rise anywhere from 59 to 98 percent by the year 2050. (Anon., 2022) [1]. The present Indian population is 1.42 billion and that was expected to reach 1.5 billion by 2030 and 1.67 billion by 2050. Whereas the present Indian food grain production is 330 MT and it is need to increase the food grain production upto 400 MT to meet the food requirement. The world's population is projected to be 9.7 billion by 2050, consequently, food production has to increase by 60 percent from contemporary production levels to fulfill the nutritious need of the billions of people. The highest rise of the population will be in the developing countries, where people are facing major challenges in socio-economic, food insecurity and poverty. Thereby, today's agriculture sector needs to produce higher yield and food grain production. Under changing climatic conditions, predicting the crop yield before harvest is crucial for handling natural disasters, ensuring food availability, predicting prices, fighting poverty *etc.*, for policy planners and decision makers, it helps to determine the levels of imports or exports needed for the food grains in a country (Noureldin *et al.*, 2013) [3]. Remote sensing is a novel technology in which its data can be used to estimate crop yield. Supplying details about crop cultivation and its surroundings, it enables the estimation of crop production. The monitoring and management of crops through the utilization of remote sensing satellite data and crop simulation models are crucial elements in ensuring food security (Fig. 1 & 2). The world's population is increasing day by day nut the per capita arable land is decreasing and it is necessary to increase the food production per unit time and per unit space in order to attain the food security and nutritional security.

Under changing climatic condition, the food grain production is fluctuating and it is difficult to attain the food security and nutritional security. So yield prediction before the harvest of the crop is necessary and it will help for attaining the food and nutritional security.

Need for yield prediction

Predicting crop yields before harvesting is pivotal in lessening the impact of natural disasters, ensuring food security, estimating food grain market prices, and reducing poverty. Early forecasts of substantial cereal yields also empower policymakers and decision-makers to assess necessary import or export levels (Noureldin *et al.*, 2013) [3]. Climate change-induced natural occurrences, like sudden heavy upstream rainfall causing flash floods, often damage nearly ripe rice in wetlands. Hence, forecasting crop yields before harvest becomes critical in minimizing losses, achieving intended yields, and maximizing profits. Additionally, it's crucial to research and develop yield prediction models, particularly during crop maturity stages, given the adverse effects of climate change.

Different methods of yield estimation

1. **Field Survey:** They collect ground truth crop condition which helps for yield prediction.
2. **Crop models:** It simulates the crop growth and development based on climate, soil, genotypes and crop management.
3. **Statistical models:** Here they use climatic variables and output from other models to simulates the yield of crop.
4. **Remote sensing:** They capture current crop health status to forecast the yield**.**

Crop yield prediction

To predict crop yields, it is crucial to comprehend the amount of sunlight plants receive and their water requirements. Plant growth is contingent on these factors, yet numerous other elements, including temperature, humidity, and soil type, influence plant development. The quantity and quality of global crop production significantly impact food security, especially in developing countries where agriculture remains a vital part of the economy. Utilizing remote sensing data proves invaluable in estimating the light received by plants and, consequently, predicting crop yield. Serving as a potent tool for crop yield estimation, remote sensing data offers insights into growing crops and their environmental conditions, facilitating accurate predictions of crop production. In the realm of agriculture, remote sensing data functions as a form of data analytics, enabling the anticipation of yield well before the harvest. This article delves into comprehensive insights about remote sensing data and its applications in agriculture.

What constitutes crop yield data in agriculture?

Crop yield data refers to information regarding the quantity of crops cultivated by an individual farmer or a group of farmers. It encompasses the harvested crop amount per hectare of land and can be quantified in tonnes, bushels, or other relevant units based on the specific crop. Within agriculture, farm yield data holds significant importance as it aids farmers in determining the optimal planting quantities for upcoming seasons. Furthermore, this data assists in pinpointing any issues affecting their crops that require immediate attention. Additionally, yield data serves as a metric to track progress towards global objectives set by governments, non-governmental organizations, and other stakeholders. Moreover, it serves as a tool to identify both strengths and weaknesses in farming practices, allowing for recommendations to enhance productivity based on this information. Yield data plays a crucial role in informed decision-making across various facets of farming, including:

Seed selection: Employing yield data to select varieties and hybrids ensures the cultivation of the most lucrative seeds for optimal field planting.

Pest management: By observing plant growth, yield data assists farmers in deciding the optimal timing for implementing pest management strategies. This approach can minimize the reliance on pesticides, leading to increased profitability.

Irrigation scheduling: Leveraging insights from yield monitors empowers farmers to refine their irrigation schedules, contributing to water and cost savings while sustaining high yields.

What constitutes remote sensing data?

Remote sensing denotes the practice of acquiring information about an object or occurrence without direct contact, employing a non-invasive approach. Within agriculture, it serves to oversee the conditions of crops, soil, and moisture. Remote sensing harnesses various electromagnetic radiation (EMR) emissions, including radio waves, microwaves, infrared, visible light, and ultraviolet light. Its application in crop monitoring facilitates the assessment of crop growth progressions over time and furnishes insights into crop conditions at specific spatial and temporal junctures. This data aids in estimating crop yields and determining optimal harvest times. Furthermore, remotely sensed data serves multiple purposes, encompassing the measurement of land-use alterations, monitoring crop growth and yield, gauging soil moisture and salinity, identifying pest infestation levels, and overseeing environmental pollution levels.

What defines crop yield prediction?

Crop yield prediction refers to the estimation of the anticipated or potential output of a particular crop within a designated area and during a specific growing season.

Remote Sensing

Remote sensing is the practice and science of acquiring information about an object without direct physical contact between the object and the sensor.Process of remote sensing:

a) Energy Source or Illumination (A)
b) Radiation and the Atmosphere (B)
c) Interaction with the Target (C)
d) Recording of Energy by the Sensor (D)
e) Transmission, Reception, and Processing (E)
f) Interpretation and Analysis (F)
g) Application (G)

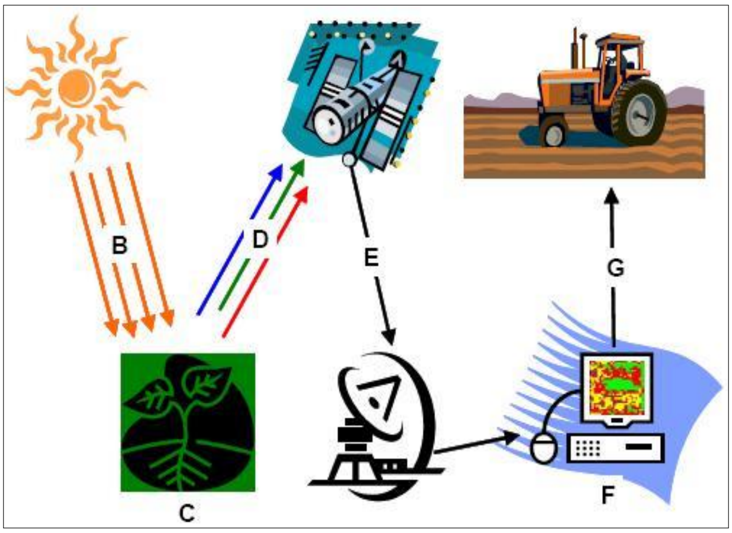

Fig 1: Remote sensing process

Types of remote sensing

Passive remote sensing: Systems that gauge naturally accessible energy can only operate When the Earth is being illuminated by the sun.

Example: Sun

Active remote sensing: It involves the generation of its own energy for illumination, with the sensor emitting radiation directed toward the target under investigation. The sensor then detects and measures the radiation reflected from the target, allowing for measurements to be obtained at any time, irrespective of the time of day or season

Example: LASER, RADAR

Remote sensing

Satellites inherently possess the capability to provide information about the spatial variability in crops due to both natural factors and agronomic practices. Certain farmers have already experienced advantages from satellite data. Remote sensing images obtained from satellites like LANDSAT, SPOT, and IRS LISS III have been effectively utilized to differentiate crop species and identify areas experiencing crop stress. Future commercial satellites are anticipated to feature optimal sensor specifications for Precision farming, including a 3-day repeat coverage, spatial resolution ranging from 1 to 4 meters, and the delivery of images to users within 15 minutes after acquisition.

Currently, the IKONOS satellite from Space Imaging has the ability to furnish multi-spectral data with a spatial resolution of 1 to 4 meters for India, enabling access to real-time information about the crop's actual state in the field. IKONOS is notably paving the way for making agricultural monitoring a reality, facilitating farmers in achieving their management and planning objectives. Additionally, merged images combining LISS III and PAN from the existing IRS series satellites can effectively display all crop fields, aiding in field boundary detection and the updating of cadastral information, including cultural and management details.

Remote sensing images provide a comprehensive view of all fields in a village or block, allowing the early detection of problems compared to ground surveys. This enables timely remedial actions before stress extends to other parts of the field. During field surveys, GPS can be employed to pinpoint stressed areas for detailed examination. Crop vitality indicators can also be deduced using images acquired at various times during a season. When integrated with crop models through calibration or re-initialization, such data proves valuable in predicting crop yields (Barnes *et al*. 1996).

How remote sensing works?

It starts with illumination of energy from source that interacts with the target object. The target object absorbs some fraction of electromagnetic radiation and reflects back some fraction that is specific to the target (Spectral signature). This reflected radiation is recorded by the sensor mounted on the satellite (remote sensing platform). This recorded information is sent back to the ground station which is forwarded to the headquarters

Yield Monitors: These devices for measuring crop yield are installed on harvesting equipment. The monitor records and stores yield data at regular intervals, along with positional data received from the GPS unit. Subsequently, GIS software processes the yield data to generate comprehensive yield maps.

How remote sensing works?

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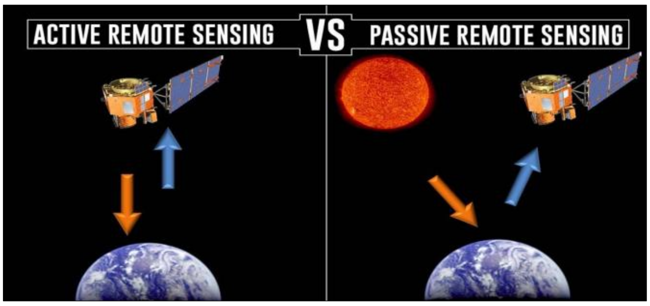


Fig 2: Types of remote sensing

Remote sensing platforms

As we know sensors make the core of remote sensing process, but where did even they present? These sensors are mounted on to some objects/equipments called as remote sensing platforms. There are three platforms of remote sensing based on their location as fallows,

a) Ground based: Tripod stands, digital cameras, vehicles (a&b)
b) Air borne: Drones, balloons, airplanes (c&d)
c) Space borne: Satellites (e)

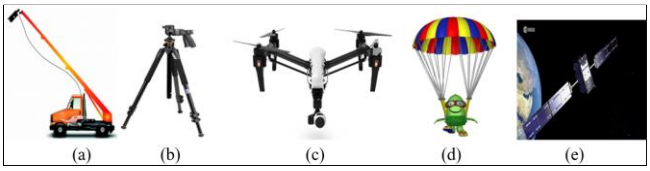


Fig 3: Remote sensing platforms

Satellites

The satellites form a very good remote sensing tool to assess the spatial as well as temporal variability associated with the all-precision farming practices. A satellite is a deliberately positioned artificial object in orbit.

Ex: Sputnik 1, launched in 1957 by the Soviet Union, stands as the inaugural artificial satellite in human history

These satellites are launched into the space from earth from various vehicles called "Satellite launching vehicles". These satellites will contain booster pumps, payload (sensors), fuel and solar panel. In these satellites, the sensors are situated to capture the variability data from the earth (image/analog/digital data) and the same data will be sent top ground stations to process and user the data for various purposes.

Types of Satellites

Geostationary Satellites

Geostationary satellites, positioned at an altitude of around 36,000 kilometers directly above the equator, play a crucial role in receiving remote sensing data.

Polar-Orbiting Satellites

A polar orbit refers to a satellite positioned in proximity to the poles or directly above them. This type of satellite is primarily utilized for Earth observation over time.

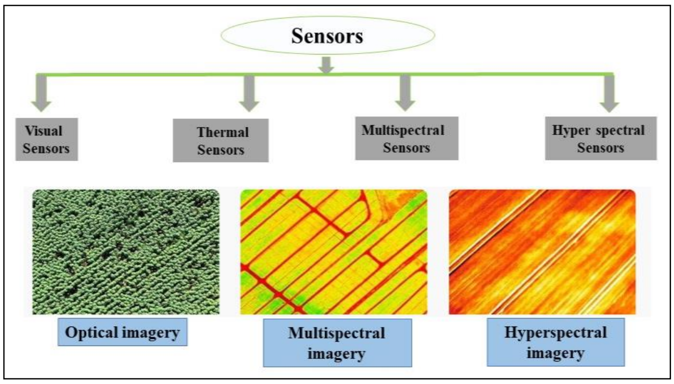
History of Satellites

The use of satellites for various applications was started with the launch of world's first satellite Sputnik I at 1975. The history of satellites is as follows.

- Sputnik I was successfully launched by the Soviet Union on October 4, 1957.
- On November 3, Sputnik II was sent into orbit.
- Explorer I was successfully launched by the United States on January 31, 1958.
- ARYABHATTA, the inaugural satellite employed for communication purposes in India, was launched on April 19, 1975.
- The inaugural Indian Experimental communication satellite, APPLE, was launched into space.
- The Indian National Satellite System (INSAT), a constellation of versatile geostationary satellites launched by ISRO, caters to India's telecommunications, broadcasting, and search-and-rescue requirements. Established in 1983, INSAT stands as the most extensive domestic communication network in the Asia-Pacific Region.
- Launched by the Indian Space Research Organization (ISRO) in October 2008, Chandrayaan-1 remained operational until August 2009.
- Chandrayaan-2, launched by the Indian Space Research Organization (ISRO) in July 2019, represents another significant mission in India's space exploration endeavors.
- Chandrayaan-3 was launched by the Indian Space Research Organization (ISRO) in August 23rd in 2023

Sensors

A device that captures electromagnetic radiation (EMR) and transforms it into a recordable signal, presenting the information in the form of either numerical data or an image.



Sishodia *et al*., 2020 [4]

Fig 4: Sensors

Types of sensors

Though there are varieties of sensors used in various fields, majorly four sensors are used in agriculture fields for mapping. Those are visual (Gives optical image), thermal (Detects variation in temperature), multispectral (Uses countable number of radiations to assess variation) and hyperspectral (Uses thousands of electromagnetic radiations) sensors.

Resolution: Resolution pertains to the dimensions of the smallest measurable unit observed or recorded for an object, exemplified by pixels in a remote sensing image or line segments employed in documenting features like a coastline curve.

Types of resolution

Spatial Resolution

Spatial resolution denotes the level of detail in discerning features on the Earth's surface, representing the sensor's capability to distinguish between different objects and characteristics. Put simply, spatial resolution is the relationship between the pixel size and the corresponding area it represents. The precision of features on the Earth's surface is contingent on both the size of the pixel and the quantity of pixels within a specific imagery

Spectral Resolution

The quantity of data present in satellite imagery is influenced by the sensor's ability to detect various wavelengths. Hence, a sensor capable of sensing a broader range of wavelengths in the electromagnetic spectrum will capture more detailed information regarding land use and land cover.

Radiometric Resolution

Radiometric resolution pertains to a sensor's capability to capture subtle distinctions in the radiated energy emanating from the Earth's surface. To put it simply, it represents the quantity of grayscale shades present in the pixels of a specific satellite imagery.

Temporal Resolution

Temporal resolution denotes the quantity of information accessible during a specific time span, characterized by the revisit time of a satellite over a particular area. In simpler terms, it signifies how often a satellite captures images of a specific area within a designated time frame. The abundance of information over a specified duration relies on the satellite's frequency of rotation around the Earth.

Spectral signature: The spectral signature represents the fluctuation in the reflectance or emittance of a material concerning different wavelengths, indicating how reflectance/emittance varies across the wavelength spectrum

The electromagnetic spectrum (EMS) encompasses various electromagnetic (EM) radiations, classified based on their wavelength, frequency, or energy. It serves as a systematic arrangement of these radiations according to their respective wavelength, frequency, or energy levels. The electromagnetic spectrum (EMS) can be categorized into seven distinct regions: gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves, and radio waves. Simply put, it represents the continuous range of energy that spans from wavelengths of meters to nanometers, moves at the speed of light, and travels through a vacuum, such as outer space. Most of the agricultural remote sensing systems use visible, infrared and micro wave remote sensing radiations due to better reflection of vegetation, water and various other agricultural features.

The Table 1 depicts the intensity of reflection and radiation of electromagnetic waves from plants, the Earth, and water varies at different wavelengths. Among different radiations, the visible, near infrared, thermal and microwave radiations, the visible radiation will give higher reflection of water, earth and vegetation. Whereas, the thermal radiation will give better reflection of ground and water surfaces. Based on these reflection patterns of different features by different radiations, various applications of different bands along with their different bands. Based on the applications of these bands, the various vegetation indices are developed.

Table 2: Electromagnetic spectrum applications

Band Wavelength (µm)	Band	Nominal principal application
0.45-0.52	Blue	mapping Coastal water, soil / vegetation,
0.52-0.62	Green	Distinguishing or identifying vegetation
0.62-0.69	Red	Region of Chlorophyll absorption
0.76-0.90	Near IR	Vegetation, Aquatic bodies, soil water content
1.55-2.35	Mid IR	Moisture content, snow & cloud, mineral & rock discrimination, vegetation moisture content
8-14	Thermal IR	Vegetation, soil moisture discrimination
1 cm-1 m	Microwave	Soil water content
1 cm-1 m	Microwave	Soil moisture

Anon., 2023 [2]

Vegetation indices

- Spectral characterization of biophysical features in plants can be achieved through vegetation indices.
- These indices are computed as ratios or differences involving two or more bands within the visible (VIS), near-infrared (NIR), and shortwave infrared (SWIR) wavelengths.
- The NDVI index is the most widely employed, frequently used to assess the condition, developmental stages, and biomass of cultivated plants, as well as to forecast their yields. It has become the predominant vegetation index.
- Leveraging multispectral and hyperspectral aerial and satellite imagery facilitates the creation of NDVI maps. These maps can distinguish between soil, grass, or forest, identify plants under stress, and differentiate between various crops and their growth stages.

Major remote sensing applications in agriculture

Crop forecasting

- Estimation of crop acreage and production.
- Predicting agricultural outcomes through the utilization of space agrometeorology and land-based observations
- Evaluation of minor crops

Sustainable agriculture

- Analysis of cropping system
- Site suitability for growth of horticulture and post-harvest infrastructure
- Command area management
- Mapping soil resources and estimating water content in soil.

Impact of disasters

- Assessment and monitoring system for national agricultural drought
- Monitoring crop loss due to floods
- Pest and disease impact assessment
- Agriculture vis-à-vis climate change

Allied themes

- Fishery forecasting
- Watershed development and monitoring
- Watershed mapping

Estimation of crop yield using satellite remote sensing

Satellite remote sensing (RS) data have found widespread applications in diverse research and practical fields. Prominent application domains include meteorology, investigations related to canopy and soil, agriculture and crop production, water, ice, and oceanography and management, geology, mapping, land use, environmental monitoring, reconnaissance, and defense, among others. Additionally, satellite RS plays a crucial role in specialized fields such as global changes and archaeology.

Among these applications, agricultural tasks like crop yield estimation and forecasting are particularly significant in research and hold substantial importance for the global society's welfare. Achieving a high level of accuracy and reliability is imperative in the agricultural application of satellite RS technology. Despite over two decades of efforts, no routine yield estimation method suitable for a wide range of operational applications has been developed. Nevertheless, substantial progress has been made in this field.

Most experiments and research efforts have focused on establishing quantitative relationships between satellite (or airborne) RS data and crop yields, employing two main types of general strategies. The first method involves integrating satellite RS data into existing models. This strategy's advantage lies in the assumption that these models, including water balance models, provide a good details of crop development and yield when deriving necessary input data. However, challenges arise in obtaining input parameters from remotely sensed data, given the relatively large number of parameters and the complexity and costliness of the required ground-truth background for result reliability.

The second general strategy relies on direct mathematical relationships between satellite RS data and crop yields. Some methods within this strategy also incorporate climatic as well as agronomical data, while a few models use only satellite RS data, requiring crop yield solely in the calibration phase. These models propose that the vitality of the crop canopy, as observed in spectral remote sensing data, is directly linked to the crops yield. While relatively simple, these models lack a deeper physiological background, as the RS data-yield relations are described in straight forward formulas.

The basic concept

- The fundamental objective of this endeavor was to devise a yield estimation method exclusively reliant on satellite RS data during the operational phase, building upon our earlier experiences and findings. The yield estimation process typically encompasses two primary stages: the calibration phase and the operational application phase. Ground-truth data play a role in the calibration phase, but no ground data are utilized during the operational phase. Calibration involves the use of historical crop yields at the field level obtained from counties, regions, and farms, provided by the Central Statistical Office of Hungary (KSH) in this project. Notably, the calibration phase coincides with the operational phase, involving the integration of data from the current year into the database (typically at the end of the agricultural year) and refining the model if necessary.
- The agricultural utilization of satellite remote sensing technology requires the quantitative processing of satellite data, emphasizing high precision and dependability. This underscores why, even after more than 20 years, a routine yield estimation method suitable for a broad spectrum of operational applications has not yet been developed. Consequently, the majority of experiments and research efforts have concentrated on establishing a quantitative relationship between satellite (or airborne) RS data and crop yields with ground truth verification

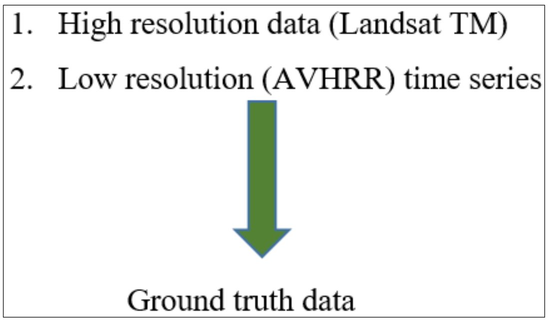
Strategies used in yield prediction

1. Integrates satellite remote sensing data into existing or advanced agrometeorological or plant-physiological models.
2. Establishes direct mathematical correlations between satellite remote sensing data and crop yields.

Phases of yield prediction

1. Calibration and development
2. Validation and applicatio**n**

Method of yield prediction in field crops using remote sensing and satellites data



Calibration and development of yield prediction model

Ground truth data

For calibration purposes in the yield estimation process and as a reference for classifying high-resolution (Landsat TM) data, ground truth data were employed. We utilized these ground truth data to explore the overall potential for yield forecasting and estimation in three counties in Hungary. The reference data, originating from local farms (10 farms per county), included farm identification, year, detailed crop-map outlining crop fields, crop species, acreage, crop yield data, sowing and harvesting dates, and relevant remarks (Stress, technological changes, etc.). The distribution of these reference crop fields in 1991 for the three counties is illustrated in Fig. 5. The composition of the reference dataset provides suitable ground truth information, essential for classifying high-resolution (Landsat TM) RS data and calibrating the relationships between crop yield and RS-derived data. The territorial sampling rate, as depicted in Fig. 5, is deemed acceptable for these objectives.

In operational applications, these ground truth data play two primary roles: (1) serving as the reference data for supervised classification, allowing for crop field-level investigations and studies of various farms, villages, small regions, and counties; and (2) enhancing the relationships between crop yield and RS-derived data at the conclusion of each agricultural year.

2. High resolution (Landsat TM) data

The enhanced resolution RS data proves valuable in discerning low-resolution pixels that exhibit distinctive characteristics for a specific crop species, both in the research and development (R&D) phase and in routine applications. Following the pre-processing of Landsat TM data, a supervised classification process was applied to these satellite RS data, resulting in a land use map. During the calibration and development (C&D) phase, these land use maps, coupled with ground truth crop field (land use) maps, form the foundation for identifying AVHRR pixel groups. These groups encompass both the known reference crop fields, characterized by known conditions and yields, and the AVHRR pixel groups containing single crop species with minimal mixing, often referred to as 'clean pixels.'

Low resolution (AVHRR) time series

The time series of NOAA AVHRR RS data at a 1 km² resolution serves as the foundation for crop canopy studies and yield estimation.

The C&D and routine application processes

The roles of various data are depicted in Fig. 5 and 6. The primary objective of the Calibration and Development (C&D) phase involves establishing the relationship between yield and remotely sensed data using a goal-oriented (specific) vegetation index. The second objective in this C&D phase is to ascertain a 'crop-filter' that aids in routine applications, proving crucial for the 'robust' method (Discussed later). In the routine application phase, the principal goal is to generate estimated (Or predicted) yield data for end-users. The secondary objective is to facilitate the recalibration-yearly updates-of the yield-RS index relationship by utilizing actual classical yield data from the reference crop fields at the conclusion of the agricultural year.

The crop-filtered VI time series: The identification of clear or nearly clear pixels offers a means to characterize diverse crop species. It is widely recognized that the time integral of a vegetation index (VI), such as the area under the VI curve (e.g., GN curve), correlates with significant crop parameters, spanning from Leaf Area Index (LAI) to yield. Further investigations have demonstrated that these correlations can be distilled to a specific time interval within the growing season, with the initiation and duration of the actual time interval varying for each crop. Precision in determining time intervals beyond the selected one is crucial, as they can jeopardize the relationship between the integral and yield, underscoring the importance of accurate delineation. The overall pattern of averaged GN data across the entire agricultural area of Hungary (in 1996–98) illustrates the primary effects observed in the VI time series.

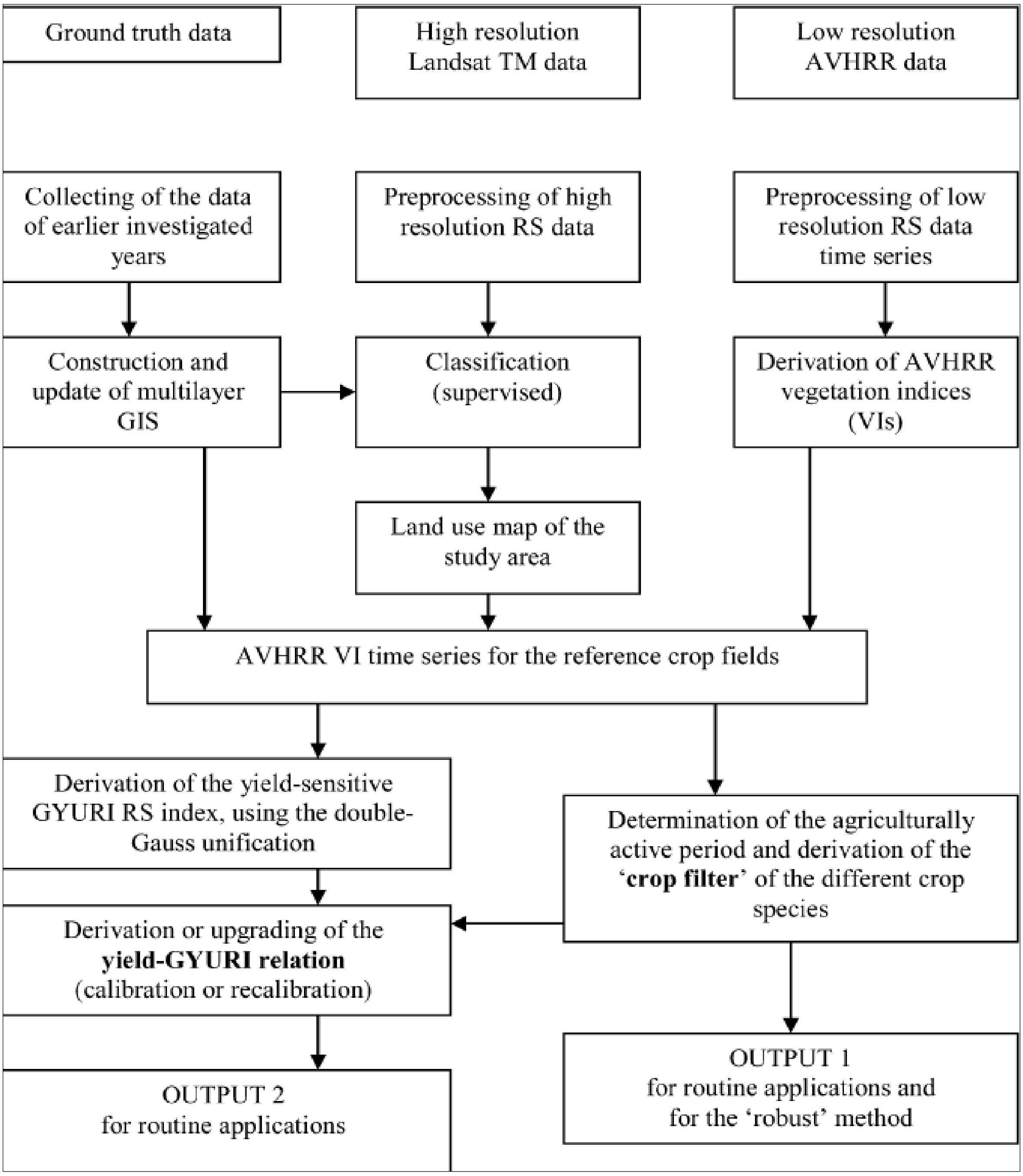


Fig 5: Calibration and development of yield prediction model

To address the challenges posed by excluded sections of the VI time series, we introduced the concept of a 'crop-filter' or 'crop-filtering.' When applying a crop-filter, two modifications were made with original RS data time series: Segments unrelated to the targeted crop species are eliminated from the complete VI time series. Supplementary points are incorporated into the retained portion of the VI time series to accurately delineate the commencement and conclusion of the growth period. These added points essentially serve as representations of the bare soil line. The core logic behind this methodology is predominantly mathematical. Relying solely on the remaining 'effective' section may not consistently achieve precise fitting of a definitive double-Gaussian curve to that portion. Consequently, we incorporate key points to improve the accuracy of curve fitting, and notably, these points are independent of yield. The determination of these points is based on empirical analysis. The process of removing and adding artificial points in each crop-filter needs standardization for each crop species, ensuring it remains unaffected by yearly variations. However, it's essential to note that these crop filters are shaped by both the type of crop and the agrometeorological regions in which they are applied

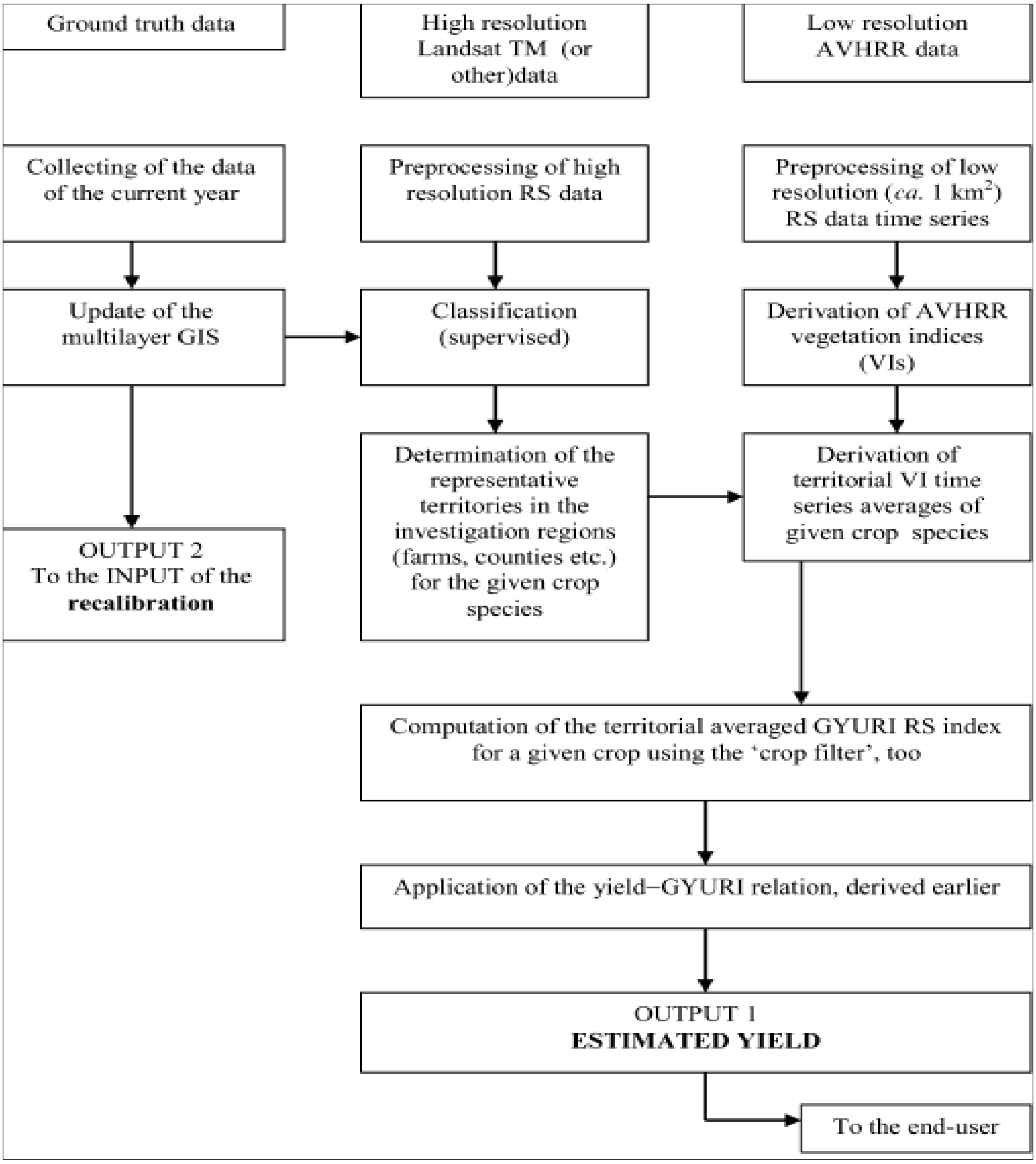


Fig 6: Validation and application of yield prediction model

Applying crop filters in the last cycle of the VI (Vegetation Index) time series generates refined data. During this stage, we can employ double-Gaussian fitting (See equations 9 and 10), producing fitted functions that become standardized representations of the examined crop in a designated field or region for a particular year. These tailored functions are designed explicitly for analyzing crop yields.

Challenges for remote sensing-based yield prediction

- Often localized & non transferable
- Mixed signals (Crop/non crop)
- Clouds (For optical systems)
- Temporal and spatial resolution (for complex cropping systems)

- Availability of *in situ* training/validation data
- Timing of running model for national scale forecasting
- Capturing impacts of events that affect yields but not biomass (i.e. late frosts) Dependency on availability of planted/harvest area information

Conclusion and Future Prospects

Yield prediction in field crops through satellite and remote sensing revolutionizes agriculture, enabling precise resource management and informed decision-making. By leveraging high-resolution data, farmers optimize inputs, mitigate risks, and enhance overall crop yield. Despite challenges like cloud cover and cost, ongoing technological advancements hold the promise of further improving accuracy and accessibility, paving the way for a sustainable and efficient future in global agriculture. Low cost, low input use and high efficiency yield predictions by integrating GIS, RS and simulation models needs further investigation because Continuous advancements in satellite and remote sensing technologies, coupled with ongoing research in data analytics and artificial intelligence, promise even more accurate and reliable yield predictions. As technology becomes more accessible and affordable, it has the potential to revolutionize agriculture globally, supporting food security and sustainability goals.

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