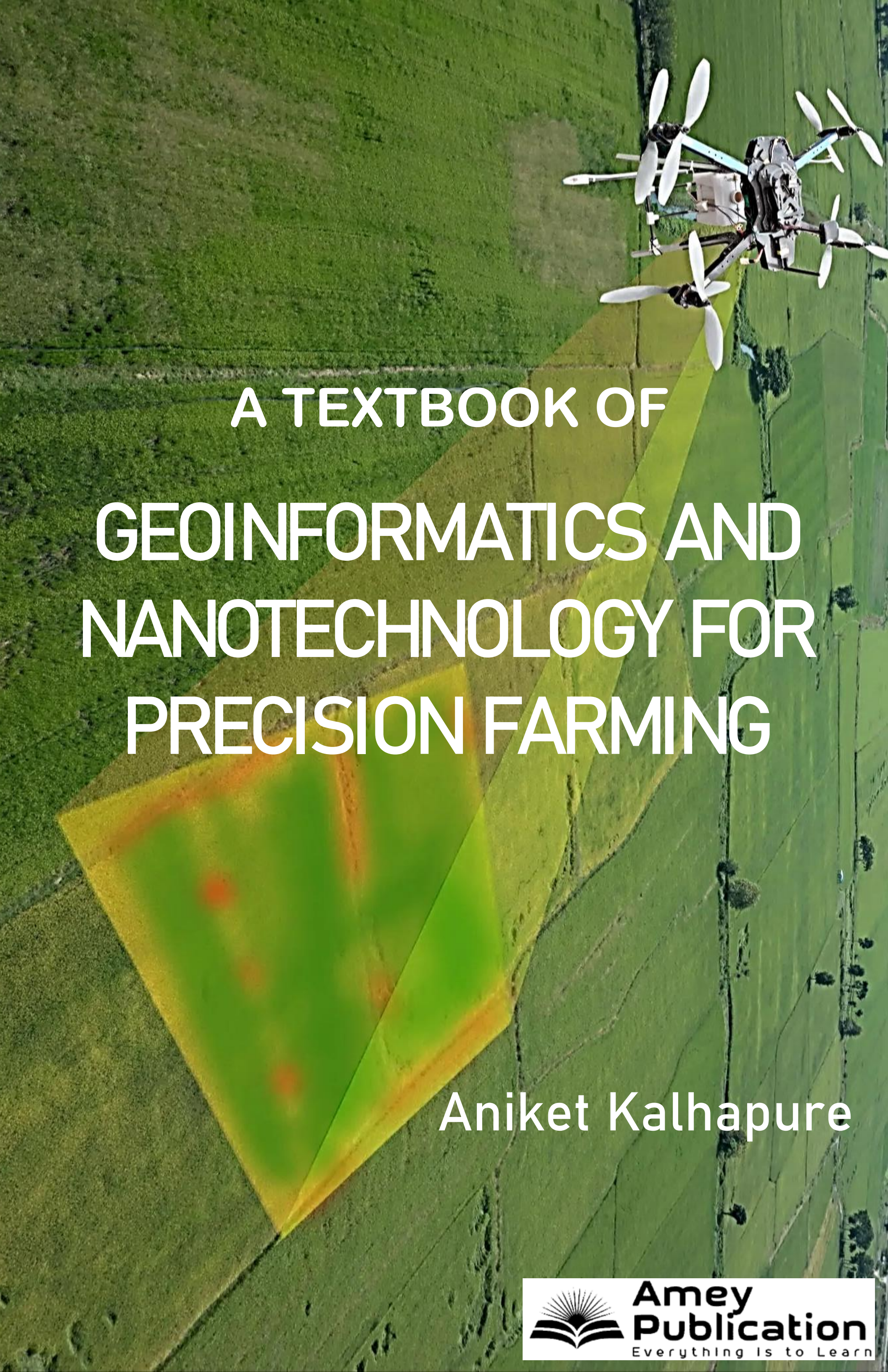


A TEXTBOOK OF

GEOINFORMATICS AND NANOTECHNOLOGY FOR PRECISION FARMING

Aniket Kalhapure

Amey Publication
Everything Is to Learn

A Textbook of

Geoinformatics and Nanotechnology for Precision Farming

Aniket Kalhapure

Amey Publication
Everything Is to Learn

Publisher
Smt. Yogita Rokade
Amey Publication,
Old Kangar Road
Rahuri- 413 705
Maharashtra
Mobile: 8423143507
❖
Printing
Satyabhama Printers
Rahuri- 413 705
❖
ISBN- 978-81-958949-0-1

A Textbook of Geoinformatics and Nanotechnology for Precision Farming

❖
Publication Year: 2022
❖
Price: ₹ 200/-

PREFACE

Education system of India is passing through the state of transition, which making learning system more comprehensive and practically efficient. Agriculture education policy of ICAR is also focusing upon the dissemination of more reliable and relevant knowledge among the agricultural students. It is really important for bringing more competence in Indian agriculture for maintaining sustainability of the production systems. Periodical improvements in the syllabus of UG and PG programmes is one of the important steps taken for making the pace of the standard of agricultural education with current time. As per the recommendations of fifth Dean's Committee of ICAR; all State Agricultural Universities also have revised UG and PG syllabus for different courses. The honest intension of publication of this series of text books is to provide more updated and relevant study material for the UG and PG students to expose the in-depth knowledge of the syllabus in course curriculum. The present book entitled "A Textbook of Geoinformatics and Nanotechnology for Precision Farming" is comprehensively fulfilling the requirement of UG and PG students for the course examinations. It is also very important for the preparation of ICAR JRF, SRF, NET, ASRB along with other competitive examinations conducted by State and Central Governments for different recruitments in various departments. Several years' experience of teaching to the agricultural UG, PG and PhD students in this subject of the author was extremely important to brought the higher-level practical utility in this book. Therefore, the book with be also helpful for the faculties and researchers of the subject of Geoinformatics and Precision Agriculture.

I am very happy to handing over this book to the readers and wishing for the great success of all the beneficiaries. I also represent my grateful thanks to the Publisher of this book Smt. Yogita Rokade for taking the necessary streps for timely publishing the book.

Date: 07.06.2022
Place: Banda

Aniket Hanumant Kalhapure
Ph.D. (Agronomy)
Assistant Professor of Agronomy
Banda University of Agriculture &
Technology, Banda. U.P- 210 001

A Text Book of Geoinformatics and Nanotechnology for Precision Farming

CONTENTS

1. CONCEPT AND IMPORTANCE OF THE PRECISION FARMING

Precision Farming

Historically, agronomic practices and management recommendations have been developed for implementation on a field basis. This generally results in the uniform application of tillage, fertilizer, sowing and pest control treatments at a field scale. Farm fields, however, display considerable spatial variation in crop yield, at the 'within-field' scale. Such uniform treatment of a field ignores the natural and induced continuous variation in soil properties, and may result in zones being under-or over-treated, giving rise to economic and environmental problems associated with this inefficient use of resource inputs. The more substantial of these problems being: economically significant yield losses, excessive chemical costs, gaseous or percolatory release of chemical components, unacceptable long-term retention of chemical components and a less than optimal crop growing environment.

Precision Agriculture (PA), in the form of Site-Specific Management, offers a remedy to many of these concerns. The philosophy involves matching resource application and agronomic practices with soil properties and crop requirements as they vary across a site. PF has three requirements such as-

- ability to identify each field location
- ability to capture, interpret and analyze agronomic data at an appropriate scale and frequency
- ability to adjust input use and farming practices to maximize benefits from each field location.

Collectively, these actions are referred to as the "differential" treatment of field variation as opposed to the "uniform" treatment underlying traditional management systems. The result is an improvement in the efficiency and environmental impact of crop production systems. It is sometimes called 'Prescription farming', site specific farming' or 'variable rate technology farming'.

Definition:

A simple definition of precision agriculture can be obtain after giving answers of three questions as given below-

What is it- It is an information and technology based farm management system to identify, analyze and manage variability within fields

How it works- by doing all practices of crop production with 5R: right input in right place at right time and in right quantity by right way

Why it is needed- for optimum productivity, profitability and environmental sustainability with protection of the land resource.

Hence; the comprehensive definition of precision agriculture is-

It is an information and technology based farm management system to identify, analyze and manage variability within fields by doing all practices of crop production with right input in right place at right time and in right quantity by right way for optimum productivity, profitability and environmental sustainability with protection of the land resource.

Technologies of Precision Farming

Following major technologies are considered under precision farming; which are explained in detail within further topics of the notes-

1. Geoinformatics

Components of Geoinformatics

a. Computer Science
b. Geodesy
c. Cartography
d. Photogrammetry
e. Remote Sensing (RS)
f. Global Positioning System (GPS)
g. Geographic Information System (GIS)

2. Yield Mapping

3. Crop Simulation Models (CSMs)

4. Variable Rate Technology

5. Site specific nutrient management

6. Nanotechnology

All the above technologies/ components of precision farming are explained in detail in other topics of this book.

Advantages of Precision Farming

1. **Simplified Farming Processes:** Precision farmers are finding that the ordinary day to day farm processes are becoming easier to manage and this is as a direct result of technology implementation and streamlining procedures. Whilst many farm jobs take a lot of effort to complete, by adopting modern technologies, farmers are finding it easier to get these completed. Two key examples of this are drones calculating final crop numbers and unmanned bots taking care of weeding. Both would have ordinarily been arduous for farmers to conduct the job by themselves and are now taken care of with minimal effort and a great degree of accuracy.
2. **Improved Farming Procedures:** Farming procedures that have been improved greatly using precision farming methods, viz.

a. **Cover Crops:** Farmers are using cover crops to protect soil during off seasons and also make extra revenue from the sale of the crops.

b. **Strip Tilling/ No-Till Methods:** Strip tilling reduces the damage done to fields by completing a traditional full till and also allows for organic matter to be left and fertilise the soil naturally. No-tilling does away with a tilling process altogether and if managed correctly can improve yields greatly.

c. **Better Farm Machinery:** Running heavy duty farm equipment over fields often causes soil damage and compacting, technology companies and machinery developers have created tractors and combines with sensors to reduce compacting from tracks and wheels.

d. **Variable Rate Fertilisation and Irrigation (Fertigation):** Precise systems that use sensors to gauge crop quality and irrigation needs. These provide fertiliser and water where needed as and when it is needed.

3. **More Cost-Efficient Farming:** Precision farming aims to reduce a farmer's expenditure by minimising the need for things like fertiliser, pesticide and herbicide. Over a growing season, grower's are seeing significant reductions in the amount of money they are

spending on all of the above where technology is using the components sparingly and only where needed. As an alternative to blanket spraying this has seen massive savings and allows farmers to better budget and keep costs to a minimum.

4. **More Time on Their Hands:** Accompanying the simplified processes, farmers are finding they are freeing up a lot more time to concentrate on the business operations of their farms rather than the nitty gritty jobs that would ordinarily be very time consuming. This means that they can focus their energy on making the farm more profitable and expansion planning rather than get bogged down completing menial tasks that technology can do instead.
5. **Higher Yields and More Profitability:** Statistically, a precision farmer will make more money than a traditional farmer. This is for a number of reasons. Their yields are higher because they have improved growing practices and they are able to sell more produce at the end of the season as a result. They also have less man hours to expend as technology is filling gaps that workers would have previously filled. There is now a huge fruit picking technology industry which is minimising labourer costs across many large fruit farms. As well as these benefits, because farmers are reducing costs by employing technology they are hitting their profit margins a lot sooner than traditional farmers.
6. **Better Quality Produce:** Implementing better growing processes is providing produce that is of a

higher quality. This is done in many ways such as actively monitoring the nutrients in soil, strip tilling and irrigating plants correctly and when irrigation is needed. Again; this not only boosts yields, but it also boosts profit margins further as when it comes to taking the crop to market, precision farmers are able to negotiate a higher price for the improved quality in the produce.

7. **Less Waste:** Lost crop is a nightmare for farmers, and over a growing season there is expectation that a certain number of plants will not see the season through. Making this worse is that historically storage practices inevitably resulted in further spoilage. With streamlined growing processes and healthier plants that crops have a much better chance of surviving and growing seasons are becoming more sustainable. Furthermore, improvements in storage by technological means has greatly reduced crop spoilage in the storage stage as well.
8. **Less Debt:** Unfortunately, a word that has become synonymous with farming is debt. Precision farmers are no more able to avoid debt as a traditional farmer however they are able to clear it quicker because they have more money to pay it down. This is as a result of the increased profitability and many precision farmers are now debt free or taking big steps towards becoming debt free.
9. **Higher Quality of Life:** Farming is a difficult and exhausting job. Farmer suicide rates are high and overall quality of life was typically non-existent. Precision farming is changing this rapidly, and as a

result of the things we have mentioned on the list they are experiencing a better quality of life with a reduction in stress levels. With more time to spend with the family, more money to go on holidays with and less physical labour involved in the farming process, precision farmers are living healthier and more fulfilled lifestyles that should see those alarming suicide statistics fall as time goes by.

Precision Farming in India

PA technologies may be relatively new to India, but the concept of precision management is not. Indian farmers have long known that soil conditions, fertility, moisture, etc. vary widely across a single field and that various parts within fields responded to different types of inputs, and cultural practices. The small size of their farms often permitted such an effective monitoring of spatial and temporal yield variation and variable application of inputs mainly by manual means.

Limitations of Precision Farming

Although precision farming is a proven technology in many advanced countries of the world but its scope in India (also in other developing countries) are limited. Different scientists have reported certain constraints, which limited the scope for site-specific farming in India, are as given follows:

1. Small farms size, heterogeneity of cropping systems, and land tenure/ownership restrictions High cost of obtaining site-specific data
2. Complexity of tools and techniques requiring new skills
3. Culture, attitude and perceptions of farmers including resistance to adoption of new techniques and lack of awareness of agro-environmental problems
4. Infrastructure and institutional constraints including market imperfections
5. PA as new story to Indian farmers needs demonstrated impacts on yields
6. Lack of local technical expertise
7. High initial investment
8. Uncertainty on returns from investments to be made on new equipment and information management systems, and
9. Knowledge and technological gaps including
    a. Inadequate understanding of agronomic factors and their interaction,
    b. Lack of understanding of the geostatistics necessary for displaying spatial variability of crops and soils using current mapping software, and
    c. Limited ability to integrate information from diverse sources with varying resolutions and intensities.

Opportunities of Precision Farming

Though farm size is the major limitation in adoption of PF technologies in India, contiguous field with same crop and mostly under similar management practice in states like Haryana, Punjab and Rajasthan can be considered as potential site for precision farming. Punjab and Haryana states in India, where farm mechanization is more common than in others, may be the first to adopt precision farming on a large scale. Rice, wheat, sugar beet, onion, potato, and cotton among the field crops, and apple, grape, tea, coffee and oil palm among horticultural crops are perhaps the most relevant for precision farming. Some have a very high value per acre, making excellent cases for site specific management. For all these crops, yield mapping is the first step to determine the precise locations of the highest and lowest yield areas of the field, and to analyze the factors causing yield variation.

In India, a few researchers in the private sector initiated studies on precision agriculture in high value crops like cotton, coffee and tea. In cotton, remote sensing coupled with GIS can assist in improved precision of insect pest management and harvesting. Testing of precision farming technologies for sustainable rice and wheat cropping system at the research farm level is in progress at Indian Agricultural Research Institute, New Delhi. Space Application Centre (SAC, ISRO), Ahmedabad in collaboration with Central Potato Research Institute, Simla has started experiment in Central Potato Research Station Farm at Jalandhar, Punjab to study the role of remote sensing in mapping the variability. The National

Bank for Agriculture and Rural Development (NABARD) with collaborative partnership with MS Swaminathan Foundation, Chennai and Arava R&D Centre in Israel has established Resource Centre for Precision Farming for developing and spreading production technologies based on integrated natural resources management. Project Directorate of Cropping System Research, Modipuam, in collaboration with SAC and National Remote Sensing Agency (NRSA) in collaboration with ICRISAT, CRIDA and ANGRAU are involved in precision farming research for capturing variability and variable rate input application.. There is also great opportunity of PF for grape and tea to start as pilot project in Nashik district of Maharastra and Assam respectively, where these crops grown in concentrated area.

Nutrient and water stress management is another area where precision farming can help Indian farmers. Detecting nutrient stresses using remote sensing and combining data in a GIS can help in site-specific applications of fertilizers and soil amendments such as lime, manure, compost, gypsum, and sulfur, which in turn would increase fertilizer use efficiency and reduce nutrient losses. In semi-arid and arid tropics, precision technologies can help growers in scheduling irrigation more profitably by varying the timing, amounts and placement of water. For example, drip irrigation, coupled with information from remotely sensed stress conditions (e.g., canopy-air temperature difference), can increase the effective use of applied water thereby reducing runoff and deep percolation.

Pests and diseases cause huge losses to crops. If remote sensing can help in detecting small problem areas caused by pathogens, timing of applications of fungicides can be optimized. Recent studies in Japan show that pre-visual crop stress or incipient crop damage can be detected using radio-controlled aircraft and near-infrared narrow-band sensors. Likewise, airborne video data and GIS have been shown to effectively detect and map black fly infestations in citrus orchards, making it possible to achieve precision in pest control. Perennial weeds, which are usually position-specific and grow in concentrated areas, are also a major problem in precision agriculture. Remote sensing combined with GIS and GPS can help in site-specific weed management.

Although thorough cost-benefit analysis has not been done yet, the possible use of precision technologies in managing the environmental side effects of farming and reducing pollution is appealing. The technologies need not be limited to input application. They can be used in-

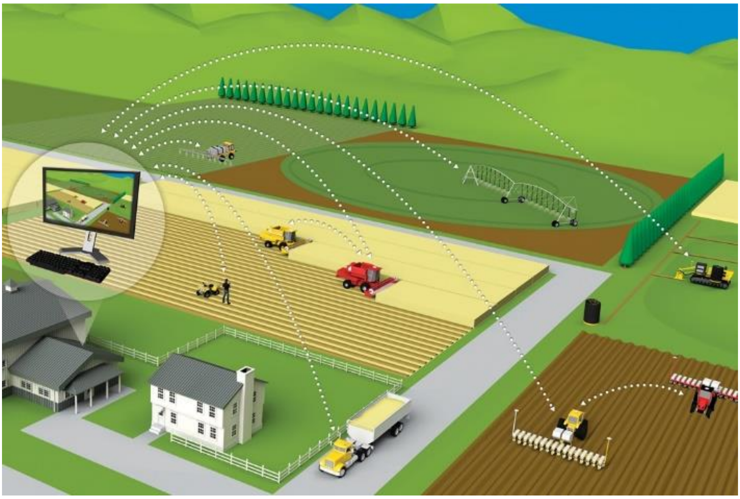
i. implementing spatially-varied farm operations such as tillage, seeding, harvesting, etc.,
ii. on-farm testing of agronomic practices to evaluate alternative management practices,
iii. plant breeding programs to test the performance of improved varieties, and in
iv. re-evaluations of trial procedures.

Strategies for dissemination od Precision Farming in India:

Precision agriculture needs to go from a technology-push to application-driven approach. As no single agency can take on the entire PF process, it is essential that various agencies join together and give a participatory approach for effective implementation of PA technologies. Small farm size will not be a major constraint, if the technologies are available through consulting, custom and rental services. For instance, by renting the equipment, manufacturers can enable early adapters to avoid the risks associated with purchasing costly machinery.

The role of agricultural cooperatives is important in dissemination of precision farming technologies to small farmers. If precision farming is considered a series of discrete services: map generation, targeted scouting, etc., it is possible to fit these services within the structure of a progressive agricultural cooperative. Since PF technology requires many costly implements farmers' cooperative no the single farmer can afford to procure them. Again, cooperative farming will solve the limitation of small field size to take PA.

Changes in agricultural policies are also necessary to promote the adoption of precision farming. There are basically two policy approaches: regulatory policies, and market- based policies. The former refer to environmental regulations on the use of farm inputs, and the latter refer to taxes and financial incentives aimed at encouraging growers to efficiently utilize farm inputs. In India, the lack of penalties for pollutant generation has partly contributed to an excessive use of inputs. Subsidies on inputs and outputs, and mechanisms that prevent the price system from rationing limited resources are also common. The latter include state-guaranteed crop prices, tariffs, import quotas, export subsidies, etc.



Theme of Precision Agriculture

2. GEOINFORMATICS

Geoinformatics

The increasing human population is exerting an unprecedented pressure on the existing natural resources. Therefore, in order to meet the ever increasing demand on the infrastructure development, urban planning, healthy neighbourhood, safe transportation of human populace and material, management of natural resources, disaster preparedness of the community, conservation of biodiversity and elevating the status of endangered animals to safe level, etc. require a comprehensive approach with careful understanding of geography of the Earth. Here comes the power of 'Geoinformatics', which uses the modern scientific and technological advancements for better utilisation of space to have for sustainable human growth.

Geoinformatics can be defined as the science and technology that deals with the geoinformation, its acquisition, creation, storage, processing, presentation and dissemination. And, by spatial information and data we mean any information and data that can be linked to a location on Earth.

The term geoinformatics consists of two words, geo (Earth) and informatics (the study of information processing). Hence, geoinformatics can be understood as the union of Earth sciences and Informatics. We can say that Geoinformatics broadly deals with the use of information technology for collection, analysis, storage, retrieval, representation and dissemination of information about the Earth. The term 'geoinformatics' is believed to have come in existence just few decades back as a result of the integration of three disciplines, namely photogrammetry, remote sensing and geographic information systems.

There is another term i.e. 'geomatics', which was first used in Canada at Laval University in the early 1980s to describe the above mentioned disciplines realising the concept that increasing potential of computing which was revolutionising surveys and representation sciences. According to the Department of Geomatics Engineering, University of Calgary, "Geomatics Engineering is a modern discipline, which integrates acquisition, modelling,

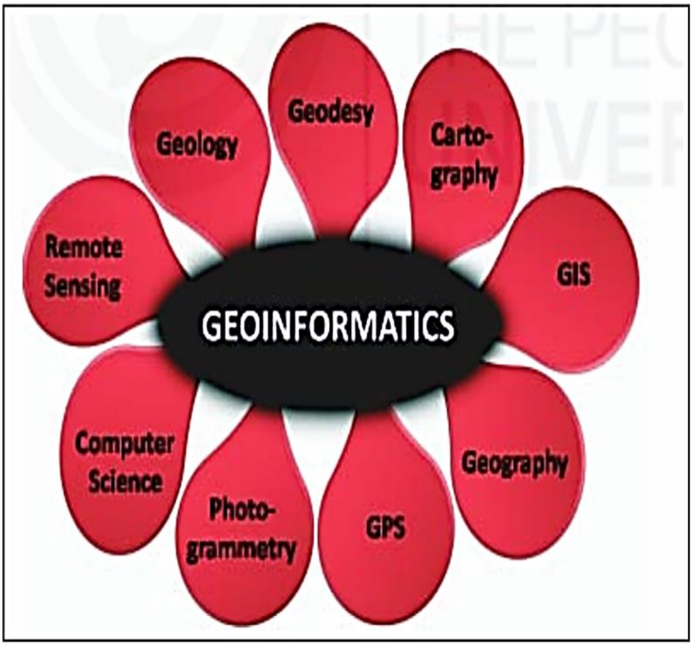
analysis, and management of spatially referenced data, i.e. data identified according to their locations".

Geomatics Industry Association of Canada (GIAC) defines geomatics "as a technology and service sector focusing on the acquisition, storage, analysis, dissemination and management of geographically referenced information for improved decision-making".

Components of Geoinformatics

It encompasses a broad range of disciplines including surveying and mapping, Remote Sensing, Geographic Information Systems (GIS), Global Positioning System (GPS), Geodesy and computer science. Various components of geoinformatics are the followings:

1. Computer Science
2. Geodesy
3. Cartography
4. Photogrammetry
5. Remote Sensing (RS)
6. Global Positioning System (GPS)
7. Geographic Information System (GIS)



1. Computer Science

Informatics, as a discipline, comprises of both the computer technologies, i.e. hardware and software. The important role of information derives from our necessity to manage more and more numerous and complex data in every field. The knowledge of computer science is a pre-requisite to represent and process applicable information through the development of hardware and software. Computer science culture is now more prevalent contributing in improvement of our activities and research. The application and usage of

computer science to geoinformatics go hand-in-hand. You will come across various aspects of the application of computer science to geoinformatics while studying about geoinformatics data acquisition, processing, product generation, data visualisation, dissemination, etc.

2. Geodesy

Geodesy also known as geodetics is the discipline that deals with the measurement and representation of the Earth. Geodesy is defined as the science concerned with the study of shape and area of the Earth. Geodesy defines the shape and dimensions of the Earth through its two branches: gravimetry and positioning astronomy. Gravimetry deals with the determination of Earth's gravity and its anomalies and the gravity determines the shape of the Earth. Positioning astronomy determines the position of the points on the globe through the observation of stars and artificial satellites. The study of geodesy began with mere curiosity and the neverending human inquisitiveness to explain the Earth's unknown through logic. It has been a great challenge for researchers to accurately represent the 3-dimensional Earth into 2-dimensional map forms. The underlying concept of geodesy helps in representing the Earth in 2-dimensions.

Applications of Geodesy in Precision Farming:

The use of geodetic technology for operating farm machinery, using the collection of techniques known as precision agriculture, is rapidly growing in the world. Precision agriculture has agronomical, economical, and environmental benefits. These techniques can save on crop inputs by optimizing the application of synthetic fertilizer and crop seed and can aid in crop protection and irrigation. Fertilizer, seed, and other products can be applied to fields with no skips, overlap/over-application, or deposition onto unwanted areas, thereby reducing waste and increasing yield. In addition, precise placement of seed can minimize tire/track compaction of the soil and eliminate crop trampling. When combined with leaf-sensing technology and remote sensing, post-emerge crop protection products such as pesticides can be applied on a variable-rate basis to meet the specific needs of a crop as it matures. Precision agriculture techniques also aid harvesting by allowing farmers to accurately apply "burn-down" products. These products hasten the ripening of grain, promoting even grain maturity across entire fields and thereby reducing the potential for "green," or immature, crop to enter the harvest chain; reducing the likelihood of crop spoilage while in storage; and reducing artificial drying costs, which will result in less use of propane or natural gas.

Currently, precision agriculture practices are not directly based on the global geodetic infrastructure, but on correction systems like the Wide Area Augmentation System, which uses local correction services. These local services are used across the U.S. corn, cotton, sorghum, and soybean crop belts to provide the required accuracy. Developing the global geodetic infrastructure to the point where it could support real-time positioning at an accuracy of 1 centimeter would have several advantages for precision agriculture. First, the infrastructure would be accessible from any location without the need to develop and maintain local infrastructure. Second, it would increase the potential to integrate straightforwardly multiple sources of information (e.g., remote sensing imagery and terrain/topography) in a GIS-based framework. Integration with agriculture management systems also could provide automation for increasingly complex farm and crop management, including crop rotation and/or crop interlacing, and improve management of polyculture farms for sustainability.

Conceptual illustration of the "farm of the future" that could be enabled by the geodetic infrastructure. The global geodetic infrastructure would provide precise positional capability anywhere in the world at all times for precise agriculture applications, including automated farm machinery and precision seed placement. Soil moisture would be monitored by remote sensing and ground-based GNSS/GPS integrated into GIS, providing accurate management of irrigation. Local GNSS/GPS networks would improve local weather forecasts.

Accurate terrain, elevation, and land cover information, integrated with GIS, would enable complex crop management. Farm produce would be transported away in autonomously navigated vehicles.

3. Cartography

Cartography is generally considered to be the science and art of designing, constructing and producing maps. It includes almost every operation from original field work to final printing and marketing of maps. It is also treated as a science of human communication. International Cartographic Association defines Cartography as the discipline dealing with the conception, production, dissemination and study of maps. Map is a drawing of the whole or part of the surface of the Earth on a plane surface to a particular scale. It is a manually or mechanically drawn picture of the Earth showing the location and distribution of various natural and cultural phenomena. A sample map is shown in Fig. given below-

Fig. Cartographic visualisation of Avenue Trees

Cartographic representation is the key in deciding the fate of any map generated out of various geoinformatics analysis. Cartographic visualisation, which is the graphical presentation of geographic information, such as data, processes, relations or concepts, limits the extent of map details which could be incorporated for the given study area as depicted in above Fig.

4. Photogrammetry

Photogrammetry is the technology developed for determining the geometric properties of objects from their photographic images. Photogrammetry is concerned with making measurements about position and shape of objects with the help of photographs. The American Society for Photogrammetry and Remote Sensing (ASPRS) has defined photogrammetry as "the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena".

Although, both maps and aerial photographs present a 'bird's eye-view' of the Earth, aerial photographs are not maps. Maps are orthogonal representations of the Earth's surface, meaning that they are directionally and geometrically accurate (at least within the limitations imposed by projecting a 3-dimensional object into 2-dimensions). Aerial photographs, on the other hand, display a high degree of radial distortion. In other words, the topography is distorted, and until corrections are made for the distortion, measurements made from a photograph are not accurate. Nevertheless, aerial photographs are a powerful tool for studying the Earth's environment.

In the late 1800s, cameras were positioned above the Earth's surface in balloons or kites and aeroplanes to take oblique aerial photographs of the landscape. During World War I, aerial photography played an important role in gathering information about the position and movements of enemy troops. After the war, civilian use of aerial photography from airplanes began with the systematic vertical imaging of large areas of Canada, the United States, and Europe. Many of these images were used to construct topographic and other types of reference maps of the natural and human-made features found on the Earth's surface.

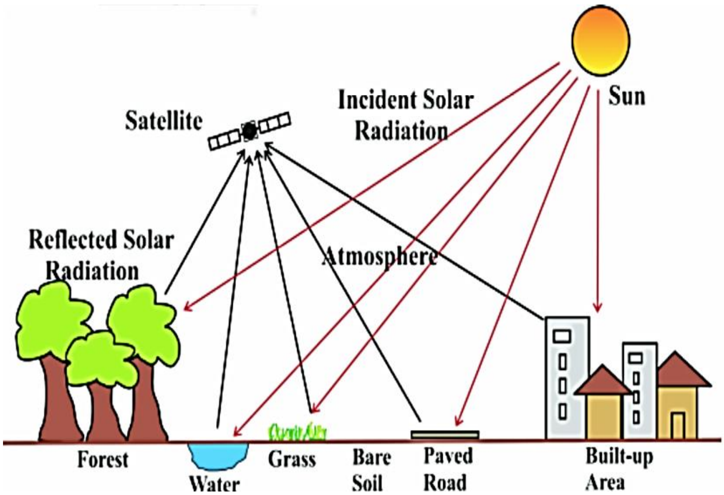
Photogrammetry is useful in various fields including topographic mapping, architecture, engineering, manufacturing, quality control, police investigation, and geology. Archeologists use photogrammetry to produce plans of large or complex sites. Meteorologists use it to determine the actual wind speed of a tornado in places where objective weather data cannot be obtained. In movie production, photogrammetry is used to combine live action with computer generated imagery.

5. Remote Sensing

Remote sensing is the collection of data about an object from a distance. Scientists use the technique of remote sensing to monitor or measure phenomena found in the

Earth's lithosphere, biosphere, hydrosphere, and atmosphere. Humans and many other types of animals accomplish this task with aid of eyes or by the sense of smell or hearing. Remote sensing is usually done with the help of mechanical device known as remote sensor. This device has greatly improved ability to receive and record information about an object without having any physical contact with them. Often, these sensors are positioned away from the object of interest by using helicopters, planes, and satellites. Most remote sensing devices record information about an object by measuring an object's transmission of electromagnetic energy from reflecting and radiating surfaces.

The simplest form of remote sensing uses photographic cameras to record information from visible or near infrared wavelengths of the electromagnetic spectrum. Concept of remote sensing is diagrammatically shown in Fig. given below. Sun is the principal source of energy. When the energy (in the form of electromagnetic radiation) reaches the Earth's atmosphere, it undergoes the process of reflection, absorption and transmission. Earth's surface consists of different natural and man-made features which reflect, absorb, store and emit Earth's radiation at different wavelengths in different percentages, depending upon their physical and chemical properties.



Remote sensing sensors record different amount of radiation that is reflected or emitted from different earth surface features and reproduce it in form of an image. Remote sensing provides synoptic view of the earth surface by virtue of recording interactions of Earth surface features with electromagnetic radiation. These interactions are recorded in remote sensing images in the form of some numerical information. When the remote sensing data is generated employing Sun's energy it is known as passive remote sensing. In the other type i.e. active remote sensing, remote sensors, such as radars, send radiation themselves and collect the signal returned back to them from Earth surface features. Based on the factors, such as portion of the electromagnetic spectrum used and the number of bands, sensors are generally categorised into optical and microwave:

A. **Optical sensors/ Optical remote sensing:** These operate in the region between 0.3 and 15 μm of the electromagnetic spectrum. Optical remote sensing makes use of visible, near infrared and short-wave infrared sensors to form images of the Earth's surface by detecting the solar radiation reflected from targets on the ground. Optical remote sensing systems are classified into the following types, depending on the number of spectral bands used in the imaging process. Panchromatic imaging systems: This sensor is a single channel detector sensitive to radiation within a broad wavelength range resulting into a black and white image. The physical quantity being measured is the apparent brightness of the targets. The spectral information of the target is lost.

Optical remote sensing is further classified as panchromatic RS, multispectral RS, superspectral RS, hyperspectral RS and thermal RS.

a. **Panchromatic imaging systems:** This sensor is a single channel detector sensitive to radiation within a broad wavelength range resulting into a black and white image. The physical quantity being measured is the apparent brightness of the targets. The spectral information of the target is lost.

A panchromatic image of a part of Allahabad acquired by Cartosat 2B PAN sensor (source: www.nrsc.gov.in/imagegallery.html)

Examples of satellites carrying panchromatic imaging systems are- Cartosat, QuickBird, WorldView, GeoEye, etc.

b. **Multi-spectral imaging systems:** This kind of sensor is a multi-channel detector with a more than one spectral band and generally 3 to 7 bands. The resulting image is a multi-layer image which contains both the brightness and spectral information of the targets observed. Examples of multispectral systems are: QuickBird MSS, GeoEye MSS, IKONOS MSS, etc.

A multispectral image of part of Riyadh as acquired by Quick bird satellite
(source: www.satimageingcorp.com)

c. **Superspectral imaging systems:** Superspectral imaging sensor has many more spectral channels (typically >10) than a multi-spectral sensor. The bands have narrower bandwidths, enabling the finer spectral characteristics of the targets to be captured by the sensor. Examples of superspectral systems are: MODIS, MERIS, etc.

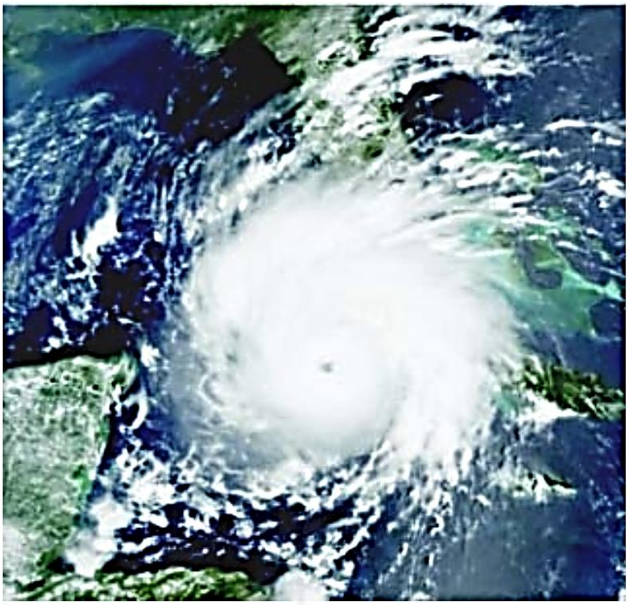
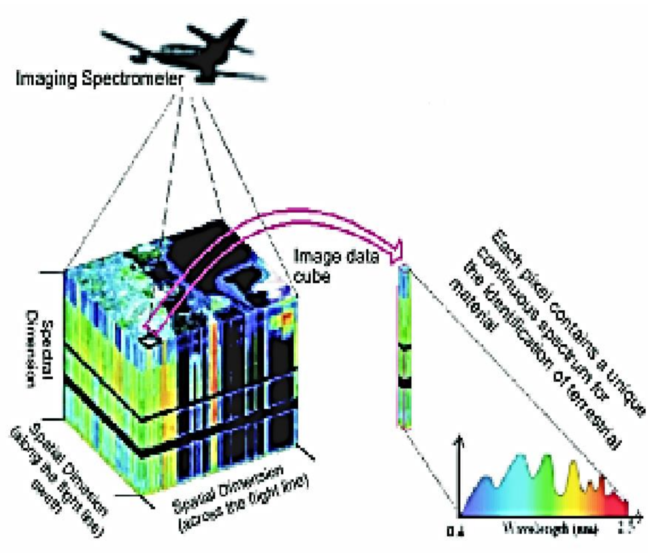


Image of hurricane from a super-spectral imaging system

d. **Hyperspectral imaging systems:** A hyperspectral imaging system is also known as an "imaging spectrometer". It acquires images in about a hundred or more contiguous spectral bands. The precise spectral information contained in a hyperspectral image enables better characterisation and identification of targets. Hyperspectral images have potential applications in fields such as precision agriculture (e.g. monitoring the types, health, moisture status and maturity of crops), coastal management (e.g. monitoring of phytoplanktons, pollution, bathymetry changes).



Concept of hyperspectral remote sensing

Hyperspectral remote sensing, also known as imaging spectroscopy, is relatively a new technology that is currently being investigated by researchers and scientists with regard to the detection and identification of minerals, terrestrial vegetation, and man-made materials and backgrounds. Imaging spectroscopy has been used in the laboratory by physicists and chemists for over 100 years for identification of materials and their composition. Recently, with advancing technology, imaging spectroscopy has begun to focus on the Earth. The concept of hyperspectral remote sensing began in mid eighties and since then it has been used most widely by geologists for the mapping of minerals. Hyperspectral remote sensing combines imaging and spectroscopy in a single system which often includes large data sets and requires new processing methods.

There are many applications which can take advantage of increased spectral information provided by hyperspectral remote sensing.

• Atmosphere: water vapor, cloud properties, aerosols

• Ecology: chlorophyll, leaf water, cellulose, pigments, lignin

• Geology: mineral and soil types

• Coastal Waters: chlorophyll, phytoplankton, dissolved organic materials, suspended sediments

• Snow/Ice: snow cover fraction, grain size, melting

• Biomass Burning: sub pixel temperatures, smoke

• Commercial: mineral exploration, agriculture and forest production.

B. **Microwave Remote Sensing:** Microwave sensors operate in the microwave region of the electromagnetic spectrum (EMS). Microwave portion of the spectrum i.e. 1cm to 1 m in wavelength is used to acquire the remote sensing information. Longer wavelength microwave radiation can penetrate through cloud cover, haze, dust, etc. This property allows detection of microwave energy under almost all weather and environmental conditions so that data can be collected at any time.

Passive microwave sensing is similar in concept to thermal remote sensing. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. Applications of passive microwave remote sensing are used in the fields of meteorology, hydrology, and oceanography. Active microwave sensors provide their own source of microwave radiation to illuminate the target. Active microwave sensors are generally divided into two distinct categories: imaging and non-imaging. The most common form of imaging active microwave sensors is RADAR. RADAR is an acronym for Radio Detection And Ranging, which essentially characterizes the function and operation of a radar sensor. This image shows RADARSAT's ability to distinguish different types of bedrock. The light shades on this image (C) represent areas of limestone, while the darker regions (B) are composed of sedimentary siltstone. The very dark area marked A is Bracebridge Inlet which joins the Arctic Ocean.

Radarsat image acquired on March 21, 1996, over Bathurst Island in Nunavut, Canada

Non-imaging microwave sensors include altimeters and scatterometers. Generally, altimeters look straight down at nadir below the platform, and thus measure height or elevation. Scatterometers are used to make precise quantitative measurements of the amount of energy backscattered from targets. Seasat-1, ERS-1, ERS-2, ENVISAT-1, JERS-1, RADARSAT-1, etc. are the examples of satellites carrying microwave sensors.

Another development is the Synthetic Aperture Radar (SAR) imaging, in which microwave pulses are transmitted by an antenna towards the Earth surface. The microwave energy scattered back to the spacecraft is measured. The SAR makes use of the radar principle to form an image by utilising the time delay of the backscattered signals.

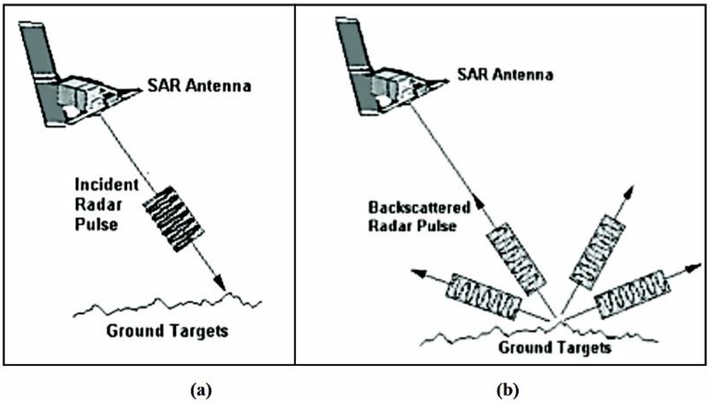


Illustration showing the concept of SAR imaging; a) A radar pulse is transmitted from the antenna to the ground, b) The radar pulse is scattered by the ground targets back to the antenna

C. **Thermal Remote Sensing:** Thermal remote sensing is the branch of remote sensing that deals with the acquisition, processing and interpretation of data acquired primarily in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum. In thermal remote sensing, we measure the radiations 'emitted' from the surface of the target, as opposed to optical remote sensing where we measure the radiations 'reflected' by the target under consideration. Thermal remote sensing, in principle, is different from remote sensing in the optical an microwave region. In practice, thermal data prove to be complementary to other remote sensing data. It is unique in helping to identify surface materials and features, such as rock types, soil moisture, geothermal anomalies, etc. The ability to record variations in infrared radiation has advantage in extending our observation of many types of phenomena in which minor temperature variations may be significant in understanding our environment. There are limitations of thermal imagery. It can be very expensive to acquire and process thermal data as most thermal imaging systems have strict operational/technical parameters, such as detector materials. Thermal infrared imaging systems are difficult to calibrate because temperature differences can be very subtle and interactions with atmospheric moisture are unpredictable. Thermal images of water measure only the very top layer of the water surface because those wavelengths are attenuated/absorbed very rapidly, especially in water.

Remote sensing imagery has many applications in mapping land-use and land cover, agriculture, soil mapping, forestry, city planning, archaeological investigations, military observation, and geomorphological surveying, mineral exploration, among other uses. One of the common examples of the use of remote sensing is the weather maps which you see in the news channels providing forecast of weather conditions.

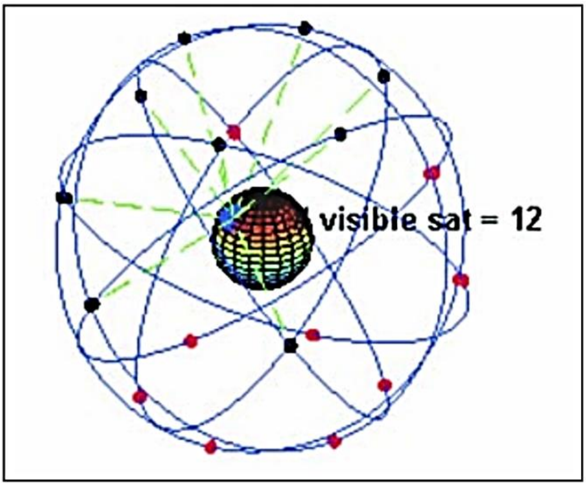
Application of Remote Sensing in Agriculture: Integrated applications of Remote Sensing along with GIS are mentioned under GIS in this chapter.

6. Global Positioning System

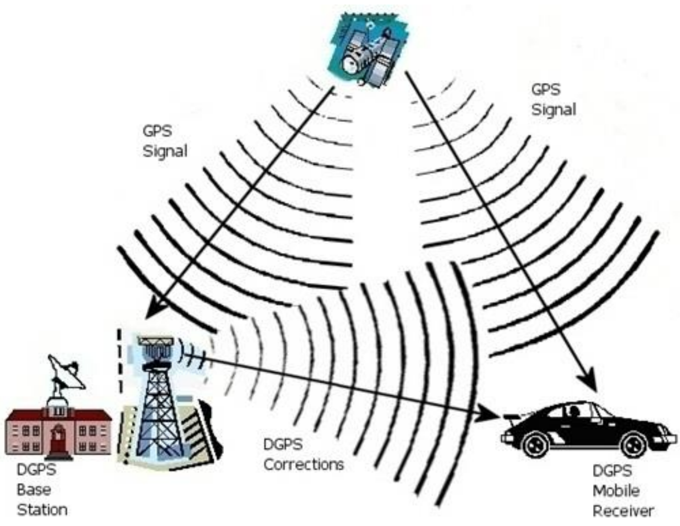
The Global Positioning System (GPS) is a satellite-based navigation system that can be used to locate positions anywhere on the earth in three dimensions (i.e. latitude, longitude and altitude). GPS provides continuous (24 hours/day),real-time, 3-dimensional positioning, navigation and timing worldwide in any weather condition. GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use. There are no subscription fees or setup charges to use GPS. Any person with a GPS receiver can access the system, and it can be used for any application that requires location coordinates.

The development of the publicly available global positioning system (GPS) has opened new doors in opportunities for spatial data. The Global Positioning System (GPS), originally Navstar GPS, is a satellite-based radionavigation system owned by the United States government and operated by the United States Air Force. It is a global navigation satellite system that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. Obstacles such as mountains and buildings block the relatively weak GPS signals. The GPS does not require the user to transmit any data, and it operates independently of any telephonic or internet reception, though these technologies can enhance the usefulness of the GPS positioning information. The GPS provides critical positioning capabilities to military, civil, and commercial users around the world. The United States government created the system, maintains it, and makes it freely accessible to anyone with a GPS receiver.

The GPS project was launched by the U.S. Department of Defense in 1973 for use by the United States military. It was allowed for civilian use in the 1980s. The GPS system includes 24 satellites deployed in space about 19,000 kilometers above the earth's surface. The satellites are evenly spread out so that four satellites are accessible via direct line-of-sight from anywhere on the globe. Each GPS satellite broadcasts a message that includes the satellite's current position, orbit, and exact time. A GPS receiver combines the broadcasts from multiple satellites to calculate its exact position using a process called triangulation. Three satellites are required in order to determine a receiver's location, though a connection to four satellites is ideal since it provides greater accuracy. In order for a GPS device to work correctly, it must first establish a connection to the required number of satellites.



Global Positioning System



Working Mechanism and Components of GPS

a. Space segment:

- Composed of satellites that transmit signals from space, on the basis of which time and position of the user is measured.
- Set of satellites is called as constellation.
- GPS uses two satellite constellations i.e. NAVSTAR and GLONASS.
- NAVSTAR (Navigation satellite timing and ranging)
- NAVSTAR composed of 24 satellites, arrayed in 6 orbital planes, inclined 55 degrees to the equator and with a 12 hours period.
- They orbit at altitudes of about 20,200km each.
- Each satellite contains four precise atomic clocks, only one of which is in used at a time.

b. Control segment:

  - Control segment consists of a group of 5 ground based monitor stations, three antennas and a master control station.
  - The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in Colorado.
  - The monitor stations measure signals from the space vehicle (SV)s continuously and provides data to the master control station.
  - The master control station calculates satellite ephemeris and clock correction coefficients and forwards them to an antenna.
  - The antenna transmit the data to each satellite at least once a day. The SVs then send subsets of the

orbital ephemeris to GPS receivers over radio signals

c. **User segment:**

- GPS User Segment consists of the GPS receivers and the user community.
- The typical receiver is composed of an antenna and pre-amplifier, radio signal microprocessor, control and display device, data recording unit, and power supply.
- GPS receivers convert SV signals into position, velocity, and time estimates.
- A minimum of four satellites are required to compute the four dimensions of X, Y, Z (position) and Time. (time is added as Fourth dimension here to getting real time position)

The access to foreign government (USA) controlled global navigation satellite systems is not guaranteed in hostile situations. It was happened to the Indian military in 1999 when it was dependent on the American Global Positioning System (GPS) during the Kargil War. USA has restricted the GPS access for Indian military operations; due to which the war resulted into considerable casualty to Indian soldiers. Hence; the Indian government approved the project in May 2006 for the development of its own GPS. The system is developed on regional basis with name Indian Regional Navigation Satellite System (IRNSS), with an operational name of NAVIC (NAVigation with Indian Constellation). It can keep watch on whole India, Pakistan, Afghanistan, China, Bhutan, Myanmar, Shrilanka and overall ocean borders of Arabic, Bengal and Hindi sea with the network of seven satellites. More recently farmers have gained access to site specific technology though GPS. GPS makes use of a series of satellites that identify the location of farm equipment within a3meter of an actual site in the field. The GPS positional accuracy when used in single receiver mode (autonomous navigation) can be degraded by various error sources. The positional (horizontal) accuracy of the GPS can be of the order of 20 m. In order to achieve the required accuracies, especially needed for precision agriculture, the GPS has to be operated in a differentially corrected positioning mode, i.e. DGPS. In the DGPS, the errors computed by a reference station, which is located in a known place, is transmitted to the mobile user and error correction is done to improve the accuracy. The most common use of GPS in agriculture is for yield mapping and variable rate fertilizer/ pesticide applicator. GPS are important to find out the exact location in the field to assess the spatial variability and site specific application of the inputs. The positional (horizontal) accuracy of the GPS can be of the order of 20 m. GPS operating in differential mode are capable of providing location accuracy of 1 m and also submeter. The availability of GPS approaches to farming will allow all field-based variables to be tied together. This tool has proven to be the unifying connection among field variables such as weeds, crop yield, soil moisture, and remote sensing data.

Real world applications of GPS fall into following five broad categories:

• Location: determining a basic position

• Navigation: getting from one location to another

• Tracking: monitoring the movement of people, animals and goods

• Mapping: creating maps of the world

Applications of GPS in Agriculture:

1. **Soil sampling:** GPS provides the necessary data to accurately determine soil variability and to establish whether a given type of soil is ideal for the growth of a particular crop. Soil sampling also helps in profiling of soils to distinguish between soils that are viable and those that are not.
2. **Weed location:** Using linear sampling techniques, GPS can be used to single out weed patches in vast areas of lands. Weed usually hinders the effective growth of a crop and hampers the eventual yields over a given period of time.
3. **Accurate planting:** GPS also comes in handy when planning the planting of a given crop. Each seed has specific spacing and depth required depending on the soil type. Using GPS, it is easier to tell what spacing a given seed requires and to what depth the seed should be planted in order to return maximum yields.
4. **Determination of planting ratios:** GPS can also be used in the determination of planting ratios of seeds. Some seeds have specific spaces in between them while others may be planted together with other seeds. GPS helps in determining the ratio of this type of planting.

5. **Creation of yield maps:** GPS plays an important role in the creation of yield maps for specific types of crops. For instance, during harvests, GPS can be used to map out expected yields of a given crop from one piece of land based on the land characteristics and the seed characteristics.
6. **Harvesting:** GPS plays an important role in the determination of what area of a farm is ready to be harvested and how the harvesting will take place. The GPS will also give an estimate of the size of the area being harvested and the expected returns from the area.
7. **Locating a yield map:** GPS can also be used to locate a yield map by mounting a GPS receiver on a farm machinery and then collecting the data.
8. **Environmental control:** Applying herbicides or pesticides based on the capacity of each square meter reduces the application amount of the pesticide being used. This allows the soil to absorb all the pesticide hence reducing the chances of runoff.
9. **Farm planning:** GPS plays an important role in the planning of a farmland ready for planting. GPS will give the overall size of the area and help in determining what crop will be planted on what part of the farmland using various factors such as soil characteristics and crop characteristics.
10. **Field mapping:** GPS gives an exact estimate of the field that is being prepared for farming. Through this, experts can tell what part of the field will be used for farming activities and what area will be used for other non-farming related activities.

11. **Soil sampling:** Soil sampling is one of the most important uses of GPS in agriculture. It is important to know what type of soil is available on a given farmland as this will help in determining the type of crop to be planted on that farm.
12. **Crop scouting:** GPS gives an exact mapping of an area helping when scouting for crops that are grown in a particular area. Through this, experts are able to tell the nature and type of crops that thrive within a given locality and help in improving the quality of that crop.
13. **Yield mapping:** After a crop has been planted and is ready for harvesting, GPS can be used to make an estimation of the yield of a given farmland. This can be achieved through aerial mapping where experts can tell the quantity of a yield based on the area covered by the crop.
14. **Correlation of production techniques with crop yields:** GPS can be used to make a correlation of the production technique that was used over a given piece of land and the crop yields after a given period of time. This information can then be used to determine the viability of a given technique.
15. **Soil property mapping:** GPS plays an important role in determining the soil property of a given soil to establish its variability and suitability for a given crop. It also helps researchers identify which area of a farmland contains what type of soil and what area is suitable for a given crop.
16. **Machinery location:** It is easier to locate any farm machinery on a vast piece of land thanks to GPS. The farmer does not need to physically go out and locate

farm equipment especially in cases where the number is high. GPS can pinpoint the exact location of these farm machineries.

17. **Machinery direction:** Technology has necessitated the use of autonomous farm machinery for use in farming. GPS is used to direct these machineries into deciding what direction the seeds will be placed and the spaces in between each seed.
18. **Identification of areas suitable for cultivation:** GPS plays an important role in deciding what areas in a given farmland are suitable for cultivation. This is done through aerial mapping of the area under cultivation and the analysis of the soil samples to determine the viability of the soil.
19. **Classification of areas for cultivation based on various characteristics:** GPS can be used to classify different areas for cultivation based on various characteristics such as soil types and the terrain maps. Areas that are not suitable for cultivation can be identified and alienated while those that are suitable can then be developed.
20. **Assessment for the availability of water in an area:** GPS has been used in the assessment of the availability of water or water sources within a given locality. Water sources such as rivers or canals can easily be singled out using GPS.
21. **Identification of irrigated crops:** GPS can also be used to identify areas where there are crops that have been irrigated and those that have not been irrigated. This helps in creating a profile between irrigated crops

and non-irrigated crops to help in making comparisons.

22. **Identification of swamps and other water logged areas:** GPS can be used to identify swampy areas and waterlogged areas that may not be ideal for certain types of crops. This helps in determining the suitability of these types of lands for certain crops and their non-suitability for other types of crops.
23. **Rivers mapping:** GPS helps in creating a map of all rivers within a locality which builds a profile of the area with regards to the water flow. Farmers and researchers can be able to tell the presence of rivers and help in determining the crops that will be grown in that locality.
24. **Land usage in the locality:** GPS can also be used to monitor the land usage within a given locality. Through GPS, it is easier to tell what area of the land has been put under cultivation and what part of the land has been left bare.
25. **Contour mapping:** In cases where the land is irregular, GPS has been instrumental in determining the contours within the specific locality. This is because some crops may not do well in contoured lands while others may thrive in these lands.
26. **Irrigation systems mapping such as dams or canals:** In cases where the land needs to be irrigated, GPS can help locate some irrigations systems such as dams and canals. This will make it easy as it will avail the necessary water needed for irrigating the lands.
27. **Meteorological mapping such as climatic patterns:** GPS plays an important role in mapping out

some climatic conditions which may determine the type of crop that can grow in a given region.

28. **Personnel mapping:** GPS may also play an important role in mapping out the number of personnel in a given farmland at specific times of the day. This is important if a farmer wants to measure the productivity of the personnel in a farm.
29. **Plantation mapping:** GPS can help in creating a map of a plantation and establishing the crop yields in a given plantation.
30. **Water bodies mapping:** GPS can also be used to map out the existing water bodies within a given area to assess the viability of crop growth and crop yields in a given area.

7. Geographic Information System (GIS)

A Geographical Information System (GIS) is a system for capturing, storing, analyzing and managing data and associated attributes, which are spatially referenced to the Earth. The geographical information system is also called as a geographic information system or geospatial information system. It is an information system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information. In a more generic sense, GIS is a software tool that allows users to create interactive queries, analyze the spatial information, edit data, maps, and present the results of all these operations. GIS technology is becoming essential tool to combine various maps and remote sensing information to generate various models, which are used in real time environment. Geographical information system is the science utilizing the geographic concepts, applications and systems.

Geographical Information System can be used for scientific investigations, resource management, asset management, environmental impact assessment, urban planning, cartography, criminology, history, sales, marketing, and logistics. For example, agricultural planners might use geographical data to decide on the best locations for allocation specific crop planning, by combining data on soils, topography, and rainfall to determine the size and location of biologically suitable areas.

In the year 1962, the world's first true operational GIS was developed by the federal Department of Forestry and Rural Development in Ottawa, Canada by Dr. Roger Tomlinson. It was called the "Canada Geographic Information System" (CGIS) and wasused to store, analyze, and manipulate data collected for the Canada Land Inventory(CLI). It is an initiative to determine the land capability for rural Canada by mapping information about soils, agriculture, recreation, wildlife, forestry, and land use at a scale of 1:50,000. Dr. Tomlinson is known as the "father of GIS," for his use of overlays in promoting the spatial analysis of convergent geographic data.

Components of GIS

GIS enables the user to input, manage, manipulate, analyze, and display geographically referenced data using a computerized system. To perform various operations with

GIS, the components of GIS such as software, hardware, data, people and methods are essential.

1. **Software:** GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are (a) a database management system (DBMS) (b) tools for the input and manipulation of geographic information (c) tools that support geographic query, analysis, and visualization (d) a graphical user interface (GUI) for easy access to tools. GIS software are either commercial software or software developed on Open Source domain, which are available for free. However, the commercial software is copyright protected, can be expensive and is available in terms number of licensees.

   Currently available commercial GIS software includes Arc/Info, Intergraph, MapInfo, Gram++ etc. Out of these Arc/Info is the most popular software package. And, the open source software are AMS/MARS etc.

2. **Hardware:** Hardware is the computer on which a GIS operates. Today, GIS runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations.

3. **Data:** The most important component of a GIS is the data. Geographic data or Spatial data and related tabular data can be collected in-house or bought from a commercial data provider. Spatial data can be in the form of a map/remotely-sensed data such as satellite imagery and aerial photography. These data forms must be properly georeferenced (latitude/longitude). Tabular data can be in

the form attribute data that is in some way related to spatial data. Most GIS software comes with inbuilt Database Management Systems (DBMS) to create and maintain a database to help organize and manage data.

4. Users: IS technology is of limited value without the users who manage the system and to develop plans for applying it. GIS users range from technical specialists who design and maintain the system to those who use it to help them do their everyday work. These users are largely interested in the results of the analyses and may have no interest or knowledge of the methods of analysis. The user-friendly interface of the GIS software allows the nontechnical users to have easy access to GIS analytical capabilities without needing to know detailed software commands. A simple User Interface (UI) can consist of menus and pull-down graphic windows so that the user can perform required analysis with a few key presses without needing to learn specific commands in detail.

5. Methods: A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization.

Functions of GIS

General-purpose GIS software performs six major tasks such as input, manipulation, management, query and analysis, Visualization.

1. **Input**: The important input data for any GIS is digitized maps, images, spatial data and tabular data.

The tabular data is generally typed on a computer using relational database management system software. Before geographic data can be used in a GIS it must be converted into a suitable digital format. The DBMS system can generate various objects such as index generation on data items, to speed up the information retrieval by a query. Maps can be digitized using a vector format in which the actual map points, lines, and polygons are stored as coordinates. The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology has the capability to automate this process fully for large projects; smaller jobs may require some manual digitizing. The digitizing process is labour intensive and time-consuming, so it is better to use the data that already exist. Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from data suppliers and loaded directly into a GIS.

2. Manipulation: GIS can store, maintain, distribute and update spatial data associated text data. The spatial data must be referenced to a geographic coordinate systems (latitude/ longitude). The tabular data associated with spatial data can be manipulated with help of data base management software. It is likely that data types required for a particular GIS project will need to be transformed or manipulated in some way to make them compatible with the system. For example, geographic information is available at different scales (scale of 1:100,000; 1:10,000; and 1:50,000). Before these can be overlaid and integrated they must be transformed to the same scale. This could be a temporary transformation for display purposes or a permanent one required for analysis. And, there are many other types of data manipulation that are routinely performed in GIS. These include projection changes, data aggregation, generalization and weeding out unnecessary data.

3. Management: For small GIS projects it may be sufficient to store geographic information as computer files. However, when data volumes become large and the number of users of the data becomes more than a few, it is advised to use a database management system(DBMS) to help store, organize, and manage data. A DBMS is a database management software package to manage the integrated collection of database objects such as tables, indexes, query, and other procedures in a database. There are many different models of DBMS, but for GIS use, the relational model database management systems will be highly helpful. In the relational model, data are stored conceptually as a collection of tables and each table will have the data attributes related to a common entity. Common fields in different tables are used to link them together with relations. Because of its simple architecture, the relational DBMS software has been used so widely. These are flexible in nature and have been very wide deployed in applications both within and without GIS.

4. Query: The stored information either spatial data or associated tabular data can be retrieved with the help of Structured Query Language (SQL). Depending on the type of user interface, data can be queried using the SQL or a menu driven system can be used to retrieve map data. For example, you can begin to ask questions such as:

- Where are all the soils are suitable for sunflower crop?
- What is the dominant soil type for Paddy?
- What is the groundwater available position in a village/block/district?

Both simple and sophisticated queries utilizing more than one data layer can provide timely information to officers, analysts to have overall knowledge about situation and can take a more informed decision.

5. Analysis: GIS systems really come into their own when they are used to analyze geographic data. The processes of geographic analysis often called spatial analysis or geo-processing uses the geographic properties of features to look for patterns and trends, and to undertake "what if" scenarios. Modern GIS have many powerful analytical tools to analyse the data. The following are some of the analysis which are generally performed on geographic data.

Integrated applications of Remote Sensing along with GIS:

1. **Crop production forecasting:** Remote Sensing along with GIS is used to forecast the expected crop production and yield over a given area and determine how much of the crop will be harvested under specific conditions. Researchers can be able to predict the quantity of crop that will be produced in a given farmland over a given period of time.
2. **Assessment of crop damage and crop progress:** In the event of crop damage or crop progress, remote sensing & GIS technology can be used to penetrate the farmland and determine exactly how much of a given crop has been damaged and the progress of the remaining crop in the farm.
3. **Horticulture, Cropping Systems Analysis:** Remote sensing & GIS technology has also been instrumental in the analysis of various crop planting systems. This technology has mainly been in use in the horticulture industry where flower growth patterns can be analyzed and a prediction made out of the analysis.
4. **Crop Identification:** Remote sensing & GIS has also played an important role in crop identification especially in cases where the crop under observation is mysterious or shows some mysterious characteristics. The data from the crop is collected and taken to the labs where various aspects of the crop including the crop culture are studied.
5. **Crop acreage estimation:** Remote sensing & GIS has also played a very important role in the estimation of

the farmland on which a crop has been planted. This is usually a cumbersome procedure if it is carried out manually because of the vast sizes of the lands being estimated.

6. **Crop condition assessment and stress detection:** Remote sensing & GIS technology plays an important role in the assessment of the health condition of each crop and the extent to which the crop has withstood stress. This data is then used to determine the quality of the crop.
7. **Identification of planting and harvesting dates:** Because of the predictive nature of the remote sensing & GIS technology, farmers can now use remote sensing to observe a variety of factors including the weather patterns and the soil types to predict the planting and harvesting seasons of each crop.
8. **Crop yield modelling and estimation:** Remote sensing & GIS also allows farmers and experts to predict the expected crop yield from a given farmland by estimating the quality of the crop and the extent of the farmland. This is then used to determine the overall expected yield of the crop.
9. **Identification of pests and disease infestation:** Remote sensing & GIS technology also plays a significant role in the identification of pests in farmland and gives data on the right pests control mechanism to be used to get rid of the pests and diseases on the farm.
10. **Soil moisture estimation:** Soil moisture can be difficult to measure without the help of remote sensing technology. Remote sensing & GIS gives the soil moisture data and helps in determining the quantity of

moisture in the soil and hence the type of crop that can be grown in the soil.

11. **Irrigation monitoring and management:** Remote sensing & GIS gives information on the moisture quantity of soils. This information is used to determine whether a particular soil is moisture deficient or not and helps in planning the irrigation needs of the soil.
12. **Soil mapping:** Soil mapping is one of the most common yet most important uses of remote sensing. Through soil mapping, farmers are able to tell what soils are ideal for which crops and what soil require irrigation and which ones do not. This information helps in precision agriculture.
13. **Monitoring of droughts:** Remote sensing & GIS technology is used to monitor the weather patterns including the drought patterns over a given area. The information can be used to predict the rainfall patterns of an area and also tell the time difference between the current rainfall and the next rainfall which helps to keep track of the drought.
14. **Land cover and land degradation mapping:** Remote sensing & GIS has been used by experts to map out the land cover of a given area. Experts can now tell what areas of the land have been degraded and which areas are still intact. This also helps them in implementing measures to curb land degradation.
15. **Identification of problematic soils:** Remote sensing & GIS has also played a very important role in the identification of problematic soils that have a problem in sustaining optimum crop yield throughout a planting season.

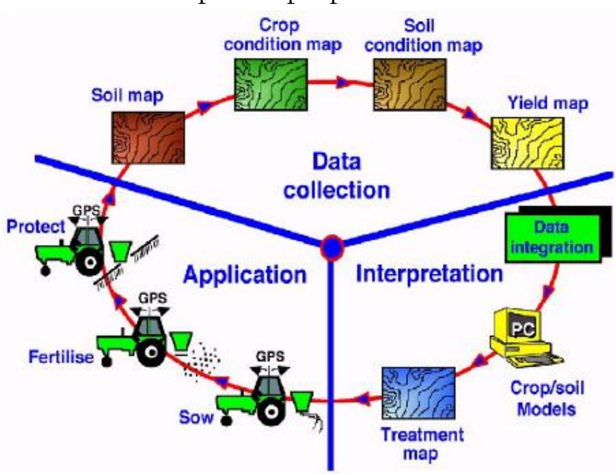
16. **Crop nutrient deficiency detection:** Remote sensing & GIS technology has also helped farmers and other agricultural experts to determine the extent of crop nutrients deficiency and come up with remedies that would increase the nutrients level in crops hence increasing the overall crop yield.
17. **Reflectance modeling:** Remote sensing & GIS technology is just about the only technology that can provide data on crop reflectance. Crop reflectance will depend on the amount of moisture in the soil and the nutrients in the crop which may also have a significant impact on the overall crop yield.
18. **Determination of water content of field crops:** Apart from determining the soil moisture content, remote sensing also plays an important role in the estimation of the water content in the field crops.
19. **Crop yield forecasting:** Remote sensing & GIS technology can give accurate estimates of the expected crop yield in a planting season using various crop information such as the crop quality, the moisture level in the soil and in the crop and the crop cover of the land. When all of this data is combined it gives almost accurate estimates of the crop yield.
20. **Flood mapping and monitoring:** Using remote sensing & GIS technology, farmers and agricultural experts can be able to map out the areas that are likely to be hit by floods and the areas that lack proper drainage. This data can then be used to avert any flood disaster in future.
21. **Collection of past and current weather data:** Remote sensing & GIS technology is ideal for collection and

storing of past and current weather data which can be used for future decision making and prediction.

22. **Crop intensification:** Remote sensing & GIS can be used for crop intensification that includes collection of important crop data such as the cropping pattern, crop rotation needs and crop diversity over a given soil.
23. **Water resources mapping:** Remote sensing & GIS is instrumental in the mapping of water resources that can be used for agriculture over a given farmland. Through remote sensing, farmers can tell what water resources are available for use over a given land and whether the resources are adequate.
24. **Precision farming:** Remote sensing & GIS has played a very vital role in precision agriculture. Precision agriculture has resulted in the cultivation of healthy crops that guarantees farmers optimum harvests over a given period of time.
25. **Climate change monitoring:** Remote sensing & GIS technology is important in monitoring of climate change and keeping track of the climatic conditions which play an important role in the determination of what crops can be grown where.
26. **Compliance monitoring:** For the agricultural experts and other farmers, remote sensing is important in keeping track of the farming practices by all farmers and ensuring compliance by all farmers. This helps in ensuring that all farmers follow the correct procedures when planting and when harvesting crops.
27. **Soil management practices:** Remote sensing & GIS technology is important in the determination of soil

management practices based on the data collected from the farms.

28. **Air moisture estimation:** Remote sensing & GIS technology is used in the estimation of air moisture which determines the humidity of the area. The level of humidity determines the type of crops to be grown within the area.
29. **Crop health analysis:** Remote sensing & GIS technology plays an important role in the analysis of crop health which determines the overall crop yield.
30. **Land mapping:** Remote sensing & GIS helps in mapping land for use for various purposes such as crop growing and landscaping. The mapping technology used helps in precision agriculture where specific land soils are used for specific purposes.



Precision agriculture cycle

3. SPATIAL DATA AND THEIR MANAGEMENT IN GIS

Spatial information is always related to geographic space. The handling of spatial data usually involves the process of data acquisition, storage, analysis, and output. Creation of spatial database in geographic information system (GIS) has become a very effective tool to aid and facilitate management decision-making. GIS provides tools and methods for the integration of different databases into a format to be compared and analyzed. Spatial analysis is a vital part of GIS and can be used for many applications like site suitability, natural resource monitoring, environmental disaster management, etc. Spatial modeling infers the use of spatial characteristics and methods in manipulating data.

Database in GIS

Database in GIS should be viewed as a representation of model of the real world developed for any speicific application. GIS technology utilizes two basic types of data, i.e., spatial data (coordinate and projection information for spatial features) and attribute data (characteristics about spatial data).

1. **Spatial Data:** Spatial data describes the absolute and relative location of geographic features. Spatial data can be point, line, polygon, or pixel. Spatial data includes location, shape, size, location, and orientation. Spatial data is usually stored as coordinates and topology. Spatial database is often updated, accessed, manipulated or analysed by using appropriate tools of GIS.
2. **Attribute Data:** Attribute data is often referred to as tabular data, and it describes characteristics of the spatial features. These characteristics can be quantitative and/or qualitative in nature. Attribute data is stored in the form of tables, and it is a database component that contains a series of rows and columns, where each row, or record, represents a geographic feature—such as a parcel, power pole, highway, or lake—and each column, or field, describes a particular attribute of the feature—such as length, depth, area, etc. Tables are stored in a database—for example, INFO, Access, dBASE, FoxPro, Oracle, or SQL Server. From a table, one can identify features with particular attributes and select them on the map. Over time, attribute data can also update to reflect changes to geographic features, for example, creating a new subdivision in the district boundary, and subsequently it also reflects in the attribution table.

Spatial Data Relationships in GIS

1. **Geo-Relational Database Model:** The geo-relational approach involves abstracting geographic information into a series of independent layers or coverages, each representing a selected set of closely associated geographic features (e.g., roads, land use, river, settlement, etc.). Each layer has the theme of a geographic feature, and the database is organized in the thematic layers. With this approach users can combine simple feature sets representing complex relationships in the real world.
2. **Topological Data Structure:** Topology is the spatial relationship between connection and adjacent coverage features. Topological relationships are built from simple elements into complex elements: line, points, and areas. Topology is defined as the mathematical procedure for explicitly defining spatial relationships between the data (connectivity or adjacency of points or lines in a GIS). The topological data structure logically determines exactly how and where points and lines connect on a map by means of nodes. The computer stores such information in various tables of the database structure. In digital maps or GIS, topological data structures provide additional intelligence for manipulating, analyzing, and using the information stored in a database. The order of connectivity defines the shape of an arc or polygon. Storing information in a logical and ordered relationship, missing information is readily apparent,

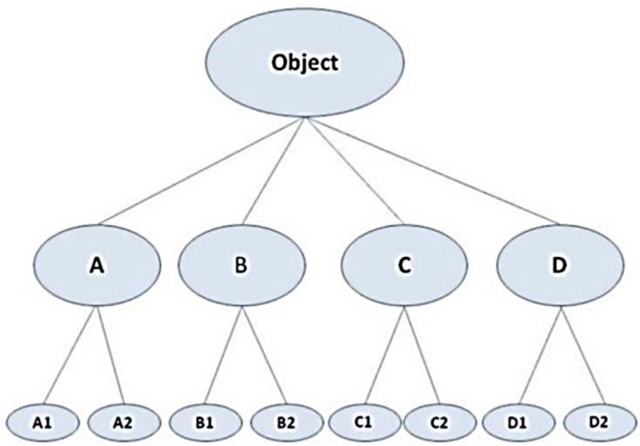
data are stored efficiently, and large datasets can be processed quickly.

Attribute Database Models in GIS

Data within a GIS environment are stored with attribute databases. A database is a collection of information about things and their relationships to each other. A variety of different data models exist for the storage and management of attribute data. The most common attribute database models are tabular, hierarchical, network, and relational and object oriented.

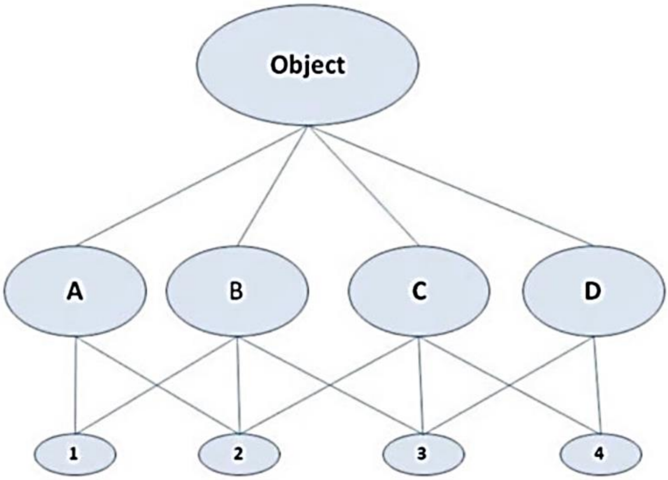
1. **Tabular Model:** The simple tabular model stores attribute data as sequential data files with fixed formats, for the location of attribute values in a predefined record structure. It lacks any method of checking data integrity, as well as being inefficient with respect to data storage, e.g., limited indexing capability for attributes or records, etc.
2. **Hierarchical Model:** The hierarchical database organizes data in a tree structure. Data is structured downward in a hierarchy of tables. The data is stored as records, which are connected to one another through links. A record is a collection of fields, with each field containing only one value. Several records or files are hierarchically related with each other, and a set of links connect all record types in a tree structure. The advantages of hierarchical model are high speed of access to large datasets and eases of updating. However, the disadvantage is that linkages are only

possible vertically but not horizontally or diagonally. Further, it is oriented for datasets that are very stable, where primary relationships among the data change infrequently or never at all. The quadtree, that is used to access a small part of a large raster image or map area, is a type of hierarchical model. The records at different levels in hierarchical model are shown in Fig. given below-



Hierarchical model shows the records at different levels

3. **Network Model:** The data in the network model are represented by collection of records, and relationships among data are represented by links, which can be viewed as pointers. Any record in the network model can be linked to any other. This model allows for children to have more than one parent. The vector mode is more suited to network analysis than the raster model. Records and relationships in network model are shown in Fig. given below-



Records and relationships in network model

4. **Relational Database:** The relational data model is conceived as a series of tables, with no hierarchy nor any predefined relations. Each table is identified by a unique table name and is organized by rows and columns. Each column within a table also has a unique name. Columns store the values for a specific attribute. Rows represent one record in the table. In a GIS each row is usually linked to a separate spatial feature. Accordingly, each row would comprise of several columns, each column containing a specific value for that geographic feature. The relation between the various tables should be made by the user. This is done by identifying a common field in two tables, which is assigned as the flexibility than in the other two data models. However, accessing the database is slower

than with the other two models. Relational Database Management System (RDBMS) follows relational database model and make it possible to pose complex queries, produce statistical summaries and tabular reports of attribute data. It also has the ability to make map analyses, often combining elements from many layers (Eastman 1992). Due to its greater flexibility, the relational data model is used widely in all GIS systems. Relational database model has simplicity in organization and data modeling and flexibility in joining tables in an ad hoc manner. This model has efficiency of storage data and minimized redundant data.

5. **Object-Oriented Model:** The object-oriented database model manages data through objects. An object is a collection of data elements and operations that together are considered a single entity. The object-oriented database is a relatively new model. This approach has the attraction that querying is very natural, as features can be bundled together with attributes at the database administrator's discretion. This model uses functions to model spatial and nonspatial relationships of geographic objects and the attributes. The model generates objects, classes, and superclasses through classification, generalization, association, and aggregation. This approach holds many operational benefits with respect to geographic data processing in GIS.

Spatial Database Query

The selective display and retrieval of information from a database are among the fundamental requirements of GIS. The ability to selectively retrieve information from GIS is an important facility. Database query simply asks to see already stored information. Basically there are two types of query in GIS: they are query by attribute and query by geometry. The procedure followed in query by attribute and query by geometry in GIS is shown in Fig. 7.3. The attribute database, in general, is stored in a table with a unique code linked to the geometric data. This database can be searched with specific characteristics. However, more complex queries can be made with the help of SQL. GIS can carry out a number of geometric queries. There are five forms of primitive geometric query: viz., query by point, query by rectangle, query by circle, query by line, and query by polygon. More complex queries can be developed, which uses both geometric and attributes search criteria together.

Analysis of Geographic Data

The heart of GIS is the analytical capabilities of the system. What distinguish the GIS system from other information systems is its spatial analysis functions. Geographic analysis facilitates the study of real-world processes by developing and applying models. The analysis functions use the spatial and nonspatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. Such models illuminate the underlying trends in geographic data and thus make new information available. In data analysis the most common operations carried out by GIS are database query, map algebra, and distance- and context-related analysis. The objective of geographic analysis is to transform data into useful information to satisfy the requirements or objectives of decision-makers. Spatial analysis helps to identify trends in the data, create new relationships from the data, and view complex relationships between datasets to make better decisions. In data analysis, the most

common operations carried out by GIS are database query, map algebra, and distance- and context-related analysis. Buffer zone creation and reclassification are some of the important techniques in geographic analysis.

Buffer Zone Creation: Distance operator in GIS is an example for analysis of geographic data by using buffer zone creation. It shows the proximity or nearness from any point, line, or polygon. Using these operations, the characteristics of an area surrounding in a specified location can be generated. This kind of analysis is called proximity analysis and is used whenever analysis is required to identify surrounding geographic features. The buffer operation generates polygon feature types irrespective of geographic features and delineates spatial proximity.

Reclassification: Reclassification is a method of changing the attribute values without altering the geometry of the map. In fact it is a database simplification process that aims at reducing the number of categories of attribute data layer. Accordingly, features adjacent to one another that have a common value will be treated and appear as one class. Reclassification is an attribute generalization technique. After reclassification, the common boundaries between polygons with identical attribute values are dissolved and rebuilt the topology.

Overlay Analysis

Overlay analysis is an operation in GIS for superimposing the multiple layers of datasets that represents different themes together for analyzing or identifying relationship of each layer. What distinguishes the GIS system from other information system is its spatial analysis functions. The analysis functions use the spatial and nonspatial attributes in the database to answer questions about the real world. Spatial analysis in GIS includes all of the transformations, manipulations, and methods, which can be applied to geographic data to add value to them, to support decisions, and to reveal patterns and anomalies that are not visible in raw data. In the overlay analysis, new spatial datasets are created in GIS by merging data from two or more input data layers. In overlay analysis, topological overlay, spatial overlay, and criterion-based overlay techniques are important. Based on data structures, vector overlay and raster overlay are the two important overlay techniques.

1. **Topological Overlay**

   Topological overlay is an analysis procedure for determining the spatial coincidence of geographic features. Append, union, identity, intersect, update, clip, split, and erase are some of the important topological overlay techniques.

a. Append: Appending is used to merge together multiple datasets that represent the same thematic data but are contiguous.
b. Union: A topological overlay of two polygon coverages, which preserves features that fall within the spatial extent of either input datasets, i.e., all features from both coverages are retained.
c. Identity: This operation overlays polygons and keeps all input layer features and only those features from the analysis layer that overlap the input layer. The resultant layer has the same spatial features as that of the input layer. In the case of polygon overlays, the number of polygon in the output layer will always be larger in number than the input layer.
d. Intersect: The topological integration of two spatial datasets that preserves features that fall within the spatial extent common to both input datasets. The resultant layer will keep those portions of the first input layer features, which fall within the second input layer polygons.
e. Update: It replaces overlapping parts of the input layer with features from the update layer.
f. Clip: It creates a new map that includes only those features of the input layer that fall within the area

extent of the clip map. The input layer may be points, lines, or polygons, but the clip layer must be polygon layer. This operator is used to extract a smaller dataset from a larger dataset.

g. Split: It divides the input coverage into two or more coverages. A series of clip operation can be performed, and each resultant layer contains only those portions of the input layer that are overlapped by the polygon satisfying the specified criteria.

h. Erase: This feature can be used to erase polygons, lines, or points from the input features in GIS. A line-erase feature can be used to erase lines or points from the input features; a point-erase feature can be used to erase points from the input features.

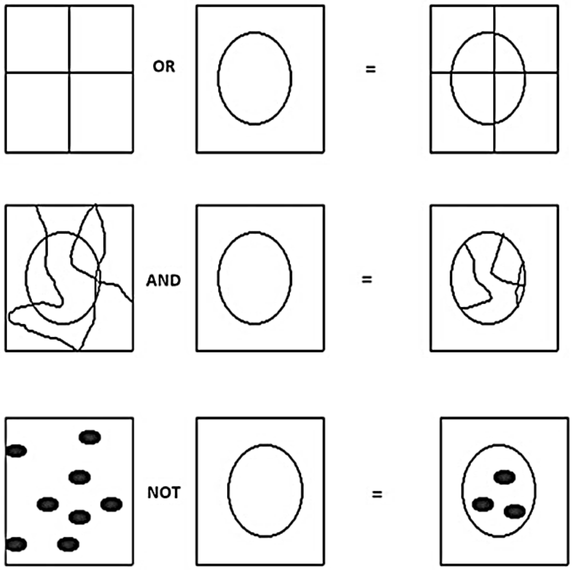
2. Spatial Overlay

In spatial overlay analysis, two or more themes can be combined to form a new spatial feature (both geometric and attribute features are combined). Spatial overlay is accomplished by joining and viewing together separate datasets that share all or part of the same area. The result of this combination is a new dataset that identifies the spatial relationships. Three types of overlay can be performed: polygon-polygon, line-polygon, and point-polygon.

a. Polygon-on-polygon overlay: This process merges overlapping polygons from two input layers in GIS to create new polygons in an output layer. The result of a polygon-on-polygon overlay is an output layer containing new polygons with merged attributes (i.e., those attributes from each of the two overlapping polygons). In this overlay, it is necessary to keep in mind that area should be common to input features.

b. Line-in-polygon overlay: Polygon features of one input layer can be overlaid on lines (arcs) of another input layer in GIS. A line can be made up of many segments, line-in-polygon analyses, and therefore identifies which polygon (if any) contains each line or line segment. The result of a line-in-polygon overlay is a new layer containing lines with additional attributes (i.e., those attributes of the polygon within which the line falls).

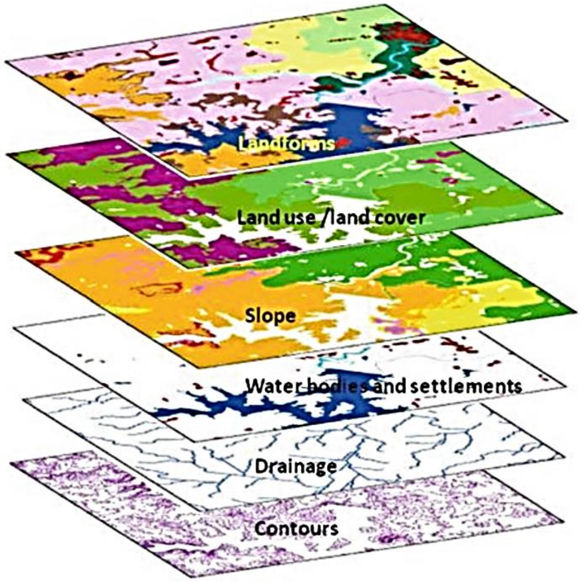
c. Point-on-polygon overlay: Point features of one input layer can be overlaid on polygon features of another input layer in GIS. Point-in-polygon analyses identify the polygon within which each point falls. The result of a point-in-polygon overlay is a set of points with additional attributes (i.e., those attributes of the polygon which the point lies within). This kind of overlay operation can be used to calculate number of points located in each of the polygon. During the process of overlay, the attribute data associated with each feature type id merged. The resulting table will contain both the attribute data. The process of overlay will depend upon the modeling approach the user needs. One might need to carry out a series of overlay procedures to arrive at the conclusion, which depends upon the criterion (Fig. given below-).



Polygon-on-polygon overlay: difference between a topologic overlay and a graphic over plot

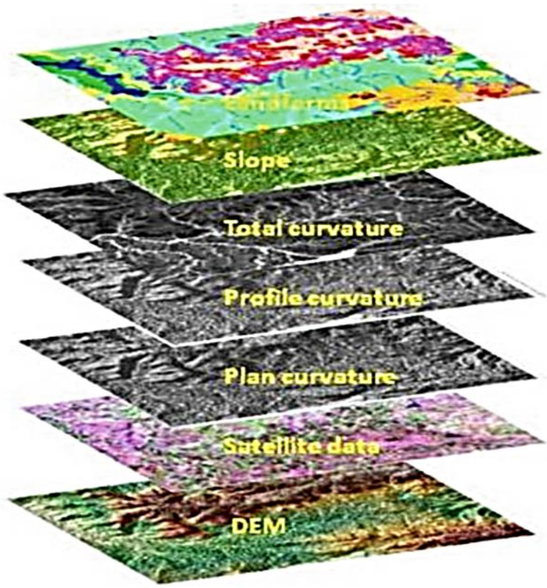
3. **Overlay Based on Data Structure**
   Based on data structures, vector overlay and raster overlay are the two overlay techniques in GIS.

a. **Vector Overlay:** The vector overlay, however, is far more difficult and complex and involves more processing. In simple vector overlay, the layers were overlaid without assigning any weightage either for layer or classes. Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input to create an integrated analysis. Geographic problems often require the analysis of many different factors. The weighted overlay process reclassifies values in the input rasters onto a common evaluation scale of suitability or preference, risk, or some similarly unifying scale. The input rasters are weighted by importance and added to produce an output raster. The weighted overlay process accepts only discrete rasters (integer values) as input. Continuous rasters should and must be reclassified to discrete rasters before they can be used. The typical vector overlay procedure performed in delineation of landforms by integrating contours, drainage, waterbodies and settlements, slope, and land use/land cover is shown in Fig. given below. During vector overlay, map features and the associated attributes are integrated to produce new composite maps. Logical rules can be applied to how the maps are combined. Vector overlay can be performed on different types of map features: viz., polygon-on-polygon overlay, line-in-polygon overlay, and point-on-polygon overlay. There are some difficulties in geographic analysis, which includes lack of required datasets. Maintenance of spatial relationships in the input datasets is also important to get the accurate areas and shapes in outputs. Inherent uncertainties in the datasets due to scale are also another difficulty in integrated analysis. When using the spatial datasets from different sources, it is difficult to make data sources compatible easily. Selection of suitable model for the analysis of specific objective is also important to get the desirable outputs. The data file produced as a result of polygon overlay may be considerably larger than the original because lines have been split into smaller segments and new nodes and polygons have been created.



Typical vector overlay procedure in GIS

b. **Raster Overlay:** aster overlays are relatively simple compared to their vector counterparts and require much less computational power (Burrough 1983). In raster overlay, the pixel or grid cell values in each map are combined using arithmetic and Boolean operators to produce a new value in the composite map. The maps can be treated as arithmetical variables and perform complex algebraic functions, and it is called as map algebra. Despite their simplicity, it is important to ensure that all overlain rasters are coregistered (i.e., spatially aligned), cover identical areas, and maintain equal resolution (i.e., cell size). If these assumptions are not met, the analysis will either fail, or the resulting output layer will be flawed (Chrisman 2002). The mathematical raster overlay is the most common overlay method. As an example, the rasters of digital elevation model (DEM), satellite data, plan curvature, profile curvature, and total curvature overlaid using raster overly model in GIS to delineate the distinct landforms in part of Katol tehsil of Nagpur district, Maharashtra, Central India is shown in Fig. given below. Weighted overlay process reclassifies the values in the input rasters onto a common evaluation scale of suitability or preference, risk, or some similarly unifying scale. The input rasters are weighted by importance and added to produce an output raster. The weighted overlay process accepts only discrete rasters as input. Continuous rasters should and must be reclassified to discrete rasters before they can be used. In raster overlay, if two grids are aligned and have the same grid cell size, then it is relatively easy to perform overlay operations. A new layer of values is produced from each pair of coincident cells. The values of these cells can be added, subtracted, divided, or multiplied, the maximum value can be extracted, mean value can be calculated, a logical expression can be computed, and so on.



Typical raster overlay procedure in GIS

4. **Overlay Analysis with Logical Operators**

   The concept of map logic can be applied during overlay. Logical operators are based on point-by-point or cell-by-cell analysis. The most important of this group is the overlay analysis. In the raster-based analysis, either the logical or arithmetic operators are used. The logical operators are Boolean functions. There are basically four types of Boolean operators: viz., OR, AND, NOT, and XOR. Basic arithmetic operators in raster overlay operations are addition, subtraction, division, and multiplication.

Spatial Modeling

Spatial modeling is an analytical process conducted in conjunction with a GIS in order to describe basic processes and properties for a given set of spatial features. The objective of spatial modeling is to be able to study and simulate spatial objects or phenomena that occur in the real world and facilitate problem solving and planning. Due to the inherent complexity of the world and the interactions in it, models are created as a simplified, manageable view of reality. Spatial models help to understand, describe, or predict how things work in the real world. There are two main types of models: representation model, which represents the objects in the landscape, and process model, which simulates processes in the landscape. Set of analytical procedures simulates real-world conditions within a GIS using their spatial relationships of geographic features. Geometric modeling (generating buffers, calculating areas and perimeters, and calculating distances between features), coincidence modeling (topological overlay), and adjacency modeling (pathfinding, redistricting, and allocation) are three important categories of spatial modeling functions that can be applied to geographic features within a GIS.

1. **Representation Models:** Representation models try to describe the objects in a landscape. The way representation models are created in a geographic information system (GIS) is through a set of data layers. These data layers will be either raster or feature data. Raster layers are represented by a rectangular mesh or grid, and each location in each layer is represented by a grid cell, which has a value. Cells from

various layers stack on top of each other, describing many attributes of each location. The representation model attempts to capture the spatial relationships within an object and between the other objects in the landscape. Along with establishing the spatial relationships, the GIS representation model is also able to model the attributes of the objects. Representation models are sometimes referred to as data models and are considered descriptive models.

2. **Process Models:** Process models attempt to describe the interaction of the objects that are modeled in the representation model. The relationships are modeled using spatial analysis tools. Since there are many different types of interactions between objects, process modeling is sometimes referred to as cartographic modeling. Process models can be used to describe processes, but they are often used to predict what will happen if some action occurs. Some process models are simple, while others are more complex. A process model should be as simple as possible to capture the necessary reality to solve your problem. Even more complexity can be added by adding logic, combining multiple process models. There are many types of process models to solve a wide variety of problems. A set of conceptual steps can be used to build a model. Some include surface modeling, distance modeling, hydrologic modeling, suitability modeling, etc. Suitability modeling in GIS helps to find out the optimum locations. Distance modeling helps to find out the distance like what is the minimum distance between the two areas. Buffering is the best example

for distance modeling. In buffering process, it creates buffer polygons to a specified distance around the input features. An optional dissolve can be performed to remove overlapping buffers. Using these operations, the characteristics of an area surrounding in a specified location are evaluated. This kind of analysis is called proximity analysis and is used whenever analysis is required to identify surrounding geographic features. The buffer operation will generate polygon feature types irrespective of geographic features and delineates spatial proximity. Hydrologic modeling helps to find out the directions like water flow in hydrological analysis. Surface modeling helps to find out the different level of information like what is the pollution level for various locations.

In this way during development of spatial databases in GIS, often data, comes from different formats and sources like manual digitization and scanning of aerial photographs, remote sensing satellite imageries, paper maps, and existing digital datasets. GIS provides tools and methods for integration of different data into a format to be compared and analyzed. In data analysis, query, map algebra, and distance- and context-related analysis are the most common operations carried out in GIS. GIS-based spatial analysis includes the transformations, manipulations, and methods to analyze the database and the anomalies that are not visible in raw data. In GIS simulation modeling, a set of analytical procedures helps to simulate real-world conditions within a GIS using their spatial relationships of geographic features. Spatial modeling is a vital part of GIS and can be used for many applications like site suitability, natural resource monitoring, environmental disaster management, etc.

4. INTRODUCTION TO CROP SIMULATION MODELS AND THEIR USES FOR OPTIMIZATION OF AGRICULTURAL INPUTS

Model:

It is a simplified description (often, a mathematical representation) of a system to assist calculations and predictions.

In the present context, 'model' is expressed as a computer program that can be repeatedly run several times for computing several designed mathematical or statistical expressions (equations) governing crop growth-environment relations, given appropriate input data.

Types of Models:

Depending upon the purpose for which it is designed the models are classified into different groups or types. A few of them are:

1. **Statistical models:** These models express the relationship between yield or yield components and weather parameters. In these models relationships are measured in a system using statistical techniques. Example: Step down regressions, correlation, etc.
2. **Mechanistic models:** These models explain not only the relationship between weather parameters and yield, but also the mechanism of these models (explains the relationship of influencing dependent variables). These models are based on physical selection.
3. **Deterministic models:** These models estimate the exact value of the yield or dependent variable. These models also have defined coefficients.
4. **Stochastic models:** A probability element is attached to each output. For each set of inputs different outputs are given along with probabilities. These models define yield or state of dependent variable at a given rate.
5. **Dynamic models:** Time is included as a variable. Both dependent and independent variables are having values which remain constant over a given period of time.
6. **Static models:** Time is not included as a variable. Dependent and independent variables having values remain constant over a given period of time.
7. **Descriptive model:** A descriptive model defines the behaviour of a system in a simple manner. The model reflects little or none of the mechanisms that are the causes of phenomena. But, consists of one or more mathematical equations. An example of such an

equation is the one derived from successively measured weights of a crop. The equation is helpful to determine quickly the weight of the crop where no observation was made.

8. **Explanatory model**: This consists of quantitative description of the mechanisms and processes that cause the behaviour of the system. To create this model, a system is analyzed and its processes and mechanisms are quantified separately. The model is built by integrating these descriptions for the entire system. It contains descriptions of distinct processes such as leaf area expansion, tiller production, etc. Crop growth is a consequence of these processes.
9. **Simulation models:** Computer models, in general, are a mathematical representation of a real world system. One of the main goals of crop simulation models is to estimate agricultural production as a function of weather and soil conditions as well as crop management. These models use one or more sets of differential equations, and calculate both rate and state variables over time, normally from planting until harvest maturity or final harvest.

Simulation:

This is the reproduction of an observed phenomenon (e.g., growth of biomass with time; water use by a growing crop etc.,) by developing a model and a computer programme written for it. Such a programme usually is comprised of mathematical, statistical, physical, graphical or empirical expressions relating the various parameters given as input information or data.

Model is a concept; simulation helps reproduction of a system in the laboratory using the concept; could contain measurable or estimated parameter values or both. Most often, the computer programme written for any particular purpose is itself called a model.

Crop-environment interactions are unlimited in number. They can be studied from several points of view (physical, physiological, chemical, biochemical, bio-technological, agronomical, entomological or pathological, economic benefit angles etc.,). We have the roots growing with passage of time and interacting with soil, taking up water and nutrients for transport to the above-ground parts of a plant. The stem, branches, leaves as they grow interact with environment (both individually and together), under the influence of solar radiation to produce flowers and pods / oils, grains— ultimately yield. Evapotranspiration, Leaf-air interactions, Photosynthesis, respiration, carbon dioxide assimilation, are the other processes involved in crop growth. Crop is also affected by pest/disease incidence.

Thus crop growth is usually viewed as a “complex system” which comprises of “sub-systems” in which several processes take place. One process leads to the other and so, individual processes (water or nutrient uptake by roots, biomass accumulation, grain growth etc.,) are considered as “sub-systems”. All the processes which interact among themselves (since the start of growth of plant from seeding to final yield) and put together are considered as a “system”. Thus one can have "sub-models" as part of a "model", "sub-systems" and a "System". One can simulate water uptake, branching pattern and growth, leaf development, pod growth, etc. and their interaction with soil and aerial environment, as individual models. The point to note is that there is no limit to the items that can be taken up to develop a simulation model.

Why we need simulation models?

1. To incorporate knowledge gain from field experimentation.
2. To provide a structure that promotes interdisciplinary cooperation.
3. To promote the use of systems investigation for solving troubles.
4. To offer dynamic, quantitative tools for analyzing the difficulty of cropping systems.

Input data requirement for crop simulation modeling:

Crop modeling requires data related to weather, crop, soil, management practices and insect- pests.

1. **Weather data:** Maximum and minimum temperature, rainfall, relative humidity, solar radiation and wind speed. Weather data is required at daily time step to assess daily crop growth processes.
2. **Crop data:** Crop name, variety name, crop phenology (days to anthesis, days to maturity etc.), leaf area index, grain yield above ground biomass, 1000 grain weight.

3. Soil data includes: Thickness of soil layer, pH, EC, N, P, K, soil organic carbon, soil texture, sand and clay percent, soil moisture, saturation, field capacity and wilting point of soil, bulk density.
4. **Crop management data:** Date of sowing of crop is required to initiate the simulation process. Generally sowing date is taken as the start time for the simulation. In case of transplanted rice date of transplanting is used instead of sowing date. Seed rate and depth of seeding are also required. Use of inputs in the crop field, namely, irrigation, fertilizer, manure, crop residue etc. needs to be mentioned. Amount of these inputs are specified along with their type, date of application and depth of placement. If crop residues or organic nutrient sources are applied in the field then C:N ratio of those sources are quantified.
5. **Pest data:** Name and type of the pest, their mode of attack, pest population at different crop growth stages. Data on insects or pests are included only in those models which contains the pest module.

Steps in modeling

1. **Define goals:** Agricultural system is complex comprising of various disciplines. In order to develop or understand a crop model one requires strong knowledge base of different subjects. Depending upon the objective of study, knowledge base of different disciplines is integrated to develop a crop model.
2. **Define system and its boundaries:** In agriculture, crop field is chosen as a system.

3. **Define key variables in system:** Variables include state, rate, driving and auxillary variables. State variables are those which can be measured or quantified, e.g. soil moisture content, crop yield etc. Rate variables are the rates of different processes operating in a system, e.g. photosynthesis rate, transpiration rate. Driving variables are the variables which are not part of the system but the affect the system, e.g. sunshine, rainfall. Supplementary variables are the intermediated products, e.g. dry matter partitioning, water stress etc. These variables are identified in the crop field. After identification of these variables relationship among different variables is determined. This helps in better understanding of the whole process.
4. **Quantify relationships:** Once the relationship is established it is then quantifies using different mathematical equations and functions.
5. **Calibration/Validation:** When the model is developed, it requires calibration and validation. First the model is run with any experimental data set and calibrated accordingly. Calibration is done by the trial and error method. Calibrated model is then validated with another experimental dataset to check its simulation ability under different situations or environment.
6. **Sensitivity analysis:** Validated model is further tested for its sensitivity to different factors (e.g. temperature, rainfall, N dose). This is done to check whether the model is responding to changes in those factors or not.

7. **Simplification:** Any model is initially written in computer programming languages. But they are made simple by making it user friendly.
8. **Use of models in decision support:** Once developed, calibrated and validated any model can be used in any decision support system for forecasting or making suitable decisions regarding crop management.

Possible applications of crop model:

1. Evaluation of potential yields.
2. Assessment of yield gaps: principal causes and their contribution.
3. Yield forecasting.
4. Impact assessment of climatic variability and climatic change.
5. Optimizing management- Dates of planting, variety, irrigation and nitrogen fertilizer.
6. Environmental impact- percolation, N losses, GHG emissions, SOC dynamics.
7. Plant type design and evaluation.
8. Genotype by environment interactions.

Limitations of modelling:

Corp models required large amount of input data, which may not be available with the user along with it, required skilled manpower, good knowledge of computers and computer language. Crop modeling needs multidisciplinary knowledge. No model can take into account all the existing complexity of biological systems. Hence simulation results have errors. A model is a tool for improving critical thought, not a substitute for it. Models can help formulate hypotheses and improve efficiency of field experiments, but they do not eliminate the need for continued experimentation. Models developed for a specific region cannot be used as such in another region. Proper parameterization and calibration is needed before using a model.

List of crop growth simulation model:

The last two decades have witnessed the development of numerous cropgrowth and yield simulation models describing the dynamics of the soil-waterplant-atmosphere system. Models are now available for all the major crops such as wheat, rice, maize, cotton, sorghum, groundnut, soybean, chickpea, potato, millet and sunflower as well as for some plantation and horticultural crops. Current literature reviewed has revealed that there are at least 100 different crop simulation models of varying complexity that presently exist and a few are as listed below-

Software	Details
SLAM II	Forage harvesting operation
SPICE	Whole plant water flow
REALSOY	Soyabean
MODVEX	Model development and validation system
IRRIGATE	Irrigation scheduling model
COTTAM	Cotton
APSIM	Modelling framework for a range of crops
GWM	General weed model in row crops
MPTGro	Acacia spp.and Leucaena Spp.
GOSSYM-COMAX	Cotton
CropSyst	Wheat & other crops
SIMCOM	Crop (CERES crop modules) & economics
LUPINMOD	Lupin
TUBERPRO	Potato & disease
SIMPOTATO	Potato
WOFOST	Wheat & maize, Water and nutrient
WAVE	Water and agrochemicals
ORYZA1	Rice, water
SIMRIW	Rice, water
SIMCOY	Corn
CERES-Rice	Rice, water
GRAZPLAN	Pasture, water, lamb
EPIC	Erosion Productivity Impact Calculator
CERES	Series of crop simulation models
DSSAT	Framework of crop simulation models including modules of CERES, CROPGRO and CROPSIM
PERFECT	
QCANE	Sugarcane, potential conditions
AUSCANE	Sugarcane, potential & water stress conds., erosion
CANEGRO	Sugarcane, potential & water stress conds
APSIM-Sugarcane	Sugarcane, potential growth, water and nitrogen stress
NTKenaf	Kenaf, potential growth, water stress

5. SOIL TEST CROP RESPONSE (STCR) APPROACH

After introduction of high yielding varieties and hybrid crops, the need for systematic soil test crop response research in different soil agro-climatic regions become evident. ICAR established the AICRP on STCR in 1967 and the STCR concept was developed by Ramamoorthy, in 1987. STCR provides the relationship between a soil test value and crop yield.

The soil test values are needed to be correlated with actual crop response obtained under field conditions. Separate calibration charts are needed for each crop and soil. Fertility gradient and regression approach and targeted yield concepts were evolved. This is also called as “rationalized fertilizer prescription approach” in which inherent soil fertility and yield level of the crop are taken in to account while recommending the fertilizer doses.

Objective of STCR

1. To prescribe fertilizer doses for a given crop based on soil test values to achieve the "Targeted yields" in a specific soil agro-climatic region under irrigation or protective irrigation conditions by using mathematical equations for different crops and different soil agro-climatic zones separately.
2. This takes in to consideration-the efficiency of utilization of soil and added fertilizer nutrient by the crops and its nutrient requirements for a "desired yield level".

Concept of STCR

STCR approach is aiming at obtaining a basis for precise quantitative adjustment of fertilizer doses under varying soil test values and response conditions of the farmers and for targeted levels of crop production. These are tested in follow up verification by field trials to back up soil testing laboratories for their advisory purpose under specific soil, crop, and agro climatic conditions.

The fertilizers are recommended based on the following criteria-

1. Fertilizer recommendations based on regression analysis approach
2. Recommendations for certain % of maximum yield

STCR methodology takes in to account the four factors;

1. Nutrient requirement (NR) in kg/ quintal of the produce
2. Percentage contribution from soil available nutrients (CS)
3. Percentage contribution from added fertilizers towards making effective fertilizer prescriptions for specific yields (CF).
4. Percentage contribution from added organic manures (C-OM).

$$NR\ (kg\ q^{-1}) = \frac{\text{Nutrient uptake (NPK)(kg ha}^{-1}\text{) by grain + straw}}{\text{Grain yield or any economic produce (q ha}^{-1}\text{)}}$$

$$\%\ CS = \frac{\text{Nutrient uptake (NPK)(kg ha}^{-1}\text{) by grain + straw in control plot}}{\text{Soil test values (Av. NPK) in control plot (kg ha}^{-1}\text{)}} X\ 100$$

$$\%\ CF = \frac{\{\text{Nutrient uptake by grain + straw in treated plot}\} - \left\{\frac{[\text{Soil test values in treated plot}]\ X\ [\%\ \text{Contribution(NPK)from soil}]}{100}\right\}}{\text{Nutrient doses applied in treated plot (kg ha}^{-1}\text{)}} X100$$

$$\%\ C-OM = \frac{\{\text{Total uptake of NPK in organic plot (kg ha}^{-1}\text{)}\} - \left\{\frac{[\text{Mean CF of control plot}]\ X\ [\text{STV in organic plot (kg ha}^{-1}\text{)}]}{100}\right\}}{\text{Amount of NPK added through FYM (kg ha}^{-1}\text{)}} X100$$

With the help of above parameters, adjustment equations have been developed for a number of crops in various soils.

E.g.: For Rice crop.

a. Fertilizer N = 4.39 T -0.6723 Soil N

b. Fertilizer P2O5 = 2.83 T – 6.110 Soil P

c. Fertilizer K2O = 1.41 T – 0.329 Soil K

Where T= Targeted yield of rice

Advantages

1. Efficient and profitable site specific fertilizer recommendation for increased crop production and for maintenance of soil fertility.
2. Aims to provide balanced, efficient and profitable nutrient application rates for pre- set yield targets giving due consideration to basic fertility status of soil

Targeted yield concepts:

These are soil test based recommendations but given for different yield goals and not for a single optimum yield level. A large variety of fertilizer prescription have been made available by putting soil test values in to certain mathematical equations and finding out the amounts of nutrients needed for a given yield target.

6. VARIABLE RATE TECHNOLOGY (VRT)

Variable rate technology refers to the application of parameters like fertilizer use, lime application, seeding, etc. based on the area, location, soil conditions, etc.

It is also known as Variable Rate Application (VRA). VRA works by encompassing the variable rate control system with application equipment to apply inputs at precise location at precise time so that the site-specific application of inputs is accomplished.

Different components used are the following:

- DGPS receiver
- Computer
- VRA software

- Controller

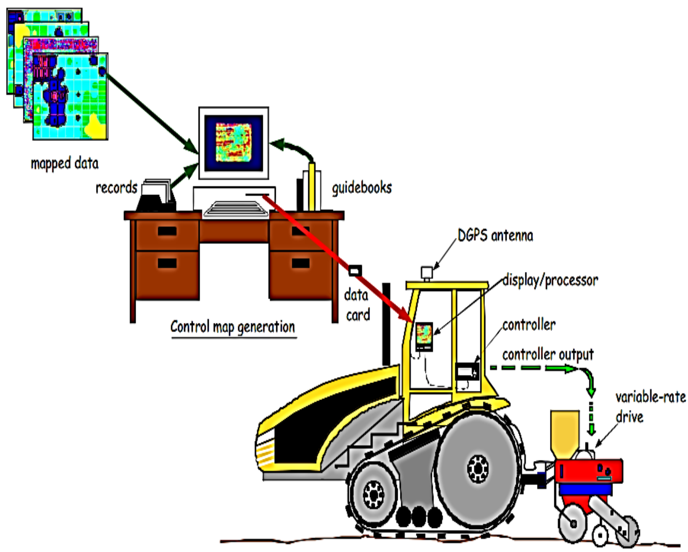
The major components of a typical map-based variable rate control system include an in-cab computer (or controller) loaded with application software, a DGPS receiver that provides vehicle position information to the computer, and an actuator that regulates material rates under direction of the computer. When the equipment is operating in the held, the computer receives position information, matches the required application rate as a function of vehicle position, and then sends a set point signal to the controller that adjusts the application to the desired rate. A variable rate system may also record actual application rates along with GPS position. This information serves as a record of what was applied to the field and allows for review of application for future recommendation considerations.

Depending upon whether the VRA technology is being used with or without GPS system, there are two methods:

- Map based
- Sensor based

(a) Map-based VRA

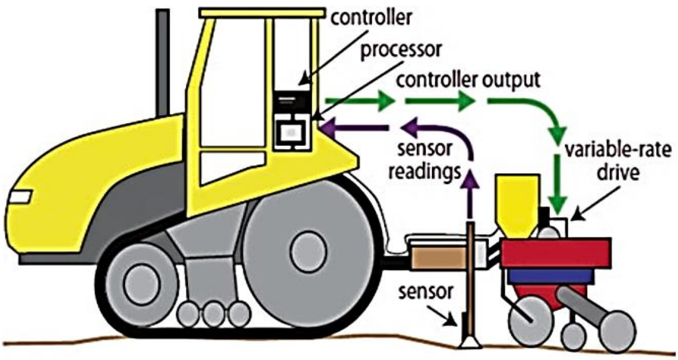
This method of VRA makes use of a GPS receiver. It adjusts the application rate by making use of electronic map which is also known as prescription map. A prescription map is an electronic data file which has all the necessary and specific information regarding the input rates to be given in every field zone. As the applicator moves through the field (using the field position from GPS receiver), the concentration of input changes which is detected by the prescription map kept at a desired rate. Map-based VRA also uses maps based on previous measurements which are then implemented using various strategies which are based on information like soil type, soil color, topography, crop yield, remotely sensed images, etc., and this information is crop- and location-specific.



An illustration of a map-based system for varying crop input application rates

(b) Sensor-based VRA (On the go/ On the fly)

This method of VRA does not require GPS or prescription maps. The sensors installed on applicators detect the soil properties as well as crop characteristics. Thus, a continuous flow of information is collected based on the sensor report which is then transferred to the control system which calculates the input rates and sends the calculated information to the controller, which then delivers the input to the location. Sensor-based VRA has an advantage of providing the real-time data using the real-time sensors unlike the map-based VRA which makes use of previously collected data to vary the application rate inputs.



On the go sensor measuring the soil characteristics before planting and adjusting seed rate

Differences between map based- and sensor-based VRA

S. No.	Parameter	Map based	Sensor based
1	Methodology	Grid sampling – lab analyses – site-specific maps and the use of variable rate applicator	Real-time sensors – feedback control measures and the use of variable rate applicator
2	GPS/DGPS	Very much required	Not necessary
3	Laboratory analysis (plant and soil)	Required	Not required
4	Mapping	Required	May not be required
5	Time consumption	More	Less
6	Limitations	Cost of soil testing and analysis limit the usage	Lack of sufficient sensors for getting crop and soil information
7	Operation	Difficult	Easy
8	Skills	Required	Required
9	Sampling unit	2 to 3 acres	Individual spot
10	Relevance	Popular in developing countries	Popular in developed countries

Applications of VRA

1. Seeding VRA
2. Weed control VRA
3. Lime VRA
4. Fertilizer VRA
5. Phosphorus VRA
6. Nitrogen VRA

1. **Seeding VRA:** Seeding VRA reduces the seed rate by identifying and sowing seeds only in those areas which fulfil the seed requirements. Sensor-based VRAs are equipped with soil organic matter (SOM) sensors which detect the different levels of organic matter content in the soil and adjust the plant population accordingly. Also soil moisture meters are used for depth adjustments and thereby adjusting the plant population. Seed rate is varied by attaching a gear box

or motor to the VRA seeder. However, planters and drills can be made into VRA seeders by adjusting the speed of seed metering drive. This will effectively change the plant population. VRA seeding is accomplished by separating or disconnecting the planter's seed meter systems from the ground drive wheel. By attaching a motor or gear box (to change speed of the ground wheel input), the seeding rate can be varied on the go.

Most of these devices will be matched with a prescription map and can have two or more rates. A two-rate scenario may be a system that reduces the seeding rates outside of the reach of a centre pivot irrigation system, while multiple rates may be needed to adjust for soil types (water holding capacity) and organic matter.

2. **Weed control VRA:** As mentioned earlier, VRT could be either map based or sensor based. Taking into consideration the map-based weed control VRA system, a computer is required which acts as signal indicator and thus provides signal which indicates the target rate for present location. The computer used is called as task computer. The other requirement is a system which changes the rate of application physically, which would match the current prescribed rate. Today's market is filled with different types of control systems adaptable to VRA.

Three important categories include:

(a) Flow-based control of a tank mix

(b) Chemical-injection-based control, with the subset, chemical-injection control with carrier
(c) Modulated spraying-nozzle control system

The desire for automatically matching up the rate of applications to variations in ground speed leads to the evolution of the abovementioned systems. One of the advantages of the above systems is the elimination of error in the application that could possibly occur if there is a change in ground speed from the calibrated setup. The ability to apply variable rates (when the application rate is managed by an electronic system) would be the next logical step.

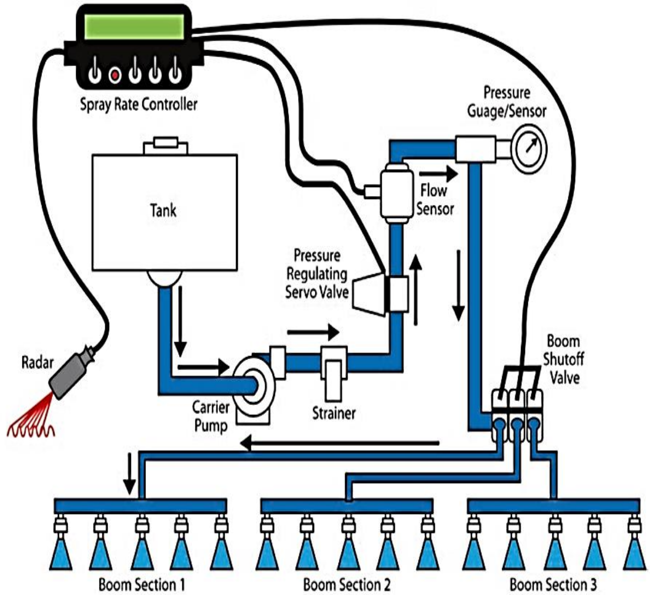
(a) Flow-based control systems: It is the simplest system of the three types mentioned above.
Flow-based control system involves a combination of:
• Flow meter
• Ground speed sensor
• Control valve (servo valve) with an electronic controller in order to apply the desired rate of the tank mix

In order to calculate the appropriate flow rate for the current ground speed, there is a microprocessor in the console which uses the information regarding the sprayer width and calculates the prescribed gallons per acre. The servo valve is then opened or closed until the flow meter measurement matches the calculated flow rate. VRA can be made if there is an establishment of the communication link between this controller and a map system.

Advantages (i) Reasonably simple and easy to use. (ii) The system is able to make the changes in rate across the boom quickly as the control system can respond to a new rate command, which is usually very fast taking only 3 to 5 s.

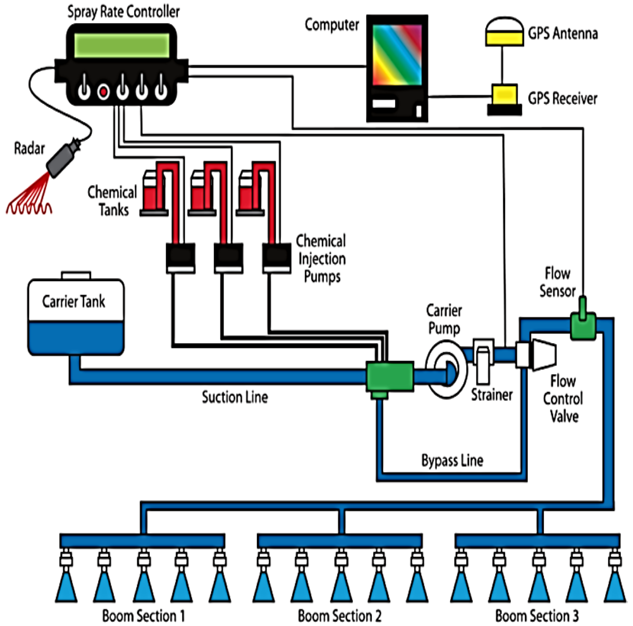
Disadvantages (i) There could be significant changes in spray droplet size and potential problems with drift as the flow sensor controls the tank mix flow by allowing variable pressure rates to be delivered to the spray nozzles.

However, this is the most widely used system, the standard operation procedures of which specify that the operator must mix the chemical with the carrier in the spray tank but will generally have to deal with the leftover tank mix. Flow-based control system meets the majority of needs while giving the operators the capability of single herbicide VRA.



VRA spraying system that is flow-based control system of application rate

(b) Chemical direct injection systems: This system involves direct injection of chemical into a stream of water, thereby acting as an alternative approach to chemical application and control. In order to manage the rate of chemical injection, the system makes the use of the controller and a chemical pump. The carrier constitutes the water. The rate of flow of the carrier is generally constant, and in order to accommodate for the changes in ground speed or prescribed rate, the injection rate is varied. The system can also be used for VRA, if the controller has been modified to accept the external command (from either a prescription map or a GPS signal).



VRA spraying system that involves chemical injection technology

Advantages (i) Elimination of leftover tank mix (ii) Reduction in the chances of exposure to chemicals during tank mixing (iii) Adjustment of the constant flow of carrier (water) which provides the optimum size and distribution of spray droplets

Disadvantages (i) Long delay between the chemical injection pump and the discharge nozzles at the ends of the boom. This means that the volume is to be applied within the hoses and attachments before the new rate has reached the nozzle. This can be a cause of delay in the rate change and would lead to "Christmas tree" application patterns as the new concentration of chemical makes its way off through the boom.

Keeping in view the above limitation, a new system worked its way out which used both carrier and injection control and came to be called as direct chemical injection with carrier control.

Direct Chemical Injection with Carrier Control: This system uses both carrier and injection control which change the chemical injection rate and the water carrier rate so as to respond to the speed and application rate changes. Injection pump is managed by one control loop, while the other control loop manages the servo valve which provides a matching flow of carrier. This system delivers a mixed and constant concentration as if they have been premixed in a tank.

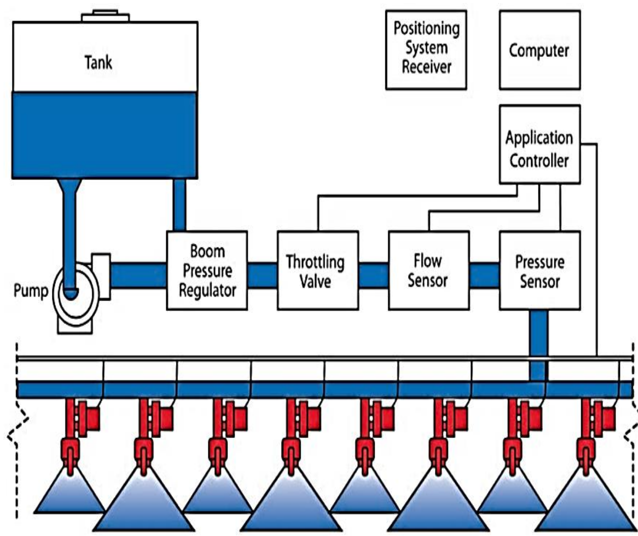
Advantages (i) It shares the advantages of both the earlier mentioned systems. (ii) No leftover mix is left. (iii) The operator doesn't have to worry as there is no exposure to chemicals in the process of tank mixing. (iv) Changeover from one rate to another occurs quickly

Disadvantages (i) Complex system (ii) Higher initial costs (iii) Problem in delivering variable rates of liquid through the nozzle spray

(c) Modulated spraying-nozzle control systems: Modulated spraying- nozzle control (MSNC) systems with spray drift operating system are useful under a wide range of conditions. MSNC controls the duration and timing of the release through the nozzles. This system consists of the high speed valves that control the quantity and the time for which the spray is delivered from the conventional nozzles. This system has the ability to control the rate of flow.

This can further be described as: MSNC equipped sprayers consist of sprayer nozzle assemblies that work in coordination with the direct-acting, in-line solenoid valves. The system is directed by microprocessor and an application controller that responds to signals from pressure and flow sensors. This system is designed to operate each nozzle at full design flow and pressure during the time for which the valve is open. The concept is however to vary the time period for which the valve stays open in order to change the rate of flow thereby changing the rate of application without changing the spray pattern. The conventional nozzle assembly is however directly mounted by a solenoid-controlled nozzle assembly. MSNC system contains solenoids that operate at a frequency of 10 Hz. This means that in 1 s, a solenoid can ten times change its position between open and close.

This is however governed by a controller that responds to inputs from a computer processor and a set of sensors. Thus, a sequence of events (valve open, spray, valve close) takes place in one-tenth of a second. Further, for the system to work at maximum efficiency, valve response must be quite rapid. For this, an electrical signal to each valve is used which produces one of the two flow conditions: zero flow (completely closed valve) or full flow (completely open valve). The valves operated by the solenoid take 4 milliseconds (ms) or 0.004 second (s) to respond to an electrical signal. Thus, changing the valve position from open to close and back (or vice versa) would take 8 milliseconds (ms). The amount of time for which the valve is open for flow describes the duty cycle. A minimum duty cycle can be of about 10% and a maximum of about 90%. The MSNC system can also be operated at a full open (100 percent duty cycle).



VRA spraying system using modulated spraying nozzle control (MSNC) technology

Since the rate of flow from each nozzle is governed by the time period, each flow control valve stays open; the percentage of full, rated, nozzle flow would be equal to the duty cycle expressed as percentage. The range of flow rates however varies from 9 to 1. The MSNC system can effectively be used to reduce the rates as per the need.

The MSNC system not only controls the flow rates at a given system pressure but also has the ability to increase the droplet size and reduce drift potential. This thereby manages application rates even at lowered system pressure by increasing the duty cycle of a nozzle. Opening and closing of nozzles might appear to be a risky proposition while the sprayer travels through the field. If a nozzle remains closed even for a fraction of a second, no liquid is released. This may result in depriving the certain areas of field. This is countered by using a 1/20 s (1/2 cycle) "phase shift" of adjacent nozzles. This depicts that when a nozzle is off, the adjacent nozzles need to be on. The sprayers are equipped with wide spray-angle nozzles (110 degree angle versus the more common 80 degree angle) to increase spray pattern overlap and minimize the effect of the "pulses and pauses" produced at the nozzles.

A chemical application system has the ability to control both application rate and droplet size distribution throughout the field and considers the following potential benefits:

- Produce a broader range in rates of flow with more consistent spray characteristics than the conventional sprayers.

- Alter the droplet size distribution without affecting the application rate to reduce the drift potential.
- Alter the application rates without affecting the droplet size distribution.
- Further, as the drift control is not a problem in case of fertilizer application, the MSNC systems can also be used to apply VRA nutrients. Thus, MSNC systems provide an easy way to be used as site-specific crop management methods.

New and Developing VRA Systems

This undoubtedly is an area of rapid upcoming changes. However, the Web can easily be searched by the manufacturer's name and can effectively be used to locate product descriptions and specifications. However, each search will definitely present latest information which will guide in selecting an appropriate system for individual farming practices.

Other Useful Devices

An automated boom section control device can beneficially be used while spraying the odd-shaped fields, grass waterways, or obstructions in a field. This system recognizes the areas of the field that should not be treated with chemicals and accordingly turn the boom (or sections of boom) on and off to prevent the chemical application over the identified areas. Also the controller can automatically turn the boom section off if the boom section is over the previously treated area thereby discarding the chances of overlap. It also manages the skips when passed back over the previously treated areas. This is because the nozzles of the implement are shut off immediately when the controller detects an overlap in order to avoid an unnecessary usage of additional chemicals. However, it requires a capital investment and may result in about 15% savings in inputs.

Sensor-Based Devices

As the quantity of the soil organic matter influences the effectiveness of some herbicides, soil organic matter sensors can be used with VRA pre plant herbicides. Such sensors do not make use of the prescription maps thus automatically adjusting the rates. In this application, the sensor is pulled or pushed through the soil by herbicide applicator. Treating the soil uniformly can lead to the unnecessary use of the herbicides which can result in unsatisfactory weed control owing to the patchiness shown by the weeds. Remote sensing is a technique which improves weed scouting and results in better management decisions.

We can easily differentiate between the weed species present in the soil based on their leaf shapes with the help of our eyes which act as remote sensors. The remote sensing instrument collects reflectance at the field scale, and the reflectance values from the individual features are averaged over the entire pixel area within the sensor. The reflectance data from the bare ground is compared with the green weeds growing between the crops. Some sprayers are equipped to switch the device application on and off.

Weed Seeker is one example of the commercial unit having the reflectance sensor identifying the chlorophyll and a microprocessor which interprets the data, and a controller turns on the spray nozzle when a threshold level is reached.

The weed seeker system is built around the close-proximity optical sensors which use the near-infrared, light reflectance to differentiate between the green vegetation, bare soil, and crop residue.

Weed seeker, controller, and sensors

Weed seeker-efficient cost-effective and environmentally sustainable

Each sensor unit consists of the optical sensor and a light source. The sensors are installed on a spray boom which is ahead of the spray nozzle and are aimed toward the ground. When the threshold level is crossed by chlorophyll reflectance signal, the controller sends the signal to the solenoid operated valve to release the herbicide. The system is designed such that it starts slightly before the weed is reached and turns off a bit later after crossing the weed. It can operate at a speed of 3–10 mph. It reduces the chemical application significantly in the areas where the weeds are variable. The weed seeker does not distinguish between the plant types, so its agricultural use is focused on between the row applications in standing crops or on spot treatment on the fallow ground. Boom height control is another sensor-based control device. Despite of not being a VRA device, it improves the coverage from a spray boom eliminating the streaks and improper overlaps. The sensors which are ultrasonic measure the distance to the ground (40 times per second). To make the sprayer booms follow the contours of the land automatically, responsive height adjustments are made by the control system using this information. This system shows reliable control with the average speeds more than 18 mph in all kinds of terrain.

3. **Lime VRA**: The variable rate application of lime has been regarded as the most effective and the profitable method of managing the soil pH levels. The crops show a unique response in the yield with respect to the soil pH. The yield is known to decrease with the high and the low pH levels in the soil. The farmers are forced to face the yield penalty if there is under or over application of the lime so there is a need of maintenance of accuracy which in turn gives the higher yields.

   For the application of the dry chemicals, e.g., lime amendments and nutrients, e.g., nitrogen, phosphorus, and potassium, two types of applicators are used:
   (a) Spinner spreaders
   (b) Pneumatic applicators

   (a) Spinner spreaders: The spinner spreaders which are used only vary one product at a time. The material is transferred from a conveyor belt to the hopper which passes it to the spinning discs. The application rate is managed by adjusting the gate opening and or changing the speed of conveyor

(b) Pneumatic applicators: A piped boom is used to convey the material uniformly via air stream. Centrally located bins and hoppers are installed which distribute the dry material contained in the air stream. With the help of the metering devices, single or multiple products can be blended or metered on each bin. The methods like grid sampling and the use of on-the-go sensors can help in making a pH prescription map. On-the-go sensors work by spooning out the soil sample and forcing it against the electrode, waiting for the electrode to stabilize, and then recording the pH, eventually rinsing the whole mechanism and preparing for the next sample.

4. **Fertilizer VRA:** The VRA techniques used for the application of the fertilizer resemble the VRA techniques of liming and weed control application. The impact can be complex based on the nutrient availability, seasonal cycle, and weather condition.

5. **Phosphorus VRA:** It is regarded as the second most profitable VRA activity. The grid soil tests can be used for a number of years as soil phosphorous is not clearly as transient as the soil nitrogen. Building up of soil phosphorous tests may increase the long-term economic benefits. This test is the capital investment characteristic that proves profitable to unleash the intrinsic differences in soil test phosphorous at least one point in time.

6. **Nitrogen VRA:** The adoption of VRA nitrogen (N) management by producers is low, despite the potential economic and environmental benefits of this practice. A major barrier is the recommended nitrogen fertilizer rates based on yield goal are often poorly correlated with the actual economically optimum nitrogen rates. Nitrogen response patterns are often field and season specific and can vary widely within the same field, thus complicating the development of prescription maps. Side-by-side comparisons of uniform and VRA-N management have revealed no consistent advantages for either strategy in yields achieved, profitability, and nitrogen use efficiency by plants. In the future, a better understanding of temporal variation in nitrogen soil test levels, improved nitrogen sensing, better crop simulation models and application models, and application equipment may assist producers in capturing the benefits of VRA-N management. Real-time sensors of the crop offer the potential for VRA-N, as these systems are planned to "sense" the nitrogen needs of the crop at the time of application. These systems require well-fertilized areas in the field to get the sensor-calibrated ongoing researches to help determine if these systems would be widely employed in the future.

7. YIELD MONITORING AND MAPPING

Yield monitoring is an aspect of precision agriculture that helps to provide farmers with adequate information to make educated decisions about their fields. Yield monitors are a rather recent development and allow farm equipment such as combine harvesters or tractors to gather a huge amount of information, including grain yield, moisture levels, soil properties, and much more.

Due to the fact that yield monitors provide farmers with so much information, they are much more able to assess things such as when to harvest, fertilize, or seed, the effects of weather, and much more.

Yield monitors work in three very simple steps:

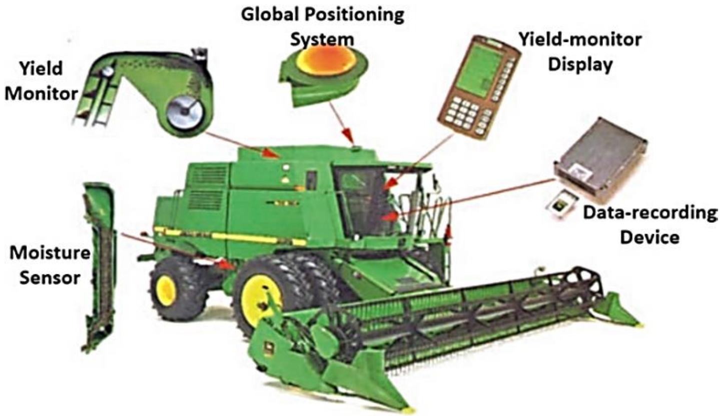
1. The grain is harvested and fed into the grain elevator which has sensors that read moisture content of the grain.
2. After that process as the grain is being delivered to the holding tank, more sensors monitor the grain yield.
3. As both of these sensors work, the information is sent to the driver cab and is displayed on a screen as well, and the information is georeferenced so it can be mapped as well as closely investigated on a later time or date.

There are many benefits for farmers to use yield monitoring technology, although one main benefit is that it helps to give the farmer accurate and often georeferenced data about their field. A farmer can better understand crop yield and crop-related

information to mitigate potential threats or enhance possible opportunities. Other benefits with a yield monitoring system include the ability for a farmer to export the information onto a personal computer, allowing this information to be available in a variety of different formats, including in equipment displays, at home, or printed. Also, in the home or office, a farmer can use specialized computer software to assess and better understand the recorded information. Yield monitors can monitor grain by a field-by-field or load-by-load basis; this gives the farmer a huge amount of flexibility as well as provides him or her with instant information about the load they have gathered.

Components of a Yield Monitor

Yield monitors are a combination of several components. They typically include a data storage device, user interface (display and key pad), and a console located in the combine cab, which controls the integration and interaction of these components. The sensors measure the mass or the volume of grain flow (grain flow sensors), separator speed, ground speed, grain moisture, and header height. Yield is determined as a product of the various parameters being sensed.



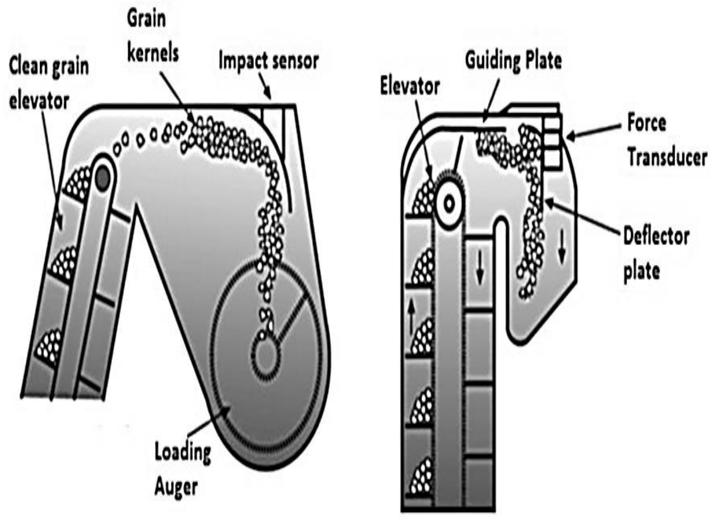
The basic components of a grain yield mapping system

1. Mass Flow Sensor

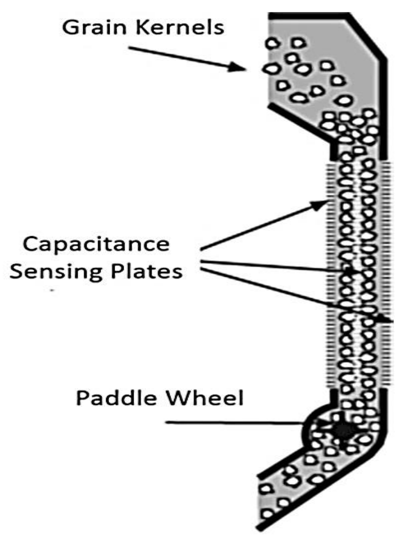
A mass flow is a sensor that helps to provide the yield monitor with enough information to establish a grain yield measurement. The mass flow sensor works by using a load cell which is fixed to the top of a clean grain elevator. When the harvested grain is fed through the combine, it eventually will hit up against this load cell; this is then transformed into an electrical signal and relayed to the yield monitor. The yield monitor uses this reading to determine how much grain is being taken into the combine at any point in time. This sensing method is very common, although there are different methods used, as well as variations of the same method.

2. Moisture Sensor

Being aware of the moisture content in grain that has been harvested can be extremely valuable information for a farmer to know, especially for aspects including harvesting, storing, and drying crops. When farmers take these moisture readings, they are better able to obtain an accurate market value for their crop. The moisture sensor works when the grain moves in between two conductive surfaces, which measure how much electric charge the grain can store – this is known as capacitance. There are various places to mount the moisture sensor, and it is a vital step of the yield monitoring process.



Mass flow sensor on yield monitor



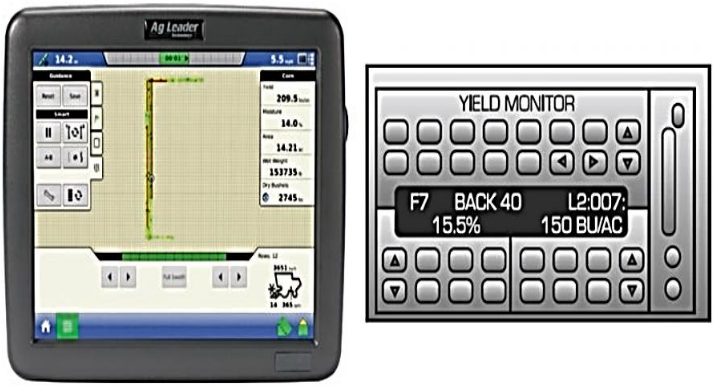
Moisture sensor installation on the clean grain elevator for yield monitoring

3. GPS Receiver

A GPS receiver, or global positioning system receiver, is a remote sensor that measures a variety of different pieces of data, including where the equipment is located, speed, altitude, and much more. A GPS receiver is a primary component when georeferencing, as the GPS receiver helps to record the position of the equipment in use and then sends that data to an onboard computer which then connects it with all other information that the computer has collected at that particular location. The GPS receiver is one of the key components that can help to transform yield monitoring data from graphs and charts, into tangible maps that the farmer can use.

4. Yield Monitor

Sometimes referred to as a task computer, receiver, or yield monitor, this piece of technology is the monitor that is located in the cab of the combine or tractor. This piece of equipment serves many different purposes, although its main function is to display the information gathered by the different onboard sensors to allow the operator to know in a real-time manner different moisture levels, crop yield, and more. These monitors also have the capability to store memory as well as transfer memory to a laptop or home computer. This transfer of memory makes analyzing data a much more comfortable experience, and it also provides the capability of using more software to interpret and render the data collected by the yield monitoring system.



Yield monitor

Data Collection and Storage

Data are often recorded on removable memory cartridges, such as a Personal Computer Memory Card Industry Association (PCMCIA) cards. Data from these cards can be downloaded to a computer. Download data daily to ensure that the yield monitor is working properly and to protect against accidental data loss. Memory cards may store several megabytes of data. The card capacity is sometimes stated in hours of operation since data are typically stored on a periodic basis. One megabyte of memory can store 15–45 h of information for yield data collection intervals of 1–3 s.

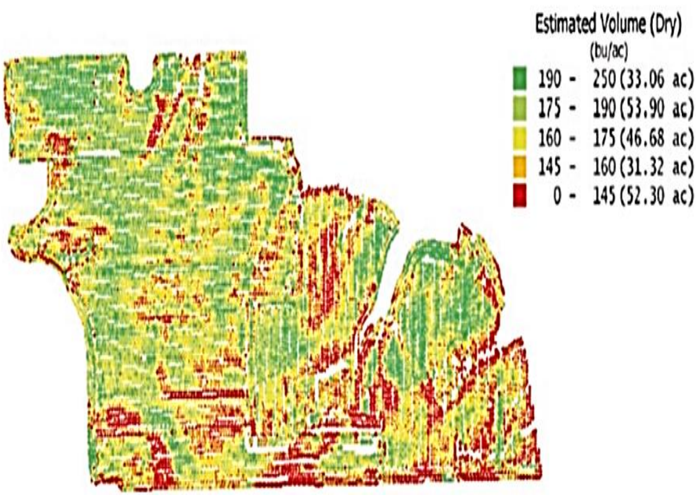
Calibration and Yield Mapping Calibration

The types of calibration that are required by yield monitoring systems vary by monitor type. Regardless of the type of monitor, yields are not measured directly. Instead, measurements of force, displacement, or volume, speed of material flow, moisture content, harvester travel speed, and working width are combined to produce an estimate of crop yield. Crop yield is a derived, or calculated, value. Calibration is performed to ensure that sensor data and operator input are properly used by a monitor to produce a final output in units of harvest units per acre. In addition, force and displacement sensing grain flow meters must be calibrated to nullify, or cancel, the effects of machine vibration on yield readings. Most calibration processes involve comparing the weights of several loads estimated by a yield monitor with those measured on a separate set of scales. The actual weights are then entered into the yield monitor. Software within the yield monitor console then computes a set of calibration curves. To properly calibrate a yield monitor, the requirement is to harvest at different speeds, harvest widths, and a number of loads.

Limitations of Yield Monitors

The combine operation is dynamic, and the flow rate of material processed can vary depending on entering and exiting the crop. These varying flow rates can influence the results of the yield monitor data. Since the yield monitor measures the rate at which clean grain is entering the grain tank, time delays between the time grain enter the combine header, and the time it passes through the clean grain elevator can be significant. Combines also smooth abrupt changes in yield; hence, the yield monitor measures delayed averages of yield.

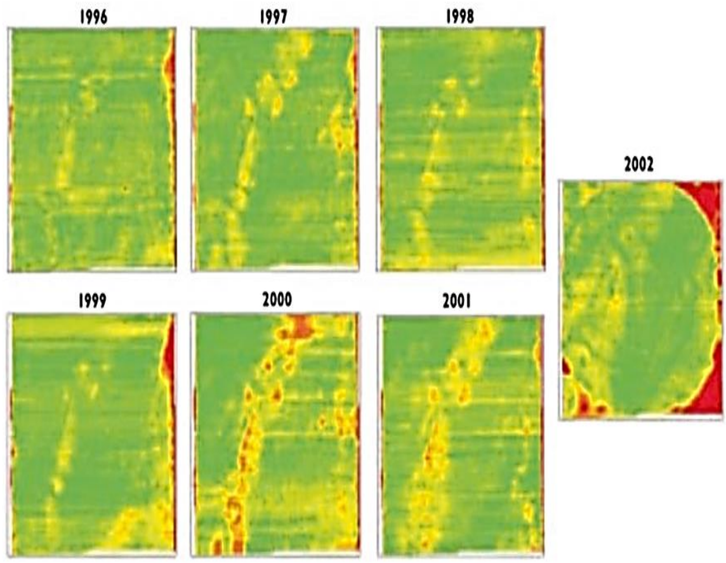
The phenomena of time delays and smoothing are most obvious when a combine enters or leaves the crop at the ends of a field. The combine, in the example above, has a delay of 15 s to process the entering crop and would travel 110 ft and harvest almost 0.04 of an acre before an accurate or stable yield is displayed on the yield monitor. Most yield mapping software compensates for equipment delays caused by the combine and corrects the yield data. The resulting yield map will not be perfect, but it will be very adequate for observing the magnitude and location of yield variability. Yield data combined with mapping software and positional data are capable of producing a colorful map.



Yield map

Yield Mapping Concept

Yield mapping refers to the process of collecting georeferenced data on crop yield and characteristics, such as moisture content, while the crop is being harvested. Various methods, using a range of sensors, have been developed for mapping crop yields. Yield maps are based on sets of instantaneous yield data points collected with the yield sensor compotes and a DGPS receiver. The complete precision farming system consists of many elements and brings together a number of different technologies. The success of the precision farming system relies on the integration of all the different elements into a single system that can be operated at the farm level. Many of the elements are required to be automatic. For example, the main task of the combine operator is to drive the combine to harvest the field and not to collect yield information used to generate yield maps. Therefore, the yield mapping system employed to collect yield data must be automatic. Yield mapping is the process of continuously recording the grain flow through the combine harvester while at the same time integrating with actual harvest position in the field. The yield and position data are transferred to a computer where interpolation techniques are used to generate a yield map of the field. Once the data is collected, users need special computer software to generate yield maps. Most collected data are stored in a binary format. Binary files store digital data very efficiently, but this data must be converted to standard text files in order for most yield mapping software to process the data. The yield map provides information to the farmer detailing which are the better and poorer yielding parts of the field. The yield map does not provide information as the cause of the yield variation. The farmer is required to use a combination of local knowledge and other sources of data to interpret the maps to make crop management decisions to improve the profitability of the field.



Maps of relative yield of corn and soybean grown during a 7-year period

(red indicates low-yielding areas and green indicates higher-than-average yields)

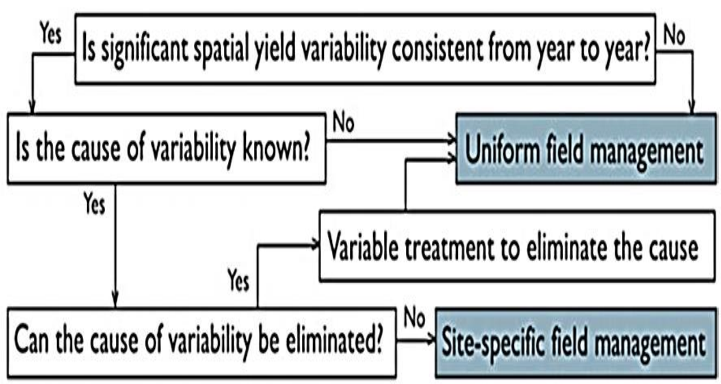
Yield History Evaluation

Evaluating the temporal (year-to-year) variation of yield distribution within the field is an essential step in defining field areas with potentially high and low yields. Several approaches can be used to evaluate temporal effects on yield. One approach is to calculate the relative (normalized) yield for each point or grid cell. Normalized yield can be defined as the ratio of the actual yield to the field average. When growing conditions in a field vary considerably, such as irrigated and dryland areas or different crops or varieties grown in different areas, normalization should be done separately for those areas, with the resulting relative yields recombined into one data file for the whole field.

Potential Applications

Yield maps represent the output of crop production. On one hand this information can be used to investigate the existence of spatially variable yield-limiting factors. On the other hand, the yield history can be used to define spatially variable yield goals that may allow varying inputs according to expected field productivity. The flowchart in Fig. given below illustrates the process one might follow in deciding whether to invest in site-specific crop management, based on analysis of yield maps. If yield variability across the field cannot be explained by any spatially inconsistent field property, uniform management may be appropriate. Site-specific management becomes a promising strategy if yield patterns are consistent from year to year and can be correlated to one or more field properties (e.g., nutrient supply, topography, past management, etc.).

If the causes for yield variation are known and can be eliminated permanently, the entire area could be brought to similar growing conditions and managed uniformly thereafter. This concept was one of the earliest philosophies behind precision agriculture but is likely only feasible for certain field properties. For example, variable rate liming can be used to correct acidic areas in a field. In this case, the yield map is used only to investigate whether low soil pH is a yield-limiting factor, and the soil map is used to prescribe variable application rates. Another example would be localized deep soil tillage to alleviate compaction in selected field areas. Most yield-limiting factors cannot be modified permanently through single measures because of economic or practical constraints. Consequently, site-specific crop management may be used to appropriately account for the existing spatial variability in attainable yield and/or soil properties.



Yield map decision-making flowchart

8. TOOLS OF SITE-SPECIFIC NUTRIENT MANAGEMENT (SSNM)

Fertilizer application recommendations are often based on crop response data averaged over large areas, though farmers' fields show large variability in terms of nutrient-supplying capacity and crop response to nutrients. Thus, blanket fertilizer application recommendations may lead farmers to over-fertilize in some areas and under-fertilize in others, or apply an improper balance of nutrients for their soil or crop. An alternative to blanket guidance, Site-Specific Nutrient Management (SSNM) aims to optimize the supply of soil nutrients over time and space to match the requirements of crops through four key principles. The principles, called the "4 Rs". They are:

1. **Right product:** Match the fertilizer product or nutrient source to crop needs and soil type to ensure balanced supply of nutrients.

2. **Right rate:** Match the quantity of fertilizer applied to crop needs, taking into account the current supply of nutrients in the soil. Too much fertilizer leads to environmental losses, including runoff, leaching and gaseous emissions, as well as wasting money. Too little fertilizer exhausts soils, leading to soil degradation.
3. **Right time:** Ensure nutrients are available when crops need them by assessing crop nutrient dynamics. This may mean using split applications of mineral fertilizers or combining organic and mineral nutrient sources to provide slow-releasing sources of nutrients.
4. **Right place:** Placing and keeping nutrients at the optimal distance from the crop and soil depth so that crops can use them is key to minimizing nutrient losses. Generally, incorporating nutrients into the soil is recommended over applying them to the surface. The ideal method depends on characteristics of the soil, crop, tillage regime and type of fertilizer.

Benefits of SSNM

1. **Higher profits:** SSNM can increase and maintain yields by optimizing the balance between supply and demand of nutrients and providing more balanced plant nutrition In general, it improves nutrient-use efficiency and provides greater returns on investments in fertilizer.
2. **Reduced nitrous oxide emissions:** Agriculture contributes 70-90% of nitrous oxide (N_2O) emissions, mostly from N fertilizer. SSNM reduces N_2O

emissions by reducing total N application and/or timing applications to crop needs, thus avoiding N losses to volatilization, leaching and runoff.

3. **Improved disease resistance:** The more balanced NPK nutrition that comes with SSNM may lead to improved resistance to plant diseases.

Methods of SSNM can be achieved through:

1. Grid soil sampling & analysis and accordingly fertilizer prescriptions
2. VRT (map bases & sensor based)
3. STCR approach
4. Yield monitoring of present crop and prescriptions for succeeding crop as per the site-specific yield results
5. Other tools and technologies

Out of above methods Sr. no. 1 to 4 are already discussed in previous chapters of this notes. Here we will discuss about Sr. no. 5.

Other tools and technologies:

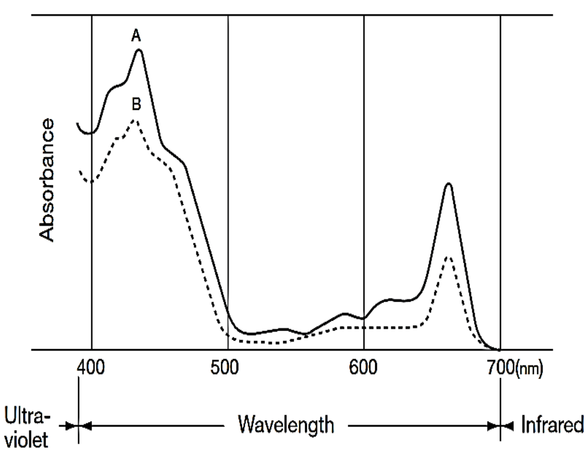
They can be listed as-

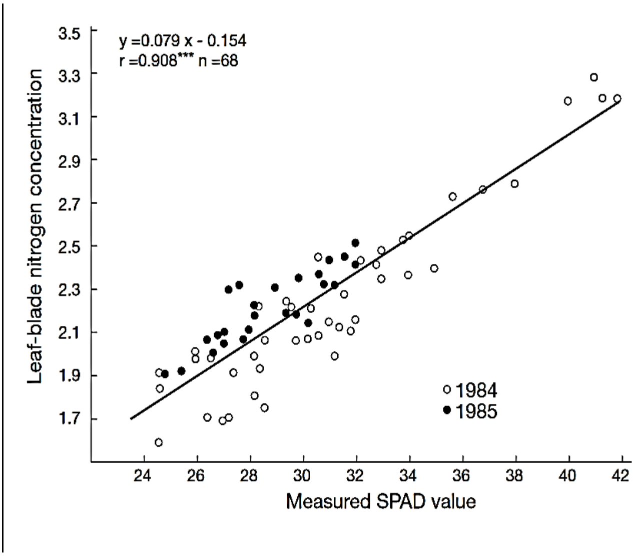
1. Optical sensors
2. Computer/ mobile phone software/ applications
3. Simple tool

1. **Optical sensors:**
    a. **GreenSeeker:** It is handheld crop sensor that can be used to assess the health or vigor of a crop in order to make better nutrient management decisions on your farm. It can instantly take a reading of crop's health. Readings can be used to make non-subjective decisions regarding the amount of fertilizer to be applied to crop, resulting in more efficient use of fertilizer.

    The sensor emits brief bursts of red and infrared light and then measures the amount of each type of light that is reflected back from the plant. The sensor continues to sample the scanned area as long as the trigger remains engaged. The sensor displays the measured value in terms of an Normalized Differential Vegetation Index (NDVI) reading (ranging from 0.00 to 0.99) on its LCD display screen. The strength of the detected light is a direct indicator of the health of the crop; the higher the reading, the healthier the plant.

    b. **Soil Plant Analysis Development (SPAD)/ Chlorophyll Meter:** The SPAD determines the relative amount of chlorophyll present by measuring the absorbance of the leaf in two wavelength regions. The graph below shows the spectral absorbance of chlorophyll extracted from two leaf samples using 80% acetone. From the diagram, it can be seen that chlorophyll has absorbance peaks in the blue (400-500 nm) and red (600-700 nm) regions, with no absorbance in the near-infrared region. To take advantage of this characteristic of chlorophyll, the SPAD measures the absorbances of the leaf in the red and near-infrared regions. Using these two absorbances, the meter calculates a numerical SPAD value which is proportional to the amount of chlorophyll present in the leaf.





Checking the nutritional condition of plants: The chlorophyll present in the plant leaves is closely related to the nutritional condition of the plant. As can be seen from the graph below, the chlorophyll content (represented by the measured SPAD value) will increase in proportion to the amount of nitrogen (an important plant nutrient) present in the leaf. For a particular plant species, a higher SPAD value indicates a healthier plant.

Nitrogen (N) management is a very important issue for plant growers and for the environment. For growers, knowing the N requirement of plant enables the proper amount of N fertilizer supply to be managed. Some experiments show that the SPAD series contributed to reductions in the use of N fertilizer by tens of percents with no loss in yield. By optimizing the N fertilization efficiency in the field, proper N fertilizer management reduces the possibility of excessive supply of fertilizer, which can cause diseases in plants and environmental contamination. There is increasing awareness of the need for applying the proper amount of N fertilizer in respect to water contamination in both flowing streams and underground water due to nutrient leaching through the field's soil.

2. **Computer/ mobile phone software/ applications:** Computer or mobile phone-based tools are increasingly used to facilitate improved nutrient management practices in farmers' fields, especially in geographies where blanket fertilizer recommendations prevail. These tools provide small-scale maize, rice and wheat farmers with crop and nutrient management advice customized to their farming conditions and needs. Nutrient Expert® and Crop Manager are examples of decision-support systems developed for SSNM in cereal production systems.
   a. **Nutrient Expert:** It is an interactive, computer-based decision-support tool that enables smallholder farmers to rapidly implement SSNM in their individual fields

with or without soil test data. The software estimates the attainable yield fora farmer's field based on the growing conditions, determines the nutrient balance in the cropping system based on yield and fertilizer/ manure applied in the previous crop and combines such information with expected N, phosphorus (P) and potassium (K) response in target fields to generate location-specific nutrient recommendations. The software also does a simple profit analysis comparing costs and benefits between farmers' current practice and recommended alternative practices. The algorithm for calculating fertilizer requirements was developed from on-farm research data and validated over 5 years of testing. The software is currently available without charge for wheat & maize systems in South Asia.

b. **Crop Manager:** It is a computer and mobile phone based application that provides small-scale rice, rice-wheat, and maize farmers with site-and season-specific recommendations for fertilizer application. The tool allows farmers to adjust nutrient application to crop needs based on soil characteristics, water management, and crop variety on their farm. Recommendations are based on user-input information about farm location and management, which can be collected by extension workers, crop advisors, and service providers.

3. **Simple tool:**

Leaf Colour Chart (LCC): Nitrogen (N) fertilizer is important in crop production. N fertilizer application for several times during the growing season is ensure that the crop's nitrogen need is supplied, particularly at critical growth stages. The Leaf Colour Chart (LCC) is used to determine the N fertilizer needs of rice, maize and wheat crops. LCC has four or six green strips, with colour ranging from yellow green to dark green. It determines the greenness of the crop leaf, which indicates its N content.

Methodology for LCC use in field:

1. Randomly select at least 10 disease-free rice/ wheat/ maize plants or hills in a field, where plant population is uniform.
2. Select the topmost, youngest, fully expanded leaf from each hill or plant. This part best reflects the N status of the plants.

3. Reading within time of 8 am to 10 am is better. Place the middle part of the leaf on the LCC and compare its colour with the colour panels. Do not detach or destroy the leaf.
4. Measure the leaf colour under the shade of observer's body. Direct sunlight affects leaf colour readings.
5. If possible, the same person should read the LCC at the same time of the day, every time.
6. If the colour of a leaf is in between two shades, take the average of the two values as the reading. For example, if the colour is in between 3 and 4, the reading should be 3.5.
7. Take the reading of the 10 leaves, and determine the average. If the colour is 3 or less than 3, N fertilizer top dressing is needed.

N management in rice crop with LCC:

- For wet season (Kharif) non-basmati rice, use LCC critical value 4, and apply 28 kg N/ha or 1.25 bag urea per hectare.
- For wet season (Kharif) basmati rice, use LCC critical value 3, and apply 23 kg N/ha or 1 bag urea per hectare.
- For direct-seeded rice, apply 23 kg N/ha as basal, then use LCC critical value 3, and apply 23 kg N/ha or 1 bag urea per hectare.
- For direct-seeded rice, apply 23 kg N/ha as basal, then use LCC critical value 4 and apply 35 kg N/ha or 1.5 bags of urea per hectare.

- Repeat LCC readings every 7 days for 110-130 day rice crops and every 10 days for more than 130 day crops until first heading.
- Different sets of 10 leaves can be used for each weekly or 10-day reading.
- If basal fertilizer with N (DAP or NPK compound) is applied 0-14 DAT or 0-14 DAS, the first LCC reading is done at 21-25 DAT or 28-30 DAS instead of 14 DAT or 21 DAS.

.

9. NANOTECHNOLOGY FOR PRECISION FARMING

Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.

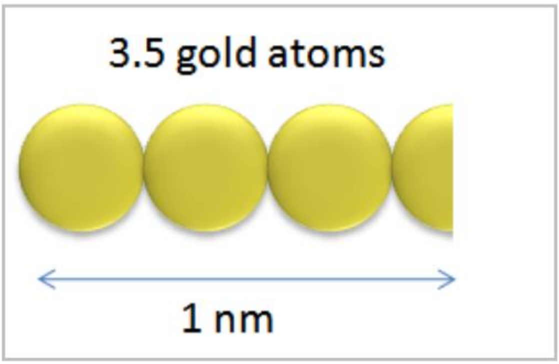
Bulk materials possess continuous (macroscopic) physical properties. The same applies to micron-sized material (e.g., a grain of sand). But when particles assume nano-scale dimension, the principles of classical physics are no longer capable of describing their behaviour (movement, energy, etc). At these dimensions, quantum mechanics principles apply. The same material (e.g., gold) at the nanoscale can have properties (e.g., optical, mechanical, electrical, etc.) which are very different from (even opposite too) the properties the material has at the macro scale (bulk).

Nanotechnologies are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale.

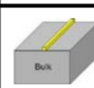
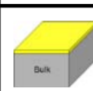
History of Nanotechnology:

- The concept of a "nanometer" was first proposed by Richard Zsigmondy in 1925. He coined the term nanometer explicitly for characterizing particle size and he was the first to measure the size of particles such as gold colloids using a microscope.
- Modern nanotechnology was introduced by Richard Feynman. During the 1959 in American Physical Society meeting at Caltech, he presented a lecture titled, "There's Plenty of Room at the Bottom", in which he introduced the concept of manipulating matter at the atomic level. This novel idea demonstrated new ways of thinking and Feynman's hypotheses have since been proven correct. It is for these reasons that he is considered the father of modern nanotechnology.
- Almost 15 years after Feynman's lecture, a Japanese scientist, Norio Taniguchi, was the first to use "nanotechnology" to describe semiconductor processes that occurred on the order of a nanometer. He advocated that nanotechnology consisted of the processing, separation, consolidation, and deformation of materials by one atom or one molecule.

The nanometre scale: The nanometre scale is conventionally defined as 1 to 100 nm. One nanometre is one billionth of a metre (10^{-9} m). The size range is set normally to be minimum mm to avoid single atoms or very small groups of atoms being designated as nano-objects. Therefore, nanoscience and nanotechnologies deal with at least clusters of atoms of mm size.



Nanomaterial: A nanomaterial is an object that has at least one dimension in the nanometre scale (approximately 1-100nm).

Nanomaterial Dimension	Nanomaterial Type	Example
All three dimensions < 100 nm	Nanoparticles, Quantum dots, nanoshells, nanorings, microcapsules	
Two dimensions < 100 nm	Nanotubes, fibres, nanowires	
One dimension < 100 nm	Thin films, layers and coatings	

Nanomaterials can be of two types:

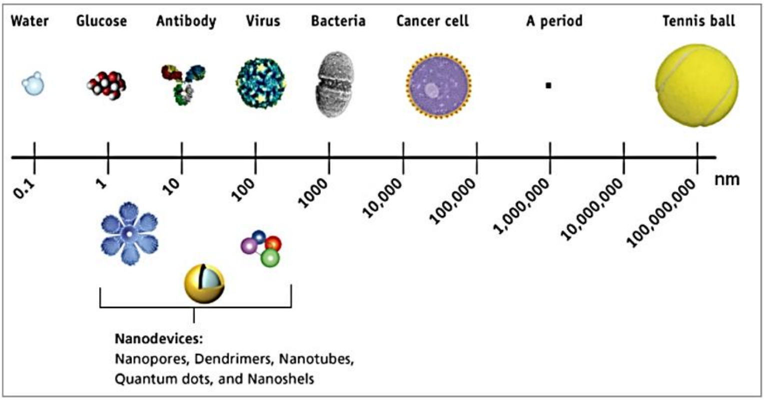
1. **Non-intentionally made nanomaterials:** which refers to nano-sized particles or materials that belong naturally to the environment (e.g., proteins, viruses, nanoparticles produced during volcanic eruptions, etc.) or that are produced by human activity without intention (such as nanoparticles produced from diesel combustion).
2. **Intentionally made nanomaterials:** which means nanomaterials produced deliberately through a defined fabrication process.

The definition of nanotechnologies does not generally include "non-intentionally made

nanomaterials", and is therefore limited to "intentionally made nanomaterials".

Size of Nano:

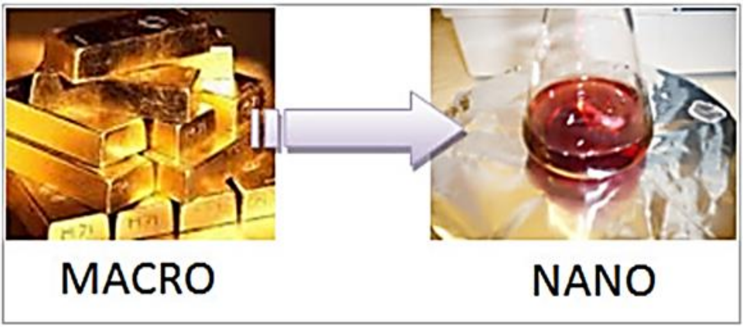
- Nanomaterials are larger than single atoms but smaller than bacteria and cells.
- Our fingernails grow at the rate of 1 nm per second.
- The head of a pin is about 1 million nanometres across.
- A human hair is about 80,000 nm in diameter.
- A DNA molecule is about 1-2 nm wide.
- The transistor of a latest-generation Pentium Core Duo processor is 45 nm.



Fundamental Nano- Effects and Properties

Properties of any matter can changes at nano scale and this the basis for Nanoscience. The macroscopic physical properties of a substance (melting point, boiling point, conductivity etc.) are determined by studying a pure sample in quantities big enough to be measured under normal laboratory conditions. One mole of any material contains 6.022 x 10^{23} molecules; one mole of water for instance weights 18 gr. Therefore when the boiling point of one mole of water is determined, in reality the value which is obtained represents an average value based on the behaviour of billions and billions of molecules of water; we assume that the result should be true for any size of group of water molecules. This is not correct for many materials: as the size of the material is reduced, and the nanoscale regime is reached, it is possible that the same material will display totally different properties (different melting point, conductivity etc.). This is because matter at the nanoscale no longer follows Newtonian physics but rather quantum mechanics.

In other words, the properties of materials can be size-dependent. For example a piece of gold is golden in colour. However, a colloid of gold nanoparticles is no longer "golden" but ruby red in colour as given figure at side.



Materials that belong to the "nanoscale" are made at least of clusters of atoms and molecules, not single atoms: for example 3.5 atoms of gold or 8 hydrogen atoms lined up in a row are one nanometre long. A glucose molecule is about 1 nm in size.

Nanoscale effects can be grouped into:

- **A.** Physical
- **B.** Chemical

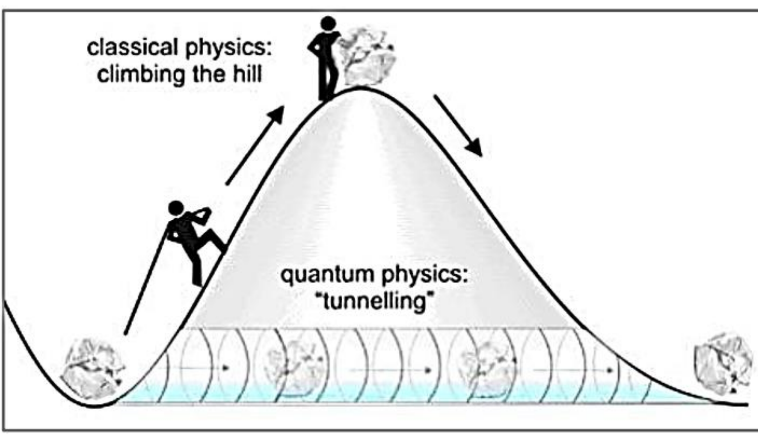
A. Physical

Nanomaterials are closer in size to single atoms and molecules than to bulk materials, and to explain their behaviour it is necessary to use quantum mechanics. Quantum mechanics is a scientific model that was developed for describing the motion and energy of atoms and electrons. Most salient quantum effects, together with other physical properties that are relevant at the nanoscale are:

1. **Increased electromagnetic forces:** Due to the smallness of nanomaterials, their mass is extremely small and gravitational forces become negligible. Instead electromagnetic forces are dominant in determining the behaviour of atoms and molecules.

2. **Wave-corpuscle duality of matter:** for objects of very small mass, such as the electron, wavelike nature has a more pronounced effect. Thus electrons exhibit wave behaviour and their position is represented by a wave (probability) function.

3. **Tunneling Effect:** One of the consequences is a phenomenon called tunnelling. Classical physics states



that a body can pass a barrier (potential barrier) only if it has enough energy to "jump" over it. Therefore, if the object has lower energy than that needed to jump over the energy barrier (the "obstacle"), in classical physics, the probability of finding the object on the other side of the barrier is null. In quantum physics a particle with energy less than that required to jump the barrier has a finite probability of being found on the other side of the barrier. It should be noted that in order to have a tunnel effect the "thickness" of the barrier (i.e., energy potential) must be comparable to the wavelength of the particle and therefore this effect is observed only at nanometre level. In simple words, electron (or quantum) tunnelling is attained when a particle (an electron) with lower kinetic energy is able to exist on the other side of an energy barrier with higher potential energy, thus defying a fundamental law of classic mechanics. Tunnelling is the penetration of an electron into an energy region that is classically forbidden. Tunnelling is a fundamental quantum effect and it is the base of a very important instrument for imaging nanostructured surfaces called the Scanning Tunnelling Microscope (STM). The same instrument can be used a nanofabrication tool (movement of single atoms).

4. **Quantum confinement**: In a nanomaterial, such as a metal, electrons are confined in space rather than free to move in the bulk of the material.
5. **Quantisation of energy:** Electrons can only exist at discrete energy levels. Quantum dots are nanomaterials that display the effect of quantisation of energy.

6. **Random molecular motion:** Molecules move due to their kinetic energy (assuming the sample is above absolute zero). This is called random molecular motion and is always present. At the macroscale this motion is very small compared to the sizes of the objects and thus it is not influential on how the object moves. At the nanoscale, however, these motions can be of the same scale as the size of the particles and thus have an important influence on how they behave. One example of a random kinetic motion is the Brownian Motion.

7. **Increased surface-to-volume ratio:** One of the distinguishing properties of nanomaterials is that they have an increased surface area.

B. Chemical

Nanomaterial is formed of at least a cluster of atoms, often a cluster of molecules. It follows that all types of bindings that are important in chemistry are also important in nanoscience.

They are generally classified as:

1. **Intra-molecular bonding (chemical interactions):** these are bondings that involve changes in the chemical structure of the molecules. They include: ionic bonds, covalent bonds and metallic bonds.

2. **Intermolecular bonding (physical interaction):** these are bondings that do not involve changes in the chemical structure of the molecules. They include ion-ion and ion-dipole interactions; Van der Waals

interactions; hydrogen bonds; hydrophobic interactions; repulsive forces (such as steric repulsions). Nanomaterials often arise from a number of molecules held together or large molecules that assume specific three-dimensional structures through intermolecular bonding (macromolecules). Therefore, nanoscience also deals with supramolecular chemistry (i.e., the chemistry that deals with interactions among molecules), which is just a subarea of the general field called "chemistry". In these macromolecules intermolecular bonding often plays a crucial role.

- Intermolecular bondings, such as hydrogen bonding and Wan der Waals bonding are weak interactions, but in a large number they can have a total energy that can be quite large. Think for instance of the structure of DNA (which has a cross-section of 2 nm): the two helixes are held together by numerous hydrogen bonds. This point becomes particularly relevant in nanoscience, where materials can have very large surface areas and consequently small forces can be applied to very large areas.
- Small forces become important on large surfaces can be observed with simple demonstration in which books made of thin paper and gradually lay one page of the first book over a page of the second book alternately. When only a few pages are overlapped, it is very easy to take the two books apart; we just need to pull. As the number of

pages interconnected increases, it becomes harder to pull the two books apart. After a certain number of pages it is no longer possible to separate the two books by hand. The interaction between the pages is due to weak forces (electrostatic and Van der Waals). When the surface area is big, these weak forces result in a very strong interaction.

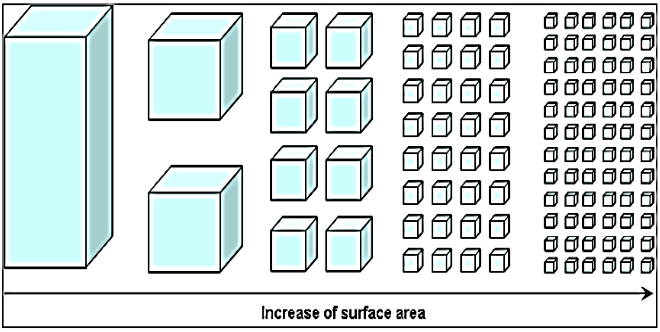
- Intermolecular bondings often hold together macromolecules (such as proteins) in specific three- dimensional structures with which precise biological functions are associated. Disruption of these interactions in a protein irreversibly affects its 3D structure (quaternary structure) and leads to a total loss of function (protein denaturation).
- One type of intermolecular bonding that is particularly significant in nanoscience is the hydrophobic effect. This is a process which is basically driven by entropy and which has a major role in biological materials. In simple words it is the property by which non-polar molecules (e.g. oil) tend to form aggregates of like molecules in water.

Properties of material at the nanoscale

1. **Surface Area:** Regardless of whether we consider a bulk material or a nanoscale material, its physical and chemical properties depend on a lot on its surface

properties. Surfaces perform numerous functions: they keep things in or out; they allow the flow of a material or energy across an interface; they can initiate or terminate a chemical reaction, as in the case of catalysts. The branch of science that deals with the chemical, physical and biological properties of surfaces is called surface science. In this context the term interface, rather than surface, is often used, to emphasise the fact that it is a boundary between two phases: the material and the surrounding environment (liquid, solid or gas).

If a bulk material is subdivided into an ensemble of individual nanomaterials, the total volume remains the same, but the collective surface area is greatly increased. This is schematically shown in Figure given below-



The consequence is that the surface-to-volume ratio of the material- compared to that of the parent bulk material is increased.

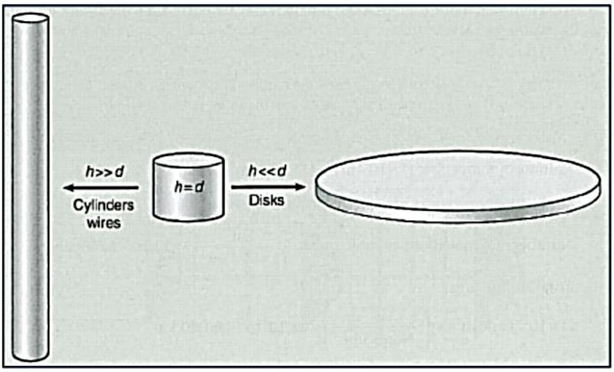
How would the total surface area increase if a cube of 1 m^3 were progressively cut into smaller and smaller cubes, until it is formed of 1nm^3 cubes can be realized from the table given below-

Size of cube side	Number of cubes	Collective Surface Area
1 m	1	6 m^2
0.1 m	1000	60 m^2
0.01 m = 1cm	10^6 = 1 million	600 m^2
0.001 m = 1mm	10^9 = 1 billion	6000 m^2
10^{-9} m = 1 nm	10^{27}	$6x10^9$= 6000 Km^2

Importance of surface atoms: In surface science the chemical groups that are at the material interface determine its properties. Properties like catalytic reactivity, electrical resistivity, adhesion, gas storage and chemical reactivity depend on the nature of the interface. Nanomaterials have a significant proportion of atoms existing at the surface. This has a profound effect on reactions that occur at the surface such as such as catalysis reactions, detection reactions, and reactions that, to be initiated, require the physical adsorption of certain species at the material's surface.

The fact, that in a nanomaterial a larger fraction of the atoms is at the surface influences some physical properties such as the melting point. Given the same material, its melting point will be lower if it is nano-sized. Surface atoms are more easily removed than bulk atoms, so the total energy needed to overcome the intermolecular forces that hold the atom "fixed" is less and thus the melting point is lower.

2. **Shape of the material:** Given the same volume, the extent of the surface area depends on the shape of the material. A simple example is a sphere and a cube having the same volume. The cube has a larger surface area than the sphere. For this reason in nanoscience

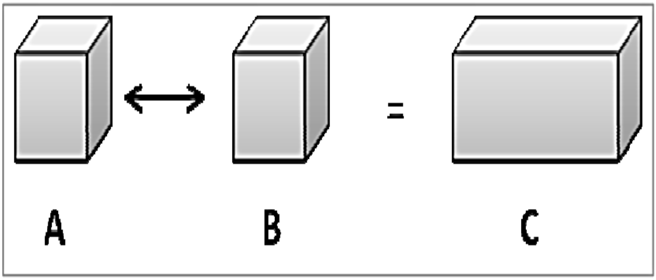


not only the size of a nanomaterial is important, but also its shape. Figure given at side illustrates this concept.

3. **Surface energy**: Atoms and molecules that exist at the surface or at an interface are different from the same atoms or molecules that exist in the interior of a material. This is true for any material. Atoms and molecules at the interface have enhanced reactivity and a greater tendency to agglomerate: surface atoms and molecules are unstable, they have high surface energy. As discussed earlier, nanomaterials have a very large fraction of their atoms and molecules on their surface. On the other hand a fundamental chemical principle is that "systems of high energy will strive to attain a state of lower energy, by whatever means possible". So how is it possible to have nanomaterials? Nature is

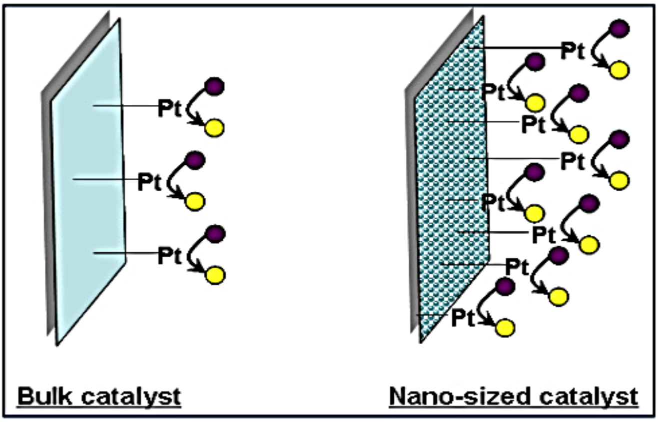
abundant with nanomaterials (proteins, DNA etc). Nanomaterials are inherently unstable, therefore there are various methods that nanomaterials adopt to minimise their inherent high surface energy.

One of the ways of reducing surface energy for nanoparticles is agglomeration. Surface energy is an additive quantity. The surface of 10 identical nanoparticles is equal to the sum of the surface energy of each individual nanoparticle. If these were to agglomerate, and become one large particle, the overall surface energy would be reduced. The concept is illustrated in Figure given at side, where- surface energy of two separate cubes is higher than the surface energy of the two cubes agglomerated.



Nanoparticles have a strong intrinsic tendency to agglomerate. To avoid that, surfactants can be used. This also explains why when nanoparticles are used in research and industry they are often immobilised on a solid support or mixed within a matrix. Even in commercial products that claim to contain nanoparticles (such as sunscreens) microscope images show that they are actually present in the form of agglomerates of > 100 nm dimensions.

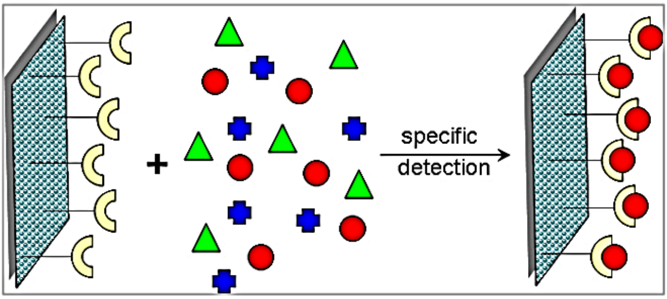
4. **Catalytic properties:** A catalyst is a substance that increases a chemical reaction rate without being consumed or chemically altered. Nature's catalysts are called enzymes and are able to assemble specific end-products, always finding pathways by which reactions take place with minimum energy consumption. One of the most important properties of a catalyst is its active surface where the reaction takes place. The 'active surface' increases when the size of the material decreased. The use of nanoparticles that have catalytic properties will allow a drastic reduction of the amount of material used, with resulting economic and environmental benefits.



Schematic representation of the increased active surface of a nano- sized catalyst compared to a bulk catalyst

5. **Detection properties:** The detection of a specific chemical or biological compound within a mixture represents the basis for the operation of numerous devices, like chemical sensors, biosensors and

microarrays. The rate, specificity and accuracy of this reaction can be improved using nanomaterials rather than bulk materials in the detection area. The higher surface to volume ratio of nanomaterials increases the surface area available for detection with a positive effect on the rate and on the limit of detection of the reaction. In addition, nanomaterials can be designed to have specific surface properties (chemical or biochemical), tailored at a molecular level. This way, the active sites on the material surface can act as "locks" to detect specific molecules (the "keys"). Scaling down using nanomaterials allows packing more detection sites into the same device, thus allowing the detection of multiple analytes.



Schematic representation showing the specific specific detection of an analyte within a mixture by "receptor" sites in a nanomaterial

All the above properties are responsible for specific behaviour of nano particles regarding to electrical, optical and mechanical characteristics. These will differ from the properties in bulk material. This concepts are used for formulation of various nano materials for benefit to various sectors in human life as- agriculture, engineering, industry, etc.

Nanotechnology and Agriculture

Major Challenges of Agriculture to be addressed by Nanotechnology:

1. Food security for growing numbers
2. Low productivity in cultivable areas
3. Lower agricultural input efficiency
4. Unsustainable farm management
5. Large uncultivable areas
6. Shrinkage of cultivable lands
7. Wastage of products
8. Perishability/ low shelf life
9. Post- harvest losses (processing, packaging)
10. Diseases and vulnerabilities to climate change due to global warming

Application of Nanotechnology in Agriculture:

A. Nanotechnology for water safety:

Nanoscience applications in water management assume a special importance for a vast developing region like India. Given the diverse geographical conditions, different regions face a range of water problems varying in terms of magnitude. Problems of safe and potable water prevail alike other developing regions of the world, more so in the arid and semi arid regions. The prevalence of waterborne diseases is also quite high. Improving the quantum of supply of water as well as its quality, at an affordable cost, is what a common Indian would expect the most from the researchers and experts engaged in exploring strategic applications of nanoscience. This one area can change the socio economic scenario substantially Challenges in the water sector in India Water availability has been a problem as a result of rising population, rapid urbanization, growing industrialization and expanding agriculture. Water treatment and remediation has been cited as the third most critical area where nanotechnology applications might aid developing countries. Some of the interventions includes Nanomembranes for water purification, desalination, and detoxification, Nanosensors for the detection of contaminants and pathogens, nanoporous zeolites, nanoporous polymers, and attapulgite clays for water purification, magnetic nanoparticles for water treatment and remediation and TiO_2 nanoparticles for the catalytic degradation of water pollutants. Nanotechnology interventions might be sought at specific junctures to alleviate the following challenges. Improve quantity and quality of water and wastewater treatment systems: The water treatment systems need to address the removal of contaminants present in the surface and ground water in order to provide potable drinking water. Many technologies exist such as candle filter, biosand filter, activated carbon, UV and chemical based systems. These have been found suitable for contaminant removal from water; however, the performance can be improved and systems made more efficient by use of nanotechnology. Nano-enabled water treatment techniques incorporating carbon nanotubes, nanoporous ceramics, and magnetic nanoparticles can be used to remove impurities from drink-ing water and could potentially remove bacteria, viruses, water-borne pathogens, lead, uranium, and arsenic, among other contaminants. Magnetic nanoparticles could be used to filter water at the point of use to remove nanocrystals and arsenic. Nanoparticle filters can be used to remove organic particles and pesticides from water.

B. Nanotechnology for detecting plant diseases:

A need for detecting plant disease at an early stage so that tons of food can be protected from the possible outbreak; has tempted nanotechnologists to look for a nano solution for protecting the food and agriculture from bacteria, fungus and viral agents. A detection technique that takes less time and that can give results within

a few hours, that are simple, portable and accurate and does not require any complicated technique for operation so that even a simple farmer can use the portable system. If an autonomous nano sensors linked into a GPS system for real-time monitoring can be distributed throughout the field to monitor soil conditions and crop, it would be of great help. The union of biotechnology and nanotechnology in sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes and diseases.

1. **Nanosensors:** Nanotechnology may be used in agriculture and food production in the form of nano sensors for monitoring crop growth and pest

control by early identification of animal or plant diseases. These nano sensors can help enhance production and improve food safety. The sensors function as external monitoring devices and do not end up in the food itself. Nanomaterials can also be introduced in or on the food itself. The effectiveness of pesticides may be improved if very small amounts are enclosed in hollow capsules with a diameter in the nanometer range which can be designed to open only when triggered by the presence of the pest to be controlled. Nano sensors may detect contaminants, pests, nutrient content, and plant stress due to drought, temperature, or pressure. They may also potentially help farmers increase efficiency by applying inputs only when necessary. The developed biosensor system is an ideal tool for online monitoring of organophosphate pesticides and nerve agents. Bioanalytical nanosensors are utilized to detect and quantify minute amounts of contaminants like viruses bacteria, toxins bio-hazardous substances etc. in agriculture and food systems. Most analysis of these toxins is still conducted using conventional methods; however, biosensor methods are currently being developed as screening tools for use in field analysis.

2. **Nano-particles controlling the plant diseases:** Some of the nano particles that have entered into the arena of controlling plant diseases are nanoforms of carbon, silver, silica and aluminosilicates. Pesticides inside nanoparticles are

being developed that can be timed-release or have release linked to an environmental trigger. Combined with a smart delivery system, herbicide could be applied only when necessary, resulting in greater production of crops and less injury to agricultural workers. Leading chemical companies are now formulating efficient nanopesticides and nanohericides at nano scale. One of such effort is use of Alumino-Silicate nanotubes with active ingredients. Pesticides via Encapsulation, Pesticides containing nano-scale active ingredients are already on the market, and many of the world's leading agrochemical firms are conducting reserach on the development of new nano-scale formulations of pesticides.

3. **Smart Treatment Delivery Systems:** Today, application of agricultural fertilizers, pesticides, antibiotics, probiotics and nutrients is typically by spray or drench application to soil or plants, or through feed or injection systems to animals. Delivery of pesticides or medicines is either provided as "preventative" treatment or is provided once the disease organism has multiplied and symptoms are evident in the plant or animal.
4. **Nano Silver:** Nanosilver is the most studied and utilized nano particle for bio-system. It has long been known to have strong inhibitory and bactericidal effects as well as a broad spectrum of antimicrobial activities. Silver nanoparticles, which have high surface area and high fraction of surface atoms, have high antimicrobial effect as compared

to the bulk silver studied the antifungal effectiveness of colloidal nano silver (1.5 nm average diameter) solution, against rose powdery mildew caused by *Sphaerotheca pannosa* var rosae. Nano silica-silver composite Silicon (Si) is known to be absorbed into plants to increase disease resistance and stress resistance. The pathogens disappeared from the infected leaves 3days after spray and the plants remained healthy thereafter also studied the 'effective concentration' of nanosized silicasilver on suppression of growth of many fungi; and found that, *Pythium ultimum, Magnaporthe grisea, Colletotrichum gloeosporioides, Botrytis cinere* and, *Rhyzoctonia solani*, showed 100% growth inhibition at 10 ppm of the nanosized silica-silver. Whereas, Bacillus subtilis, Azotobacter chrococum, Rhizobium tropici, Pseudomonas syringae and Xanthomonas compestris pv. Vesicatoria showed 100% growth inhibition at 100 ppm.

5. **Nano-emulsions:** It is a mixture of two or more liquids (such as oil and water) that do not easily combine. In nanoemulsion, the diameters of the dispersed droplets are 500 nm or less. Nano-emulsions can encapsulate functional ingredients within their droplets, which can facilitate a reduction in chemical degradation.

C. Fertilizer Management:

Nanofertilizers could be used to reduce nitrogen loss due to leaching, emissions, and longterm incorporation by soil microorganisms. They could allow for selective release linked to time or environmental condition. Slow-controlled-release fertilizers may also improve soil by decreasing toxic effects associated with fertilizer over application.

D. Veterinary Sciences:

1. **Nanofeed additives**: Chicken feed containing nanoparticles that bind with harmful bacteria could help reduce food-borne pathogens. Nanoclays can ameliorate aflatoxin's deleterious effects on poultry.
2. **Nanocoatings:** Self-sanitizing photocatalyst coating for use in poultry houses with nano–titanium dioxide could be used to oxidize and destroy bacteria in the presence of light and humidity. Smart drug-delivery systems Smart delivery systems can detect and treat an animal infection or nutrient deficiency and provide timed-release drugs or micronutrients.

E. Food Safety and Nutrition:

1. **Nanofood:** A food is nanofood when nanoparticles, nanotechnology techniques or tools are used during cultivation, production, processing or packaging of the food. Nanofood is often associated with color & flavor improvement, better storage & preservation, pathogen detection, antimicrobial properties, intelligent packaging, etc. for example drinks that turn pink or yellow when microwaved, Nanocapsules incorporating tuna fish

oil, a source of É-3 fatty acids into bread. A nanoadditive for animal feed can deactivate aflatoxin, deoxynivalenol, and zealalenone mycotoxins in animal feed. Nanoparticles can also remove food-borne patho-gens in the gastrointestinal tracts of livestock.

2. **Nano lamination:** This technique is another viable option for protecting the food from moisture, lipids and gases. Moreover, they can improve the texture and preserve flavor as well as color of the food. Nanolaminates consist of two or more layers of nano-sized (1-100) thin food grade films which are present on a wide variety of foods: fruits, vegetables, meats, chocolate, candies, baked goods, and French fries. Nanolaminates are prepared from edible polysaccharides, proteins, and lipids has shown that polysaccharide- and proteinbased nanolaminates are good barriers against oxygen and carbon dioxide, but poor in protecting against moisture. Whereas, lipid-based nanolaminates are good at protecting food from moisture.
3. **Enhanced barriers to microbial contamination or spoilage:** Barriers can reduce opportunity for microbial contamination by keeping bacteria away from food or preventing condi-tions that allow bacteria to grow. Nanocomposites used in food and beverage containers provide effective barriers to gas transmission.
4. **Food processing:** Nanocapsulated flavor enhancers Nanocapsules to improve bioavailability of neutraceuticals in standard ingredients such as cooking oils Nanotubes and nanoparticles as gelation and viscosifying agents nanocapsule

infusion of plant basd steroids to replace a meat's cholesterol Nanoparticles to selectively bind and remove chemicals or pathogens from food Nanoemulsions and particles for better availability and dispersion of nutrients.

5. **Food packaging:** Conventional plastics, used widely in food packaging, are difficult to degrade thereby creating a serious problem of solid waste disposal. In this context, biomass based materials have been explored for the development of eco-friendly food packaging. The challenge is to overcome performance related issues (e.g. poor mechanical strength, brittleness, poor gas and moisture barrier), processing problems (e.g. low heat distortion temperature), and high cost associated with biopolymer based packaging. Silver nanoparticles can be embedded in polymeric materials such as PVC, PE, PET while polymerization occurs. Silver nanoparticles kill pathogens, bacteria, viruses and fungus and are used as a good and safe packaging pot. Such nanotechnology based packaging materials are 100 times more secure than the normal one for the storage of juices, milk and other agri-products. Food packaging films in the name of "hybrid system" films have enormous number of silicate nano particles. They massively reduce the entrance of oxygen and other gases, and the exit of moisture, thus preventing food from spoiling or drying.
6. **Nanoclays:** Clays and silicates are layered inorganic solids that are readily available at low cost; further they are easy to process and can result in significant improvement in properties. The most extensively investigated clay is montmorillonite,

hydrated alumina-silicate layered clay. Addition of nanoclays in polymer formulations results in several benefits viz. enhanced mechanical properties, superior barrier properties because of the high tortuosity imparted by these materials thus, permeability of oxygen and water vapor can be significantly reduced.

7. **Cellulose nanofiber:** This is a low cost and readily available nanomaterial obtained from the natural polymer cellulose. This has been used to improve thermo mechanical and barrier properties in biopolymers like starch without affecting the biodegradability. Cellulose nanoreinforcements also improve moisture barrier and enhance thermal stability.
8. **Detection of food-borne pathogens or spoilage organisms:** Nano-based methods of detecting harmful pathogens are being developed for several pathogens: a nanobiosensor can identify the presence of E. coli and prevent the consumption of contaminated foods. Similarly, nanosensors can indicate the deterioration of foods due to spoilage microorganisms or other factors.
9. **Detection of pesticides, heavy metals, or other chemical contaminants:** Several nano-based biosensors have been developed to detect contaminants, such as crystal violet or malachite green concentrations in seafood and parathion residues or residues of organophosphorus pesticides on vegetables.
10. **Quality Maintenance:** Identity Preservation (IP) is a system that creates increased customers with information about the particles and activities used to produce a particular crop or other agricultural

products. Quality assurance of agricultural products safety and security could be significantly improved through IP at the nanoscale. Nanoscale IP holds the possibility of continuous tracking and recording of the history which a particular agricultural product experience.

11. **Quality control and testing:** Food safety is a major concern for food producers, consumers and food safety authorities. Nanosensors may help to improve food safety by enabling faster quality control and testing not only in the factory but also on the shelf and even in your refrigerator. These sensors can be integrated in the food processing equipment or in refrigerators and do not introduce nanoparticles into the food itself. A nanosensor is a device consisting of an electronic data processing part and a sensing layer or part, which can translate a signal such as light, or the presence of an organic substance or gas into an electronic signal.

F. Environment protection:

Nanotechnology will also help protect the environment indirectly through the use of alternative (renewable) energy supplies, and filters or catalysts to reduce pollution and clean-up existing pollutants. Nanotechnology Research also aims to make plants use water, pesticides and fertilizers more efficiently.

G. Crop improvement:

1. **Nanobiotechnology:** Research in nano-biotechnology is advancing toward the ability to

sequence DNA in nano fabricated gel-free systems,which would allow for significantly more rapid DNA sequencing. Coupled with powerful approaches such as association genetic analysis, DNA sequencing data of the crop germplasm, including the cultivated crop gene pool and the wild relatives can potentially provide highly useful information about molecular markers associated with agronomically and economically important triats. Thus, nanobiotechnology can enhance the pace of progress in molecular marker assisted breeding for crop improvement.

2. **DNA Microarrays and Expression Profiling:** Microarrays based hybridization methods allow to simultaneously measure the expression level for thousands of genes.
3. **Protein Microarrays:** The structures and functions of proteins are much more complicated that of DNA, and proteins are less stable than DNA. Protein microarrays are being used to discover protein biomarkers that indicate disease stages to access potential efficacy and toxicity of pesticides to measure different protein production across cell types and developmental stages, in both healthy and diseased stages, to study the relationship between protein structure and function and to evaluate binding interactions between proteins and other molecules.
4. **Atomically Modified Seeds:** In March 2004, ETC group reported a nanotechology research initiative in Thailand that aims to atomically modify the characteristics of local rice varieties. They drilled a hole through the membrane of rice cell to insert nitrogen atom that would stimulate the

rearrangement of the rice. DNA, they are able to change the colour of local rice variety from purple to green one of the attraction of this nano-scale technique is that it does not require the controversial technique of genetic modification.

5. **Nanofuels:** Levesque's lab (University of Otawwa) is working on nanoconversion of agricultural materials into valuable products. The design and development of new nanocatalysts for the conversion of vegetable oils into biobased fuels and biodegradable solvents is already under scientific examination and could be greatly enhanced with the help of nanotechnological abilities. This is based on the concept that the organic fuels at nano scale would be able to give greater energy with lesser energy loss during conversion.
6. **Particle Farming:** Nanoparticles may not be produced in a laboratory, but grown in fields of genetically engineered crops what might be called particle farming.Researchers have shown that plant can also soak up nanopacticles that could be industrially harvested alfalfa plant were grown on an artificially gold rich soil. Gold nanopacticles in the roots and along the entire shoot of plant are then extracted simple by dissolving them in organic material. NCL, Pune, India have been carring out similar work with geranium leaves immersed in goldrich solution.
7. **Carbon Nanotubes (CNTs):** CNTs have become attractive electronic materials to date and their applications in future electric circuits and bio-sensing chips. CNT as vehicle to deliver desired molecules into the seeds during germination that

can protect them from the diseases. Since it is growth promoting, it will not have any toxic or inhibiting or adverse effect on the plant.

8. **Mesoporous silica Nanoparticles (MSNs):** MSNs have been extensive investigated as a drug delivery system. It is well know that MSNs possess excellent properties such high specific area, high pore volume, tunable pore structures and physicochemical stability. In the beginning MSNs were used for controlled delivery of various hydrophilic or hydrophobic active agents. Later advances in the MSNs surface properties such as surface functionalization and PEG ylation rendered them as a promising drug delivery. Mesoporous silica Nanoparticles (MSN) helps in delivering DNA and chemicals into isolated plant cells. MSNs are chemically coated and serve as containers for the genes delivered into the plants. The coating triggers the plant to take the particles through the cell walls. It was found that MPS/DNA complexes showed enhanced transfection efficiency through receptor-mediated endocytosis via mannose receptors. These results indicate that MPS can be employed in the future as a potential gene carrier to antigen presenting cells.
9. **Nanosilica based transformation in plant cells:** Francois Tourney Brian Tsceoyn & colleagues at Jowa State University describe the use of silica nanoparticles to deliver foreign genetic material into plant cells in a process called transformation. Nanoparticles can be used to carry and release effectors small molecule (- estradiol) that induce the expression of genes within the plant cells in a controlled fashion.

10. **Nanoparticles mediated nonviral gene delivery:** Gene delivery systems are an important area in the field of genetic nanomedicine. Gene delivery involves the transport of genes, which requires a transport vehicle referred to as a vector. Possible vectors include viral "shells" or lipid spheres (Liposomes), which have properties that allow them to be incorporated into host cells5. Peptides and proteins have become the drugs of choice for the treatment of numerous diseases as a result of their incredible selectivity and their ability to provide effective and potent action. These studies suggest that research should be focused on designing a drug with an enhanced permeability and retention (EPR) effect. nanoconjugate is being developed for non-invasive detection of gene expression in cells.
11. **Polymer based gene transfer:** Non-viral gene medicines have emerged as a potentially safe and effective gene therapy method for the treatment of a wide variety of acquired and genetic diseases. An important advantage of polymer-based gene delivery systems over viral transfection systems is that transient gene expression without the safety concerns can be achieved. In addition to the polymeric systems to deliver DNA, therapeutic ultrasound is potentially useful because ultrasound energy can be transmitted through the body without damaging tissues and could be applied on a restricted area where the desired DNA is to be expressed.
12. **Liposome gene transfer:** The liposome-based gene transfer strategy is one of the most studied Nonviral gene delivery strategies. A liposomal

delivery system requires a complete understanding of the physicochemical characteristics of the drug liposome system. Many bacteria can control plant diseases by altering molecular processes leading to the production of pathogenicity and/or virulence factors by the pathogen. Liposomes may offer several advantages as vectors for gene delivery into plant cells. Enhanced delivery of encapsulated DNA by membrane fusion, protection of nucleic acids from nuclease activity, targeting to specific cells, delivery into a variety of cell types besides protoplasts by entry through plasmodesmata. In liposome based gene therapy there is no toxicity potential in humans and plants.

13. **Biobeads gene transfer:** Micrometer-sized calcium alginate beads referred to as "bio-beads" that encapsulate plasmid DNA molecules carrying a reporter gene. In order to evaluate the efficiency of the bio-beads in mediating genetic transfection, protoplasts isolated from cultured tobacco cells. Transfection was up to 0.22% efficient. These results indicate that bio-beads have a possibility for efficient transformation in plants. Application of Nanoscale materials has been grown exponentially due to high sensitivity and fast response time.

Challenges for Nanotechnology in Agriculture

1. **Societal effects:** Coming nanotechnologies in the agricultural field seem quiet promising. However, the potential risks in using nanoparticles in agriculture are no different than those in any other industry. Through the rapid distribution of nanoparticles to food

products – whether it be in the food itself or part of the packaging - nanoparticles will come in direct contact with virtually everyone. The environmental group ETC (Action Group on Erosion, Technology and Concentration) is deeply concerned with the implications and regulation of nanotechnology used in food. Currently, there are none. Their main concern is that of the unknown. Since there is no standardization for the use and testing of nanotechnology, products incorporating the nanomaterials are being produced without check. The ability for these materials to infiltrate the human body is well known, but there is really no information on the effects that they may have. While there is no evidence of harm to people or the environment at this stage, nanotechnology is a new and evolving area of study that could cause a great deal of harm due to its still ambiguous chemical properties. With the current application and advancements soon to come, nanotechnology will have a great impact on the direction that agriculture will take.

2. **Cost and Access** Intellectual property rights, innovation, and technology access: In private-sector development, economic incentives, such as intellectual property rights (IPR), play a critical role in the innovation process in a globalized world. Patents provide incentive for research and invest-ment, but their use still generates significant criticism. Enforcing IPR and, more specifically, patents can create barriers to entry and raise the cost of products for consumers, thereby contributing to a growing divide between developed and developing economies.

Environmental and human-health risks Using nanomaterials is not inherently risky for instance, traditional foods contain many nanoscale materials but the use of certain engineered nanoscale materials in agriculture, water, and food may have risks for human use and consumption, for the environment, or for both. Possible migration of the nanoparticles from such bulk materials into the food or the environment is the issue. Food safety experts are looking into whether the legislative controls on food packaging materials already in place for plastics etc. are adequate to deal with the new properties of nanoparticles of the same food grade materials.

REFERNCES

Krishna K. R. 2013. Precision Farming: Soil Fertility and Productivity Aspects. Apple Academic Press. ISBN: 9781926895444 - CAT# N10735

Oliver and Margaret A. 2010. Geostatistical Applications for Precision Agriculture. Springer. ISBN: 978-90-481-9133-8

Qin Zhang. 2015. Precision Agriculture Technology for Crop Farming. CRC Press. ISBN: 9781482251074 - CAT# K23803

Ancha Srinivasan. 2006. Handbook of Precision Agriculture: Principles and Applications. CRC Press ISBN: 9781560229551 - CAT# HW15263

Rabi Narayan Sahoo, Vinay Kumar Sehgal, Sanatan Pradhan and KH Kamble. 2012. Practical Manual on Basics of Remote Sensing Data Processing, GPS and GIS. IARI, New Delhi

Claudia Parisi, Mauro Vigani and Emilio Rodríguez- Cerezo. 2015. Agricultural Nanotechnologies: What are the current possibilities? Frontiers in Microbiology. 10 (2): 124- 127. doi: [10.3389/fmicb.2017.01014]

Yogesh Bhagat, K Gangadhara, Chidanand Rabinal and Padmabhushan Ugale. 2017. Nanotechnology in Agriculture: A Review. Journal of Pure and Applied Microbiology 9(1): 1- 11

Pallab Ghosh. Introduction to Nanomaterials & Nanotechnology. NPTEL Chemical Engineering Interfacial Engineering Module 9: Lecture 1.
Online published at:
https://nptel.ac.in/courses/103103033/module9/lecture1.pd

ABOUT THE AUTHOR

Dr. Aniket Kalhapure is presently working as Assistant Professor of Agronomy at Banda University of Agriculture & Technology, Banda (U.P.). He has completed B.Sc. (Agri.) from Mahatma Phule Krishi Vidyapeeth, Rahuri; M.Sc. (Agri.) in Agronomy discipline from Marathwada Agricultural University, Parbhani and Ph.D. (Agronomy) from GB Pant University of Agriculture & Technology, Pantnagar. He has fourteen years active experience in research, teaching, farm management and implementing the extension activities in the field of Agriculture. His more than 25 research papers have been published in various national and internationally recognized journals. He also has the credit of several technical papers, popular articles, book chapters, text books, other extension literature and radio talks in his name and contributed to the recommendation of various agro-technologies for the welfare of farmers. He is rewarded with the fellowships of South Asia Foundation and SERB- Department of Science & Technology, Govt. of India.

ISBN: 978-81-958949-0-1

9 788195 894901