Course No: AGRON-312

Course Title: **Geoinformatics, Nano-technology and Precision Farming**

Credit: (1+1)

AGRON.312: Geoinformatics, Nano-technology and Precision Farming (1+1=2)

Theory: Precision agriculture: concepts and techniques; their issues and concerns for Indian agriculture; Geo-informatics- definition, concepts, tool and techniques; their use in Precision Agriculture. Crop discrimination and Yield monitoring, soil mapping; fertilizer recommendation using geospatial technologies; Spatial data and their management in GIS; Remote sensing concepts and application in agriculture; Image processing and interpretation; Global positioning system (GPS), components and its functions; Introduction to crop Simulation Models and their uses for optimization of Agricultural Inputs; STCR approach for precision agriculture; Nanotechnology, definition, concepts and techniques, brief introduction about nanoscale effects, nano-particles, nano-pesticides, nano-fertilizers, nano-sensors, Use of nanotechnology in seed, water, fertilizer, plant protection for scaling-up farm productivity.

CHAPTER - 1

PRECISION AGRICULTURE

INTRODUCTION

Precision agriculture (PA) or precision farming (PF) aims at optimizing profitability and protecting environment through efficient use of inputs based on temporal and spatial variability of soils and crops. Both sensors based and satellite image based technologies have been developed and are being promoted in the developed world. Economic analyses of adoption of precision farming have indicated marginal profitability to already existing best management practices (BMPs) and higher productivity levels. Wide gap between potential and actual yield levels in developing world necessitates promotion of PF to achieve the intended benefits.

Gap between average farm yields and yield potential ceiling must shrink during the next 5 years because the yield potential of major crops appears to be stagnant. Rice, maize and wheat yield potentials are increasing more slowly than the expected increase in demand. Hence sustainable crop yields that exceed at least 70 per cent of yield potential barrier depends on sophisticated management of soil, water resources and other inputs. Precision agricultural approach is required to insure that the requisite resources for crop growth are available and crop protection needs are met without deficiency or excess at each point in time during the growing season. Precision management can be applied based on the requirement to the field at right time, right place, right quantity and by right method.

CONCEPTS OF PRECISION FARMING

"Precision farming is the technology which involves the targeting of inputs to arable crop production according to crop requirement on the localized basis". (Stafford, 1996)

Aims

To Replace

- Big machinery
- High energy consumption
- Chemicals / at least over application

With

- Intelligent machines
- Intelligent processes

PRECISION FARMING v/s TRADITIONAL FARMING		
S. No.	PRECISION FARMING	TRADITIONAL FARMING
1.	Farm field is broken into "management zones"	Whole field approach where field is treated as a homogeneous area
2.	Management decisions are based on requirements of each zone	Decisions are based on field averages
3.	PF tools (e.g. GPS/GIS) are used to control zone	Inputs are applied uniformly across a field

Precision farming needs the requisition, management, analysis and output of large amount of spatial and temporal data. Mobile computing systems were needed to function on the go in farming operations because desktop systems in the farm office were not sufficient.

Basic concept of Precision Farming

- Use the right input
- At the right time
- In the right amount
- At the right place
- In the right manner

Precision farming basically depends on measurement and understanding of variability. Main components of precision farming system must address the variability.

Variability

There are 3 types of variability

- **Spatial variability:** Varies with space from one part of the field to other.
- **Temporal variability:** Varies with time from year to another.
- **Predictive Variability:** Varies with Farmers Prediction.

Precision farming is a farm management concept based on modern information technologies.

Components (enabling technologies) of precision farming include:

- Remote sensing (RS).
- Geographical information system (GIS).
- Global positioning system (GPS).
- Soil testing.

- Yield monitors.
- Variable rate technology (VRT).

Precision farming is concerned with spatial and temporal variability and it is information based and decision focused. It is the spatial analysis capabilities of GIS that enable precision agriculture. The GPS and DGPS has greatly enabled precision farming and of great importance to precision farming, particularly for guidance and digital evaluation modelling position accuracies at the centimeter level are possible in differential global positioning system (DGPS) receivers.

In India, we have all these technologies available and they can be implemented through agricultural training centers by giving training to agriculture officers in these technologies.

Precision agriculture is a phrase that captures the imagination of many concerned with the production of food, feed and fiber. The concept of precision agriculture offers the promise of increasing productivity while decreasing production cost and minimizing environmental impacts. Precision agriculture conjures up images of farmers overcoming the elements with computerized machinery that is precisely controlled via satellites and local sensors and using planning software that accurately predicts crop development. This image has been called the future of agriculture.

In Indian contest, precision farming may be defined as an accurate application of agricultural inputs for crop growth, considering relevant factors such as soil, weather and crop management practices. It is actually information and technology based farming system where inputs are managed and distributed on a site-specific basis for long-term benefits.

Precision farming system (PFS) is based on the recognition of spatial and temporal variability in crop production. Variability is accounted for in farm management with the aim of increasing productivity and reducing environmental risks. In developed countries, farms are often large (sometimes 1000 ha or more) and comprise several fields. The spatial variability in large farms, therefore, has two components: within-field variability and between-field variability. The concepts of PF can be presented as shown in Fig 1.1.

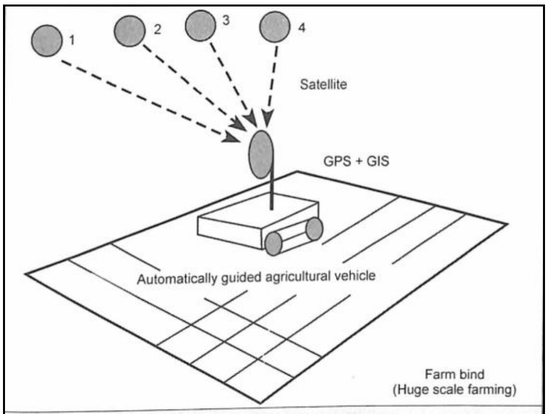
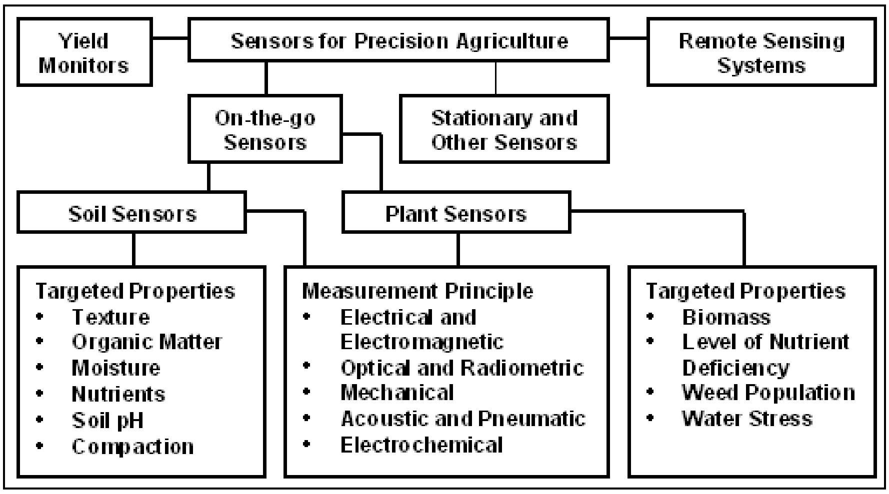


Fig 1.1. Components of precision agriculture.

Precision farming system within a field is also referred to as site-specific crop management (SSCM). According to the Second International Conference on Site-Specific Management for Agricultural Systems, held in Minneapolis, Minnesota, in March 1994 precision farming or SSMC refers to a developing agricultural management system that promotes variable management practices within a field according to site or soil condition, (national Research Council 1997).

However, according to Batte and Van Buren (1999), SSCM is not a single technology but an integration of technologies permitting:

1. Collection of data on an appropriate scale at a suitable time.
2. Interpretation and analysis of data to support a range of management decisions.
3. Implementation of management response on appropriate scale and at suitable time.



Precision farming is concept of using the new technologies and collected field information. Precision farming provides farmers with a tool to apply fertilizer according to the need of a particular sub-field and no longer based on the average of the field. The savings made with this variable application can be fairly large. Precision farming technology would be a viable alternative to improve profitability and productivity (Fig 1.2).

Precision agriculture can be presented as management of three conceptual components: data collection, data analysis/interpretation and application/variable rate treatment. Another way of presenting these components is shown in Fig 1.3, in the form of cycles and the technology/operations involved in SSCM.

Production of food, feed and fiber are dependent on the quantity and quality of soil, plant, water and air. No matter what agricultural systems are used, without protecting the natural resources, yields will decrease until the point of no return. The concept that precision agriculture is a system, (Webster: interrelated, interacting, independent elements forming a complex whole), provides a more useful foundation for understanding precision agriculture. An agricultural system that can be used for:

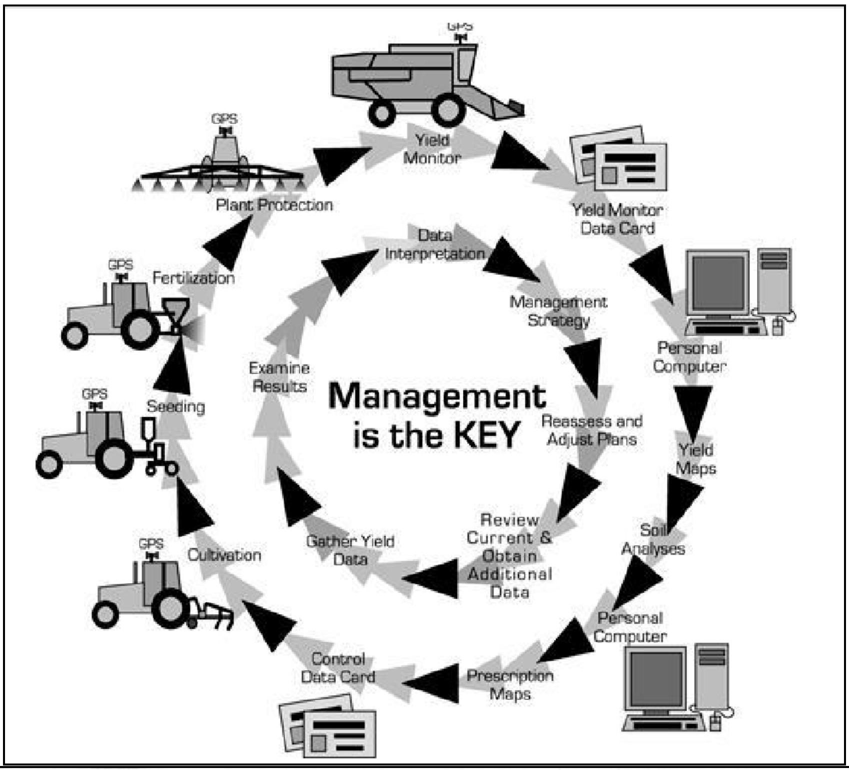


Fig 1.2. Precision agriculture: a comprehensive approach.

- Land preparation.
- Seeding.
- Chemical application.
- Fertilizer application.
- Crop monitoring.
- Nutrient auditing.
- Soil and leaf testing.
- Pest management.
- Conservation practices.
- Gross margin analysis.

- Agro-geo-information, the agricultural-related geo-information, is the key information in the agricultural decision making and policy formulation process. Agro-geo-informatics, a branch of geo-informatics, is the science and technology about handling digital agro- geo-information, such as collecting (mainly through remote sensing and field investigation), processing, storing, archiving, preservation, retrieving, transmitting, accessing, visualization, and analyzing, synthesizing, presenting and disseminating agro-geo-information. Recent advances in geo-informatics have created new opportunities and challenges in applying agro-geo-informatics to agriculture monitoring, assessment and decision making.

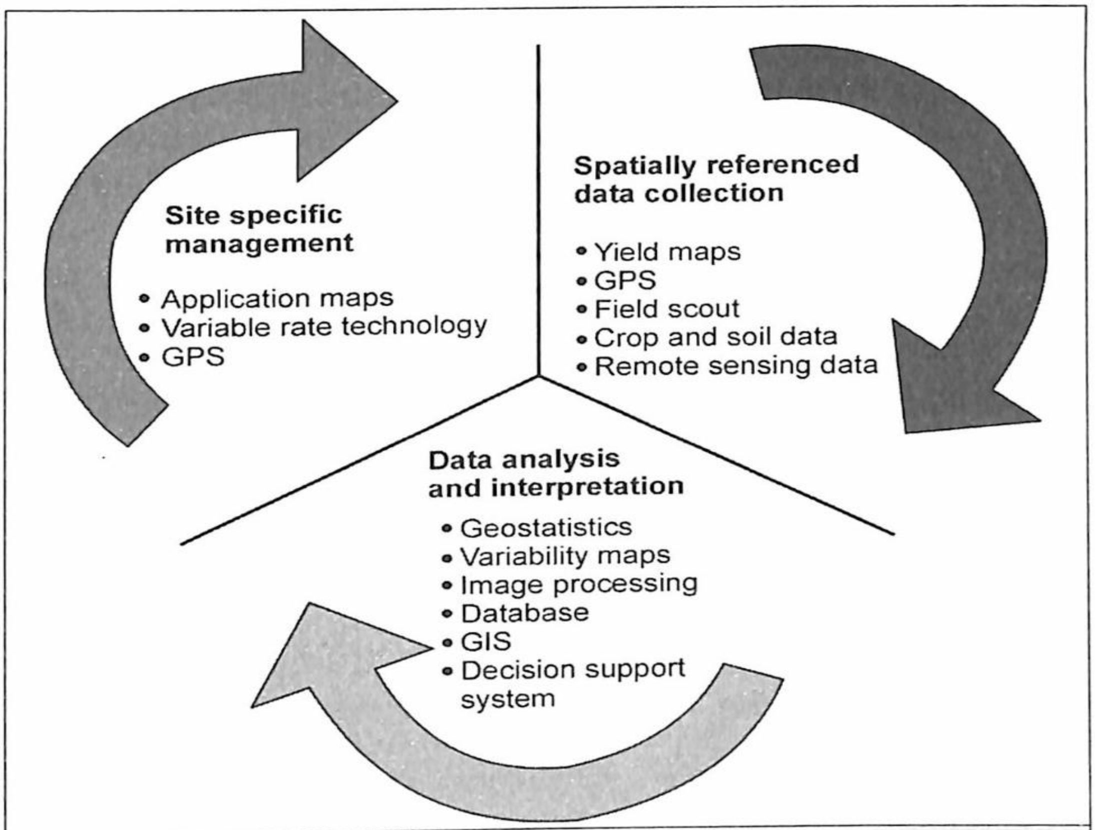


Fig 1.3. Data processing and management cycles for precision farming.

STEPS IN PRECISION FARMING

Two basic steps in precision agriculture are: (1) Identification and assessment of variability and (2) Management of variability.

1. Identification and Assessment of Variability

Assessing variability:-

- In precision farming, inputs are to be applied precisely in accordance with the existing variability
- Spatial variability of all the determinants of crop yield should be well recognized, adequately quantified andproperly located
- Construction of condition maps on the basis of the variability is a critical component of precision farming
- Condition maps can be generated through (i) Surveys, (ii) Point sampling & interpolation, (iii) Remote sensing (high resolution) and (iv) Modeling

- **Grid soil sampling:** Grid soil sampling uses the same principles of soil sampling but increases the intensity of sampling compared to the traditional sampling. Soil samples collected in a systematic grid also have location information that allows the data to be mapped. The goal of grid soil sampling is to generate a map of nutrient/water requirement, called an application map.
- **Yield map:** 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. One way to determine yields map, is to take samples from the land in a 100 x 100 m grid pattern

to test for nutrient levels, acidity and other factors. Results can then be combined with the yield map to see if application levels need to be adjusted for more effective, yet more economical placement that produces higher crop yields.

- **Crop scouting:** In-season observations of crop conditions like weed patches (weed type and intensity); insect or fungal infestation (species and intensity) and crop tissue nutrient status can helpful later when explaining variations in yield maps.
- **Use of precision technologies for assessing variability:** Faster and in real-time assessment of variability is possible only through advanced tools of precision agriculture.

2. Management of Variability

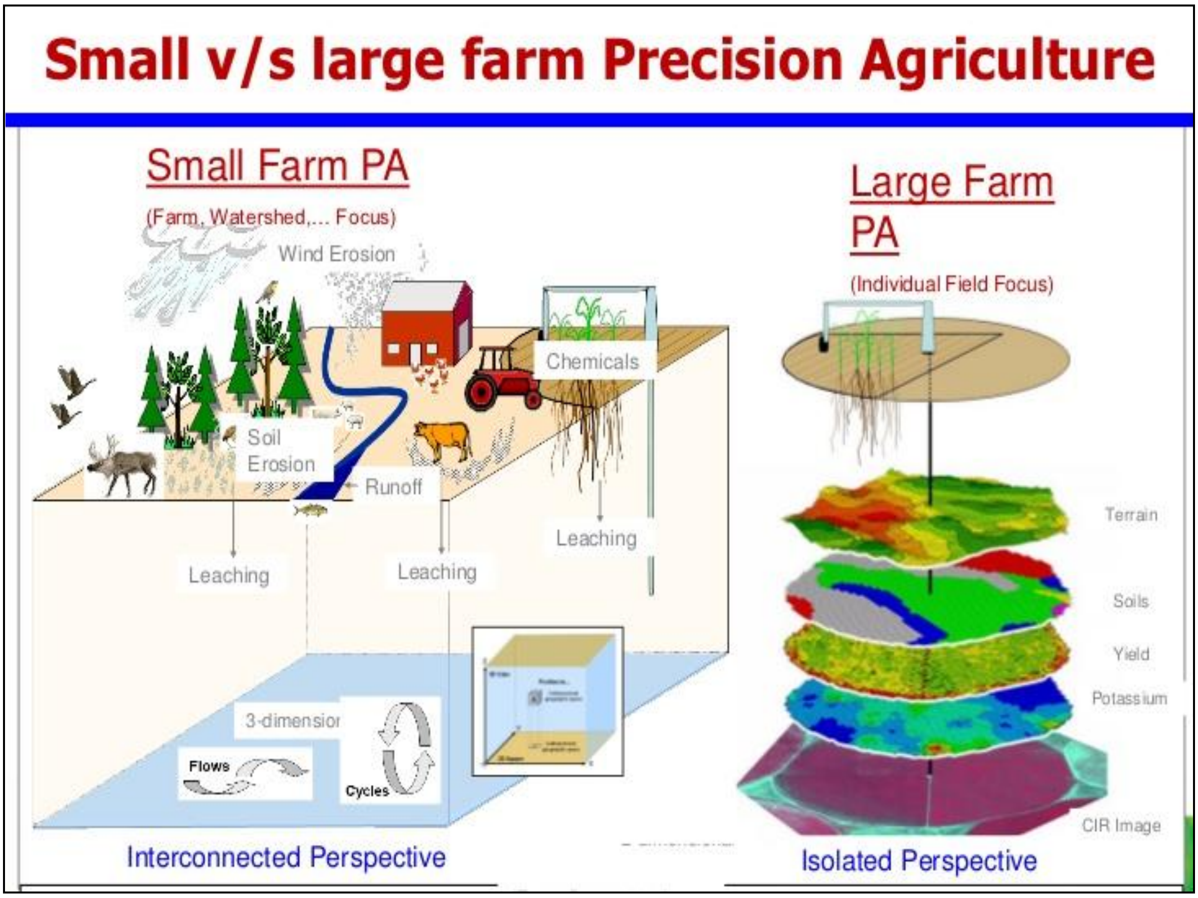
Managing variability:-

Variations occur in crop or soil properties within afield.

- These variations are noted, and often mapped.
- Management actions are taken as a consequence of the spatial variability within the field.
- Land leveling
- VRT
- Site specific planting
- Site Specific Nutrient Management
- Precision water management

- **Variable rate application:** Grid soil samples are analyzed in the laboratory and an interpretation of crop input (nutrient/water) needs is made for each soil sample. Then the input application map is plotted using the entire set of soil samples. The input application map is loaded into a computer mounted on a variable-rate input applicator. The computer uses the input application map and a GPS receiver to direct a product-delivery controller that changes the amount and/or kind of input (fertilizer/water), according to the application map.
- **Yield monitoring and mapping:** Yield measurements are essential for making sound management decisions. However, soil, landscape and other environmental factors should also be weighed when interpreting a yield map. Used properly, yield information provides important feedback in determining the effects of managed inputs such as fertilizer amendments, seed, pesticides and cultural practices including tillage and irrigation. Since yield measurements from a single year may be heavily influenced by weather, it is always advisable to examine yield data of several years including data from extreme weather years that helps in pinpointing whether observed yields due to management or climate induced.
- **Quantifying on farm variability:** Every farm presents a unique management puzzle. Not all the tools described above will help determine the causes of variability in a field and it would be cost-prohibitive to implement all of them immediately. An incremental approach is a wiser strategy, using one or two of the tools at a time and carefully evaluating the results and then proceeding further.

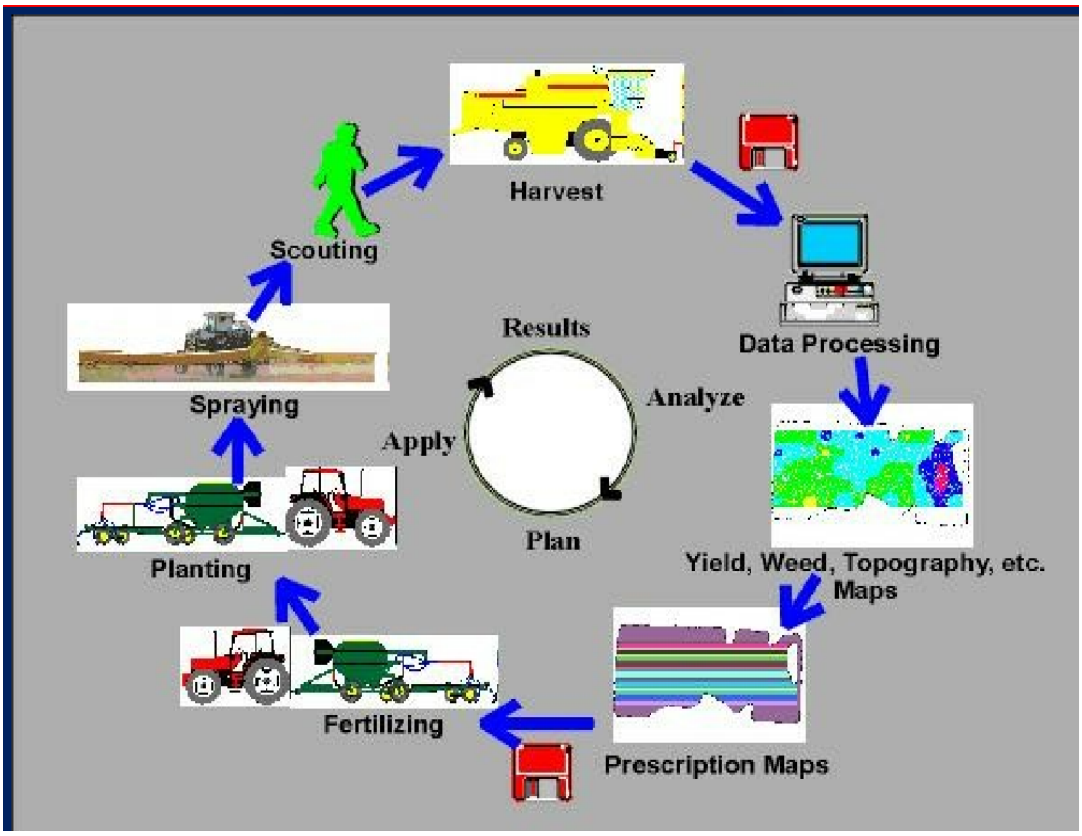
- **Flexibility:** All farms can be managed precisely. Small-scale farmers often have highly detailed knowledge of their landa based on personal observations and could already be modifying their management accordingly. Appropriate technologies. Here might make this task easier or more efficient. Larger farmers may find the more advanced technologies necessary to collect and properly analyze data for better management decisions.



Advantages of PFS to farmers

1. **Overall yield increase:** Precise selection of crop varieties, application of exact types and doses of fertilizers, pesticides and herbicides and appropriate irrigation meet the demands of crops for optimum growth and development. This leads to yield increase, especially in areas or fields where uniform crop management practices were traditionally practised.
2. **Efficiency improvement:** Advanced technologies, including machinery, tools and information, help farmers to increase the efficiency of labour, land and time in farming. In developed countries like United States, a mere 2 hours are sufficient to grow 1 ha of wheat or maize.
3. **Reduced production costs:** Application of exact quantities at the appropriate time reduces the cost of agrochemical inputs in crop production. In addition, the overall high yield reduces the cost per unit of output.
4. **Better decision-making in agricultural management:** Agricultural machinery, equipment and tools help farmers acquire accurate information, which is processed and analysed for appropriate decision making - in land preparation, seeding, fertilizer, pesticide and herbicide application, irrigation and drainage and post production activities.
5. **Reduced environmental impact:** Timely application of agrochemicals at an accurate rate avoids excessive residue in soils and water and thus reduces environmental pollution.

6. **Accumulation of farmers' knowledge for better management with time:** All PFS Field activities produce valuable field and management information and the data are stored in tools and computers. Farmers can thus accumulate knowledge about their farms and production systems to achieve better management.



Precision Farming Cycle

TOOLS and TECHNIQUES

In addition to mechanization, other tools and equipment (techniques) used in PF, are briefly presented.

1. Global Positioning System (GPS)

The GPS is a navigation system based on a network of satellites that helps users to record positional information (latitude, longitude and elevation) with an accuracy of between 100 and 0.01 m. GPS allows farmers to locate the exact position of field features, such as soil type, pest occurrence, weed invasion, water holes, boundaries and obstructions. There is an automatic controlling system, with light or sound guiding panel (DGPS), antenna and receiver. GPS satellites broadcast signals that allow GPS receivers to calculate their position. In many developed countries, GPS is commonly used as a navigator to guide drivers to a specific location.

The GPS provides the same precise guidance for field operations. The system allows farmers to reliably identify field locations so that inputs (seeds, fertilizers, pesticides, herbicides and irrigation water) can be applied to an individual field, based on performance criteria and previous input applications.

Specific advantages of GPS in farm operations include:

1. Farm machines are guided along a track hundreds of meters long making only centimetre scale deviations.
2. Rows are not forgotten and overlaps are not made.
3. Number of rows can be counted during work.
4. Tools and equipment can be operated in the same way from year to year.
5. It is possible to work at night or in dirt with precision.
6. The system is not affected by wind.
7. An additional recorder can store field information to be used in making a map.

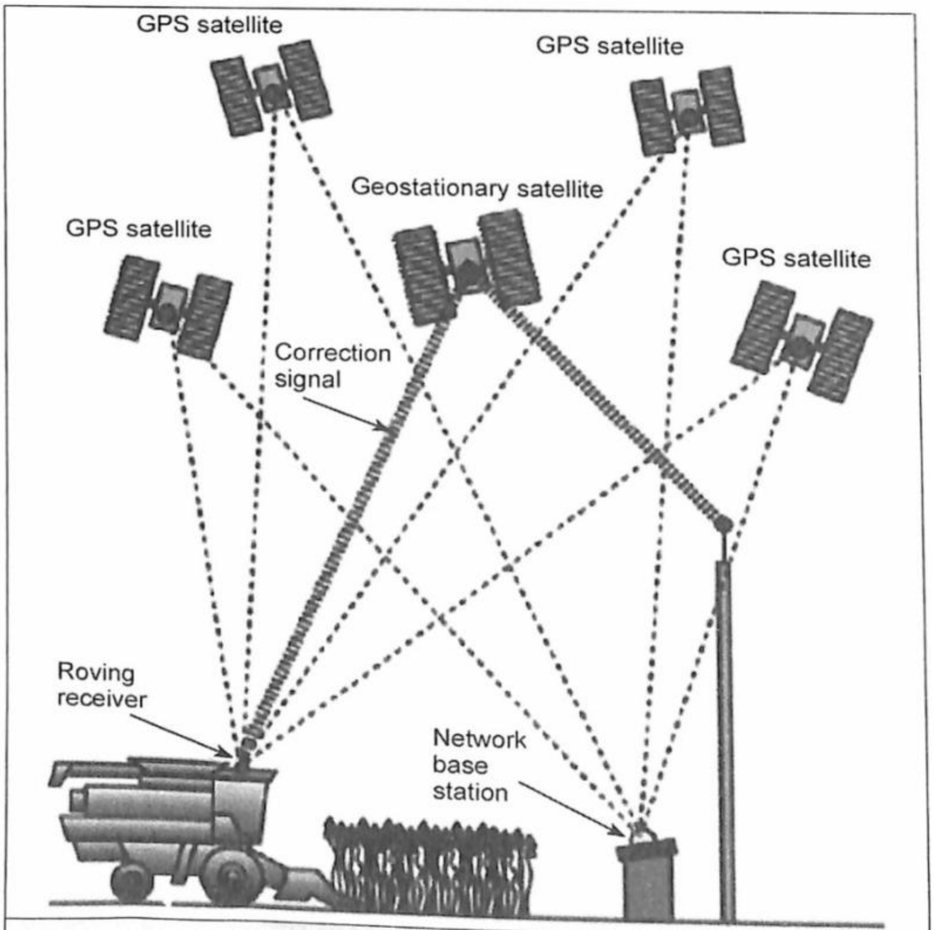


Fig 1.4. GPS for precision agriculture.

2. Sensor Technologies

Various technologies - electromagnetic, conductivity, photo-electricity, ultrasound- are used to measure humidity, vegetation, temperature, vapour, air etc. Remote sensing data are used to: distinguish crop species, locate stress conditions, discover pests and weeds and monitor drought, soil and plant conditions. Sensors enable the collection of immense quantities of data without laboratory analysis.

The specific uses of sensor technologies in farm operations are as follows:

1. Sense soil characteristics: Texture, structure, physical character, humidity, nutrient level and presence of clay.

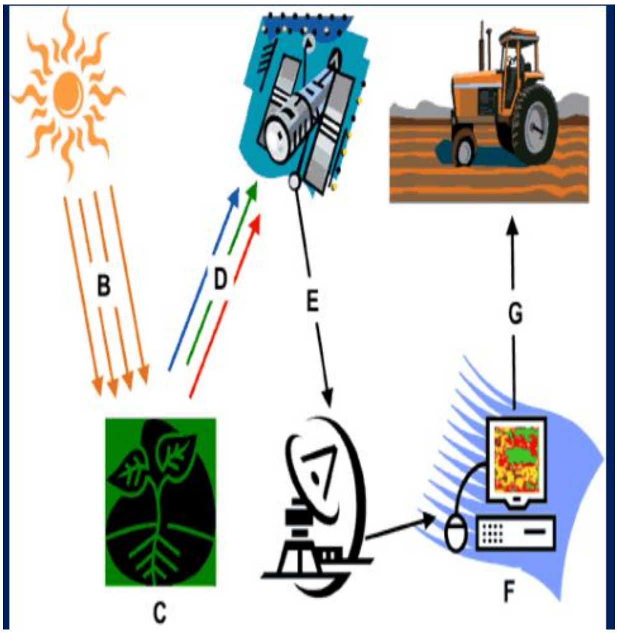
2. Sense colours to understand conditions relating to: Plant population, water shortage and plant nutrients.
3. Monitor yield: Crop yield and crop humidity.
4. Variable rate system: To monitor the migration of fertilizers and discover weed invasion.

3. Geographic Information System (GIS)

Use of GIS began in 1960. This system comprises hardware, software and procedures designed to support the compilation, storage, retrieval and analysis of feature attributes and location data to produce maps. GIS links information in one place so that it can be extrapolated when needed. Computerized GIS maps are different from conventional maps and contain various layers of information (yield, soil survey maps, rainfall, crops, soil nutrient levels and pests). GIS helps convert digital information to a form that can be recognized and used. Digital images are analyzed to produce a digital information map of the land use and vegetation cover. GIS is a kind of computerized map, but its real role is using statistics and spatial methods to analyze characters and geography. Further information is extrapolated from the analysis. A farming GIS database can provide information on: filed topography, soil types, surface drainage, subsurface drainage, soil testing, irrigation, chemical application rates and crop yield. Once analyzed, this information is used to understand the relationships between the various elements affecting a crop on a specific site.

4. Remote Sensing

- Remote sensing has been used in soil mapping, terrain analysis, crop stress, yield mapping and estimation of soil organic matter, but on a scale larger
- Than what is required for precision agriculture.
- Remote sensing at high resolution can be of great use in precision farming because of its capacity to monitor the spatial variability.
- The role of satellite remote sensing in PF is to acquire spatially- and temporally-distributed information to identify and analyze crop and soil variability within fields.



5. Variable-Rate Technologies (VRT)

Variable rate technologies (VRT) are automatic and may be applied to numerous farming operations. The VRT systems set the rate of delivery of farm inputs depending on the soil type noted in a soil map. Information extrapolated from the GIS can control processes, such as seeding, fertilizer and pesticide application and herbicide selection and application, at a variable (appropriate) rate in the right place at the right time. The VRT is perhaps the most widely used PFS technology.

6. Grain Yield monitors For Mapping

A monitor mounted on a combine continuously measures and records the flow of grain in the grain elevator. When linked with a GPS receiver, yield monitors can provide data for a yield map that helps farmers to determine the sound management of inputs, such as fertilizer, lime, seed, pesticides, tillage and irrigation.

CROP MANAGEMENT

Precision farming system employs the innovations and technologies described above. With satellite data, farmers have a better understanding of the variation in soil conditions and topography that influence crop performance within the field. Farmers can, therefore, precisely manage production factors, such as seeds, fertilizers, pesticides, herbicides and water control, to increase yield and efficiency.

The management scheme of typical PFS comprises following steps:

- Determine management zones to be applied with PFS.
- Establish yield goals.
- Carry out soil sampling and data interpretation.
- Make decisions regarding management of land preparations, varieties, fertilizers and other nutrients to achieve yield goals.
- Establish maps to discover the pest population: insects, diseases and weeds, using an integrated pest management (IPM) approach.
- Apply precision irrigation.
- Apply logging and automated record keeping.
- Monitor and establish yield maps, evaluate PFS response and identify strengths and weaknesses for future improvement.

DEVELOPING SYSTEM TECHNOLOGY FOR PF

Developing system technology for precision farming is shown in Fig 1.5. First of all, it is necessary to describe and understand the variability within and between fields. Field sensors with GPS and monitors for machine application make this easier. The next stage is to develop machines, which can be operated by remote control.

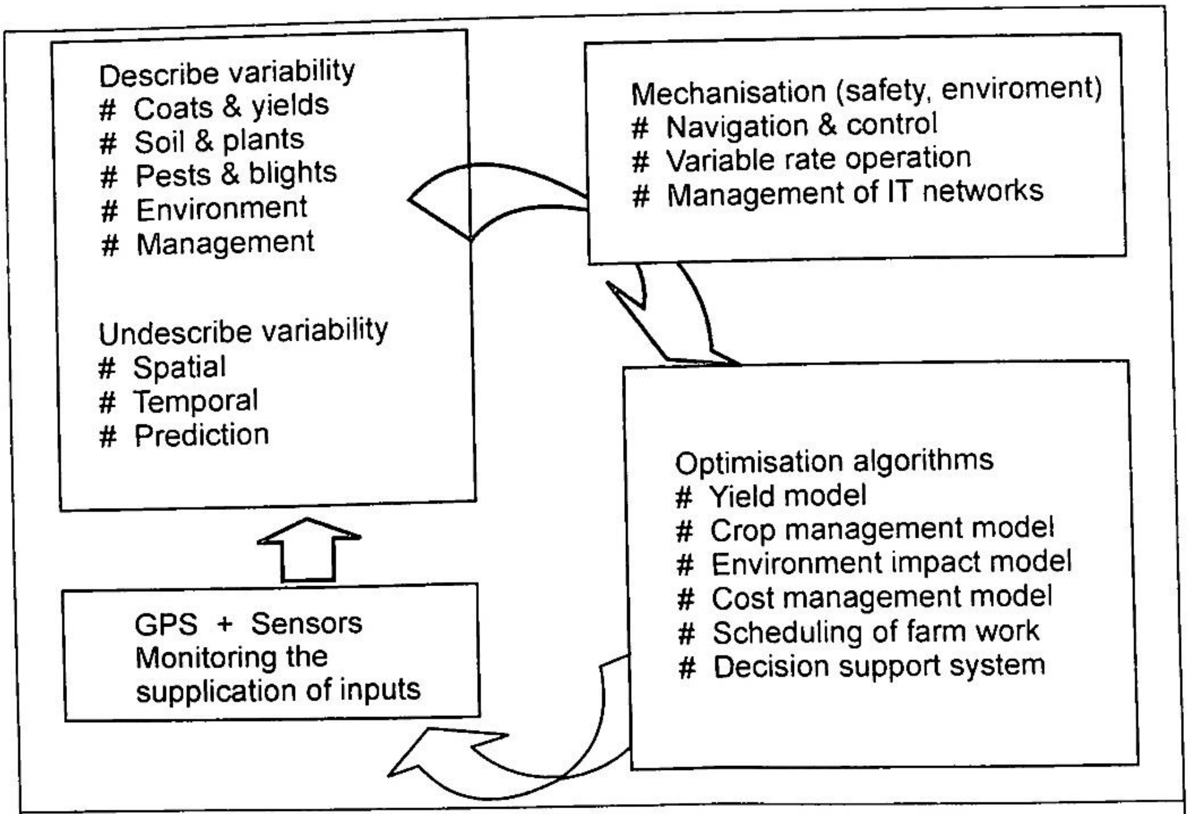


Fig 1.5. Development of PF technologies.

There are three steps and strategies in technology development for PF.

Step 1: is based on conventional farming technology, with intensive mechanisation to reduce the labour input.

Step 2: involves the development of mapping techniques.

Step 3: implies the maturity of wisdom-oriented technologies.

Scenario 1 is based on a "high-input and high-output" conventional strategy. Scenario 2 has a strategy for "low-input but constant-output". Scenario 3 aims at "optimized input- output" as the goal of precision farming. Advanced technology levels allow us to choose freely between these three scenarios. Effective regulations will encourage progress in precision farming.

Precision Farming Concerns for Indian Agriculture

Farmers in developed countries typically own large farms (10-1000 ha or more) and crop production systems are highly mechanized in most cases. Large farms may comprise several fields in differing conditions. Even within a relatively small field (<30 ha) the degree of pest infestation, disease infection and weed competition may differ from one area to another.

In conventional agriculture, although a soil map of the region may exist, farmers still tend to practice the same crop management throughout their fields: crop varieties, land preparation, fertilizers, pesticides and herbicides are uniformly applied in spite of variation. Optimum growth and development are thus not achieved. Furthermore, there is inefficient use of inputs and labour. Availability of information technology since the 1980s provides farmers with new tools and approaches to characterize the nature and extent of variation in the fields, enabling them to develop the most appropriate management strategy for a specific location, increasing the efficiency of input application.

Practical Problems in Indian Agriculture

Precision agriculture has been mostly confined to developed countries. Reasons of limitations of its implementation in developing countries like India are:

1. Small land holdings.
2. Heterogeneity of cropping systems and market imperfections.
3. Complexity of tools and techniques requiring new skills.
4. Lack of technical expertise knowledge and technology (India spends only 0.3% of its agricultural GDP in research and development).
5. Infrastructure and institutional constraints including market imperfections.
6. High cost.

In India, major problem is the small field size. More than 58% of operational holdings in the country have size less than 1 ha. Only in states of Punjab, Rajasthan, Haryana and Gujarat more than 20% of agricultural lands have operational holding size of more than 4 ha. There is scope of implementing precision agriculture for crops like rice and wheat especially in states of Punjab and Haryana. Commercial as well as horticultural crops show a wider scope for precision agriculture.

In India, broadly two types of agriculture *viz*., high input agriculture characterized by provision of assured irrigation and other agricultural inputs and subsistence farming, which is confined mostly to rainfed or Dryland regions are prevalent. Crop yields are very low (near 1.0/ha) and good potential exists for increasing productivity of rainfed cropping systems.

Steps to be taken for Implementing PF in India

In the present situation, potential of precision agriculture in India is limited by the lack of appropriate measurement and analysis techniques for agronomically important factors. High accuracy sensing and data management tools must be developed and validated to support both research and production. Limitation in data quality/availability has become a major obstacle in the demonstration and adoption of the precision technologies. Adoption of precision agriculture needs combined efforts on behalf of scientists, farmers and the government.

The following methodology could be adopted in order to operationalize precision farming in the country:

1. Creation of multidisciplinary teams involving agricultural scientists in various fields, engineers, manufacturers and economists to study the overall scope of precision agriculture.

2. Formation of farmer's co-operatives since many of the precision agriculture tools (GIS, GPS etc.) are costly.

3. Government legislation restraining farmers using indiscriminate farm inputs and thereby causing ecological/environmental imbalance would induce the farmer to go for alternative approach.

4. Pilot study should be conducted on farmer's field to show the results of precision agriculture implementation.

5. Creating awareness amongst farmers about consequences of applying imbalanced doses of farm inputs like irrigation, fertilizers, insecticides and pesticides.

Realizing the potential of space technology in precision farming, the Department of Space, Government of India has initiated eight pilot studies in well-managed agricultural farms of the ICRISAT, the Indian Council of Agricultural Research and the Agricultural Universities, as well as in farmers' fields. Pilot studies aim at delineating homogeneous zones with respect to soil fertility and crop yield, estimation of potential yield, yield gap analysis, monitoring seasonally-variable soil and crop conditions using optical and microwave sensor data and matching the farm inputs to bridge the gap between potential and actual yield through Spatial Decision Support Systems (SDSS). The test sites are spread over a fairly large area across a cross section of agro-climatic zones of the Indian sub-continent and cover some of the important crops like wheat, rice, sorghum, pigeon pea, chickpea, soybean and groundnut.

The next step would be to generate detailed-level information on soil resources addressing potentials and limitations of individual fields since except for states like Punjab, Haryana, Madhya Pradesh and Maharashtra where fields size is quite large, practically individual field could be treated as a homogenous management unit for the purpose of precision farming.

Agriculture has continued to be the cornerstone of Indian economy. In the years to come, precision agriculture may help the Indian farmers to harvest the fruits of frontier technologies without compromising the quality of land and produce. Adoption of such a novel technique would trigger a techno-green revolution in India which is the need of the hour.

CHAPTER - 2

GEO-INFORMATICS

INTRODUCTION

Natural resources provide the basis for human survival and development. Because of increasing demands on these resources and decrease in its availability, there is urgent need for coordinated approach to their sustainable management. Sustainable use and management of natural resources demands an interdisciplinary approach and sound knowledge on each specific resource, as well as on the ecological, economic and social perspectives related to their use.

Natural resource management activities seek to increase agricultural productivity through adoption of practices that maintain the long-term ecological and biological integrity of natural resources. Hence, towards achieving the goal of livelihood security, it is important to conserve the natural resource bases and improve economic viability of farming.

Geo-informatics deal with handling digital geo-information, such as collecting (mainly through remote sensing and field investigation), processing, storing, archiving, preservation, retrieving, transmitting, accessing, visualization, analyzing, synthesizing, presenting and disseminating geo-information.

Geo-informatics is a modem technology that provides accurate means of measuring the extent and pattern of changes and other related information about environment (Boakye *et al.*, 2008). The term geo-information consists of two main words: geo means earth’s surface or the environment and informatics stands for fact about something. Thus, geo-information is the science and technology of communicating the evidences about the state of the earth’s surface.

It is known for technological robustness to assess spatial and temporal change occurring on the earth’s surface. In the recent years, geo-informatics has been used to provide electronic representation about earth’s surface and man’s interaction with the earth. Geo-informatics has emerged, in the last two decades, as an exciting multi-disciplinary endeavor, spanning such areas as geography, cartography, remote sensing, image processing, environmental and computer aspects of environmental studies.

Geo-informatics may be broadly defined as the combination of technology and science dealing by means of the spatial information, its acquisition, its qualification and classification, its processing, storage and dissemination. Geo-informatics is an integrated tool to collect process and generate information from spatial and non-spatial data. Geo-informatics is an appropriate blending of modules like remote sensing (RS), global positioning system (GPS), geographical information system (GIS) and relational data base management system (RDBMS).

In general, the science and technology of geo-informatics encompasses application of remote sensing and GIS data and methodology. The GIS is an acronym that stands for geographic information systems while the remote sensing data are those data collected through various devices without human (researcher) contact with field. The GIS, in actual sense, is not a new development, it is only recently that it has gained widespread acceptance as a tool to assess both spatial and non-spatial issues.

The GIS was initially referred to as the management of information with a geographic component primarily stored in vector form with associated attributes. This definition quickly became too limiting with advances in software and recent digital ideas about earth. The GIS involves spatiotemporal data analysis using software, hardware, people and approaches to acquire, store, update and manipulate for presenting information about the human environment.

The GIS could be seen as a digital computing environment and human interactions with the environment. For environmental change analysis, the GIS uses both remote sensing and non-remote sensing data. Non-remote sensing data may include field observation, topographic, geological and edaphic data. It may also include terrain data, as well as socio-economic survey data and reports relating to human environmental relation. Though non-remote sensing data are those data acquired by other means than remote sensing approach, they are sometimes used in geo-informatics analysis, for identification and interpretation of environmental features and their significant change over time. In general, it has been shown in several other recent studies that geo-informatics is not only good for preparing precise environmental change assessment, but also for observing changes at regular intervals of time, it is cost and time effective.

Recent advances in **geo-informatics** have created new opportunities and challenges in applying geo-informatics to agriculture monitoring, assessment and decision making. Geo-informatics are incredibly helpful in being able to map and project current and future fluctuations in precipitation, temperature, crop output and more. By mapping geographic features (potential), scientists and farmers can work together to create more effective and efficient farming techniques for increasing food production in parts of the world that are struggling to produce enough for the people around them. GIS can analyze soil data combined with historical farming practices to determine ideal crops for different agro-climates and how to maintain soil productivity for sustainable agriculture.

Application of geo-informatics includes:

- Land use mapping and farm planning,
- Assessing crop variability and performance tracking,
- Plant nutrition assessments,
- In-field plant vigour zone delineation,
- Irrigation and drainage assessments,
- Storm, frost or fire crop damage insurance assessments,
- Crop yield management, monitoring and prediction,
- Impacts of soil compaction,
- Pest and disease management,
- Spatial management systems and databases,
- Sustainable agricultural engineering and many more.

Therefore, geo-informatics is playing an increasing role in agriculture throughout the world by helping farmers increase production, reduce costs and manage their land more efficiently. While natural inputs in farming cannot be controlled, they can be better understood and managed with geo-informatics tools.

Climate change poses a serious challenge for natural resource management. As temperatures, rainfall patterns and disturbance regimes change and sea levels rise, ecosystems are being transformed. Some species of plants and animals are already shifting their distributions in response to climate change and changes in phenology are disrupting ecological relationships and species interactions. In the present context of climate change, there is possibility of decrease in crop yield in various regions of the world.

Geo-informatics widely believed that it can play an increasingly important role in natural resource management in face of climate change. Global climate change and shrinking resources have compelled to develop our understanding about the dependence on the dynamic and complex earth system and its environment. Geo-informatics enables to take advantage of the unprecedented amount of digital geo-database and computational capability through electronic networks. Thus, it facilitates multi/interdisciplinary research and capacity to understand the earth as dynamic and complex system to manage natural resources in a sustainable way.

Agro-geo-information, the agricultural-related geo-information, is the key information in the agricultural decision making and policy formulation process. Agro-geo-informatics, a branch of geo-informatics, is the science and technology about handling digital agro-geo-information, such as collecting (mainly through remote sensing and field investigation), processing, storing, archiving, preservation, retrieving, transmitting, accessing, visualization, and analyzing, synthesizing, presenting and disseminating agro-geo-information. Recent advances in geo-informatics have created new opportunities and challenges in applying agro-geo-informatics to agriculture monitoring, assessment and decision making. The International Conference on Agro-geo-informatics is a major venue for professionals and students to exchange ideas, research results, professional experiences and future vision in the fields of geo-information science, remote sensing, and their applications in agriculture.

GEOINFORMATIC CONCEPT, TOOLS AND PRINCIPLES

Geo-informatics is a new discipline concerned with the modeling of spatial data and the processing techniques in spatial information systems. It is a multidisciplinary science that integrates the technologies and principles of digital cartography, remote sensing, photogrammetry, surveying, global positioning systems (GPS), geographic information systems (GIS) and automated data capture systems using high-resolution geo-referenced spatial information from aerospace remote sensing platforms.

Thus, geo-informatics provide tools that allows for the processing, manipulation and analysis of spatial data into information tied explicitly to, and used to make decisions, about portions of the earth and environmental problems. The techniques can include all stages of data collection, data processing, data base management, data analysis and modeling and data presentation to end use in the creation of maps and spatial information products. We can understand the concepts clearer when we consider the principles of the following component sub-fields:

- **Cartographic principles** involve map, map design and map visualization and production in analogue or digital computer environment.
- **Remote sensing** involves the acquisition of spatial data of the environment without physical contact with the objects or features sensed by using electromagnetic energy radiation, interaction and detection principles in analogue or digital formats.
- **Photogrammetric principles** involve the art and scientific processes of obtaining reliable information about the physical environment by interpreting remotely sensed aerospace data (aerial photographs and satellite imageries) in analogue or digital formats.
- **Surveying principles** involve the adroit use of fundamental methods (processes) and technologies (instruments) to determine the precise position and dimensions of points (features) on the earth’s surface and the presentation of the results in analogue or digital format.
- **Global positioning systems (GPS)** involve precise surveying (determination of position dimensions of points) by applying resection and satellite constellation principles and the presentation of the results in analogue (maps, tables) or digital formats.
- **Geographic information systems (GIS)** principles involve data gathering, data processing, database management, data modeling and visualization in a digital environment.
- **Automated data capture systems** include multi-spectral remote sensing processes, GPS data, map digitization and scanning and computer input and output technologies.

RELEVANCE OF GEOINFORMATICS IN AGRICULTURE

Geo-informatics, and in particular remote sensing, geographic information systems and global positioning systems technologies have become indispensable in modem agriculture. Advances in remote sensing have revolutionized the gathering of information on agricultural activities, including land-use, soil condition, weather condition etc. that are essential for site characterization and consequent site selection for farming. For instance, the biophysical components of the soil and environment can readily be deduced from information interpreted from satellite imagery, which will in turn serve as the basis for determining site suitability for specific agricultural purposes when duly analyzed in a geographic information system environment.

Remote Sensing System

Since remote sensing techniques have the unique capability of recording data in visible as well as invisible (including ultraviolet, reflected infrared, thermal infrared and microwave) parts of the electromagnetic spectrum, it enables us see beyond the capability of the human eye. For instance, trees or plants, which are affected by diseases or insect attack, can be detected by remote sensing technique much before human eye sees them. Such early detection is vital for the application of remedial measures. Remote sensing techniques are also useful in the determination the spatial distribution of plant status (health or efficiency) and corollary expected yield by measuring the greenness of the field.

Detection, identification, measurement and monitoring of agricultural phenomena are predicated on the assumption that agricultural landscape features (such as crops, livestock, and crop infestation and soil anomalies) have consistently identifiable signatures on the type of remote sensing data. These identifiable signatures are a reflection of crop type, state of maturity, crop density, crop geometry, crop vigour, crop moisture, crop temperature and soil moisture as well as soil temperature. Detection of features to a large extent depends on the type of sensor used and the portion of the electromagnetic spectrum used in sensing. Areas of specific application of remote sensing in agricultural surveys include:

1. Applicable to Crop Survey

Crop identification, area under crop, crop vigour, crop density, stage of crop growth, crop growth rates, yield forecasting, actual yield, soil fertility, effects of fertilizers, toxicity on crops, water quality, irrigation requirement, pests and diseases incidence, water availability and location of canals.

2. Applicable to Range Survey

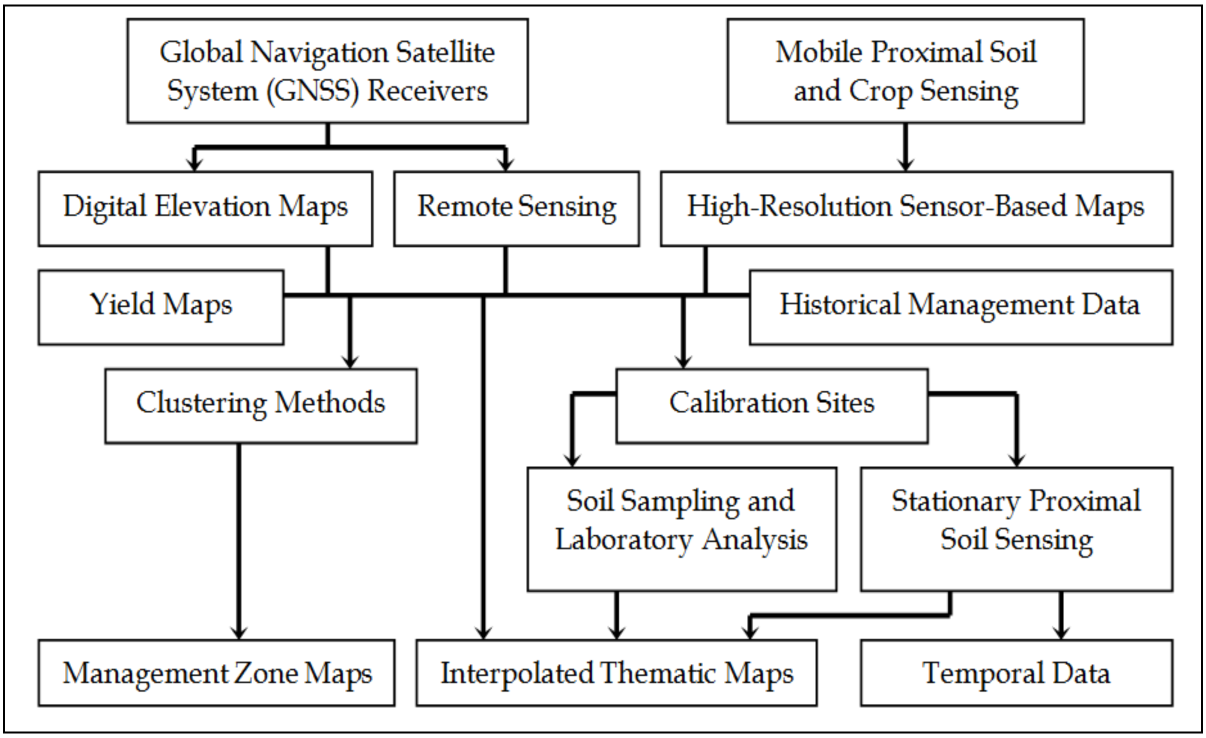
Delineation of forest types, condition of range, carrying capacity, forage, time of seasonal change, location of water, water quality, soil fertility, soil moisture, insects infestations, wild life inventory.

3. Applicable to Livestock Survey

Cattle population, sheep population, pig population, poultry population, age sex distribution, distribution of animals, animal behavior, disease identification, types of farm buildings.

Geographic Information System

Geographic information system is another geo-informatics technique that is quite relevant in agricultural development. There are numerous definitions of geographic information systems in the literature. For our purpose geographic information system can be defined as a system for capturing, storing, checking, manipulating, analyzing and displaying data, which are spatially referenced to the earth. Thus, a true geographic information system is designed to accept, organize, statistically analyze and display diverse types of spatial information that are geographically referenced to a common coordinate system of a particular projection and scale.



Geographic information system comprises five major components and three main subsystems.

Main components of geographic information systems are:

1. The hardware which include a host computer, data acquisition device(s) such as digitizer, scanner, digital image processing system, digital theodolite, analytical and digital photogrammetric plotter and output device(s) such as plotter, printer, high resolution screen among others.
2. The spatial database, containing the objects of interest, including the objects' geometric (position and spatial relationships) and thematic data in structured form.
3. Software for the acquisition, manipulation and management of data in the database.
4. Procedures (conventions and algorithms to guide its operations).
5. Expertise in terms of skilled human operators.

The main subsystems of a geographic information system are:

1. Data acquisition subsystem for collecting and/or processing spatial data from existing maps, remotely sensed data, aerial photography, land survey among others.
2. Database management subsystem for the storage, retrieval, manipulation and analysis of data.
3. Visualization and reporting subsystem for displaying database query results in graphic and/or alphanumeric form.

Geographic information systems are needed for the collection, analysis and management of agricultural data for the purpose of timely decision-making. Database will contain layers of spatial data from remote sensors, existing maps or field surveys. Information system has the capability to integrate diverse data sets from these diverse sources and ensure compatibility of the various data sources.

Geographic information system analysis, basically, includes rectification for geometrical correction of digital image data, spatial and spectral enhancements, classification and visualization of digital images. In this way, information on vegetation and soil types, plant stress, crop infestation etc. can be harnessed.

Geographic information system modeling capability through analytical functions like overlay, cluster analysis, clumping functions, reclassification, indexing and spatial searching provides information on which agricultural land-use planning can be based. For instance, spatial models will allow for the production of fertility and pest infestation maps as well as maps of spatial distribution of plant nutrients and productivity potential (expected yield). Yield can be achieved with geographic information system technology when yield and moisture sensors are combined with global system to provide geo-referenced location specific yield data for the generation of yields maps.

Global Positioning System

- The global positioning system is yet another geo-informatics tool required for agricultural development.
- Global positioning system enables accuracy in the location of terrain features.
- It receives signals and positioning information from a series of satellites in space.
- Global positioning system is basically for the geo-referencing of terrain attributes.
- Geo-referencing is done because location serves as a means to link terrain data collected by different mapping disciplines through overlay analysis.
- Therefore, global positioning system capability is necessary in the integration of the diverse agricultural data sets from diverse sources, in geographic information system environment.
- Spatial data collected by global positioning system can be automatically recorded with the geographic information system programme.
- In addition, the use of global positioning system allows for the accurate location of soil sample points within a field and hence the determination of physical, chemical and biological characteristics of the soil at different locations.
- Consequently, fertility levels can be mapped across the field to serve as a basis for the application of farm inputs.
- The global positioning system is also required to establish the accurate location of yield data collected. It is thus needed for the production of yield maps and for yield monitoring.

GEOINFORMATICS AND PRECISION AGRICULTURE

Integration of remote sensing, geographic information system and global positioning system technologies has taken agriculture to the space age. This has given rise to a new concept variously termed precision agriculture (PA), precision farming (PF) or site specific crop management (SSCM).

Precision farming is an information and technology-based agricultural management system that identifies analyses and manage site-soil spatial and temporal variability within paddocks (farm fields) for optimum yield or productivity, profitability, sustainability and protection of the environment. The concept identifies the agricultural suitability of land parcels from the spatial variability of soil fertility status and other land qualities (water and oxygen availability and retention capacity, plant root conditions, salt hazards and topographic conditions).

The concept recognizes that variations occur within agricultural fields and thus seeks to identify the spatial location and extent of such variations.

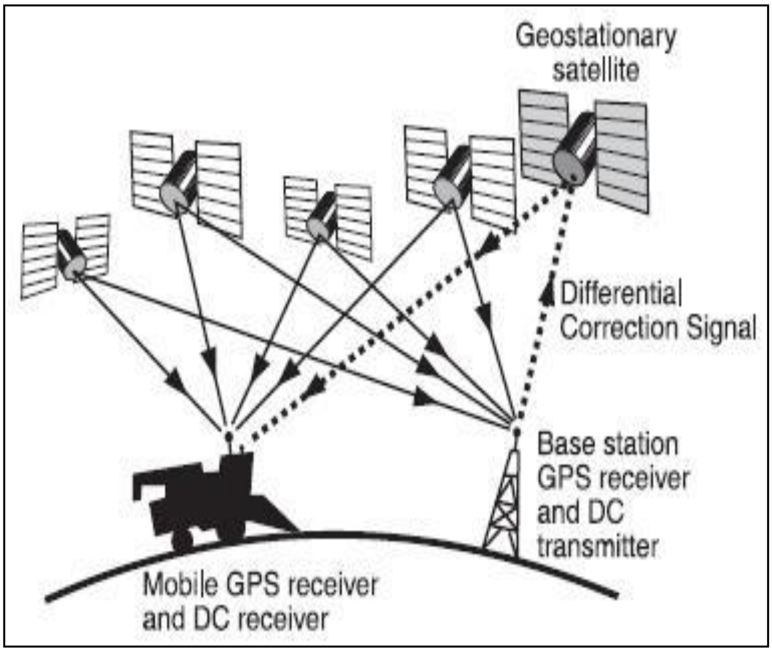
The objective is to assess the causes of such variations to ensure that the right decision is taken with regards to type of crops to be cultivated, time to cultivate and management practices required. Precision farming implies doing the right thing, in the right way, at the right place and at the right time.

Components of precision farming are remote sensing, geographic information systems (GIS), differential global positioning system (DGPS) and variable rate applicator (VRA).

Remote sensing techniques play a pivotal role in precision farming by providing continuous data on spatial and temporal variability in agricultural fields. Sensors provide data on soil properties, crops condition and yield, fertilizer flow, as well as weed detection.

GIS is a potential tool for handling voluminous remotely sensed data and has capability to support spatial statistical analysis, presentation of spatial data in the form of a map, as well as storage, management, modeling of input data and presentation of model results.

Differential global positioning system (DGPS) is used for precise location of activities. Global positioning system (GPS) device makes use of a series of military satellites that identify the location of farm equipment within a meter of an actual site in the field. This is required to accurately link location and result of soil samples to a soil map, prescribe farm inputs to fit soil properties, adjust tillage to suit field conditions and determine yield data across the field.



Variable rate applicator is used to operationalize precision farming at the farm level. **Variable rate technology (VRT)** consists of the machines and systems used to apply a desired rate of crop production materials at a specific time and by implication, a specific location. The components are a control computer, a locator and an actuator. The control computer co-ordinates field operations with the aid of database in its memory. Based on the desired activity, the computer from the locator (which holds a GPS) receives the current location of equipment and issue command to the actuator, which does the input application.

The operational procedure of precision farming requires geo-referenced point data obtained with grid spacing with minimal number of observations. Patterns are obtained by geo-statistical interpolation of these point data. Techniques involves the integration of databases or sensors that provide information needed to develop input response to site- specific conditions, positioning capabilities to know where equipment is located and real-time mechanism for controlling crop production inputs. The new paradigm is being adopted in the United States and Europe since the middle of 1990s.

CROP DISCRIMINATION

Currently computers are being used for automation and to expand **decision support systems (DSS)** for the agricultural research. Recently, **geographic information systems (GIS) and remote sensing technology** has come up with a capable role in agricultural research, predominantly in crop yield prediction in addition to crop suitability studies and site specific resource allocation. Role of geo-informatics to discriminate different crops at various levels of classification, monitoring crop growth and prediction of the crop yield has been briefly presented.

Remote sensing is an efficient technology and worthy source of earth surface information, as it can capture images of reasonably large area on the earth. Due to advancement in the sensor technologies, there is availability of high spatial as well as spectral resolutions imageries and also non-imaging spectro-radiometer. With the use of these imaging and non-imaging data, we can easily characterize the different species.

Different crops show distinct phonological characteristics and timings according to their nature of germination, tillering, flowering, boll formation (cotton), ripening etc. Even for the same crop and growing season, the duration and magnitude of each phonological stage can differ between the varieties, which introduce data variability for crop type discrimination with imaging systems. Agricultural crops are significantly better characterized, Classified, modeled and mapped using **hyper-spectral data**.

SPECTRAL FEATURES FOR CROP CLASSIFICATION

Spectral characteristics of green vegetation have very noticeable features. Two valleys in the visible portion of the spectrum are determined by the pigments contained in the plant. Chlorophyll absorbs strongly in the blue (0.4-0.5um) and red (0.68 um) regions, also known as the chlorophyll absorption bands. Chlorophyll is the primary photosynthetic pigment in green plants. This is the reason for the human eye perceiving healthy vegetation as green. When the plant is subjected to stress that hinders normal growth and chlorophyll production, there is less absorption in the red and blue regions and the amount of reflection in the red waveband increases.

The **spectral reflectance signature** has a dramatic increase in the reflection for healthy vegetation at around 0.7 um. **In the near infrared (NIR)** between 0.7 um and 1.3 um, a plant leaf will naturally reflect between 40 and 60 per cent, the rest is transmitted, with only about 5 per cent being adsorbed. For comparison, the reflectance in the green range reaches 15-20 per cent. This high reflectance in the NIR is due to scattering of the light in the intercellular volume of the leaves mesophyll. Structural variability in leaves in this range allows one to differentiate between species, even though they might look the same in the visible region. Beyond 1.3 um, the incident energy upon the vegetation is largely absorbed or reflected with very little transmittance of energy. Three strong water absorption bands are noted at around 1.4, 1.9 and 2.7 um and can be used for plant-water content estimation.

2.5.1. Band Selection

Band selection is one of the important steps in hyper-spectral remote sensing. 1 here are two conceptually different approaches of band selection like unsupervised and supervised. Due to availability of hundreds of spectral bands, there may be same values in several bands which increase the data redundancy. To avoid the data redundancy and to get distinct features from available hundreds of bands, we have to choose the specific bands by studying the reflectance behaviour of crops.

2.5.2. Narrowband Vegetation Indices

Spectral indices assume that the combined interaction between a small numbers of wavelengths is adequate to describe the biochemical or biophysical interaction between light and matter. The simplest form of index is a **simple ratio (SR)**, a potentially greater contribution of **hyper-spectral systems** is their ability to create new indices that integrate wavelengths not sampled by any broadband system and to quantify absorptions that are specific to important biochemical and biophysical quantities of vegetation. Examples include most of the pigment-oriented indices, all indices formulated for the red edge, several water absorption indices and indices that use three or more wavelengths. Vegetation properties measured with **hyper-spectral vegetation indices (HVIs)** can be divided into three main categories: (1) structure, (2) biochemistry and (3) plant physiology/stress.

Structural properties: These properties include fractional cover, green leaf biomass, leaf area index (LAI), senesced biomass and fraction absorbed photo-synthetically active radiation (FPAR). Majority of the indices developed for structural analysis were formulated for broadband systems and have narrowband, hyper-spectral equivalents.

Biochemical properties: It includes water, pigments (chlorophyll, carotenoids, and anthocyanin), other nitrogen-rich compounds (proteins) and plant structural materials (lignin and cellulose).

Physiological and stress indices: It measure delicate changes due to a stress-induced change in the state of xanthophyll's, changes in chlorophyll content, fluorescence or changes in leaf moisture. In general, biochemical and physiological/stress indices were formulated using laboratory or field instruments ($\leq$ 10 nm spectral sampling) and are targeted at very fine spectral features.

Narrowband vegetation indices can be used as potential variables for crop type discrimination. Best vegetation indices of different category (Table 2.1) to discriminate the seven crop types which are greenness/leaf pigment indices (ARVI, EVI, NDVI and SGI), chlorophyll red edge indices (RENDVI and VOG-1), light use efficiency indices (SIPI and PRI) and leaf water indices (DWSI and NDWI).

IMPORTANCE OF HYPERSPECTRAL REMOTE SENSING

Now a day, hyper-spectral remote sensing has stepped into a new stage all over the world. Several advanced hyper-spectral imaging systems developed are playing important role for agricultural application. **Hyperion imaging spectrometer** on board the Earth Observing One (EO-1) satellite has provided significantly enhanced data over conventional multi-spectral remote sensing systems. Hyper-spectral narrowband (HNBs) and hyper-spectral vegetation indices (HVIs) derived from EO-1 and field spectral measurements in the 400-2500 nm spectrum allow us to study very specific characteristics of agricultural crops. Non imaging sensors as discussed earlier also give fine spectral signatures with approximate 1-10 nm sampling rate, which is very effective for distinct feature identification. Availability of hyper-spectral data overcomes the constraints and limitations of low spectral resolution (multispectral).

Both spatial and spectral information are necessary for better discriminations of species. Hyper-spectral data gives detailed information about crops but it is necessary to select appropriate bands, Narrowband vegetation indices plays important role for mapping plant biophysical and biochemical properties of agricultural crops (BB-PACs). Combination of spatial and spectral feature can be used effectively to discriminate the crops types but available hyper-spectral imageries have not provided good spatial resolution which doesn't give proper spatial information. Hence, we need to include both, good spatial resolution and hyper-spectral imageries for better information extraction.

TABLE : Narrowband vegetation indices.

Sr. No.	Index	Acronym	Formula
1.	Normalised difference vegetation index	NDVI	(R864 - R671)/(R864 + R671)
2.	Simple ratio	SR	(R864/R671)
3.	Enhanced vegetation index	EVI	2.5 (R864 -R671)/(R864 + 6 X R671) - 7.5 X R467 + 1)
4.	Atmospherically resistant vegetation index	ARVI	(R864 - (2 X R671) - R467)/ (R864 + (2 X R671-R467)
5.	Sum green index	SGI	(R508 + R518 + R528 + R538 + R549 + R559 + R569 + R579 + R590 + R600/10)
6.	Red edge normalised difference vegetation index	RENDVI	(R752 - R701)/(R752 + R701)
7.	Vogelmenn red edge index	VREI	(R743/R722)
8.	Structure intensive pigment index	SIPI	(R803 - R467)/(R803 + R681)
9.	Photochemical reflectance index	PRI	(R529- R569)/(R529 + R569)
10.	Disease water stress index	DWSI	(R803/R1598)
R — Reflectance of the closest hyper ion bands to the original wavelength formulations.			

CHAPTER - 3

REMOTE SENSING

INTRODUCTION

Remote sensing techniques play an important role in crop identification, crop area and production estimation, disease and stress detection, soil and water resources etc. Remote sensing applications have become very important for making macroeconomic decisions related to food security, poverty alleviation and sustainable development in the country.

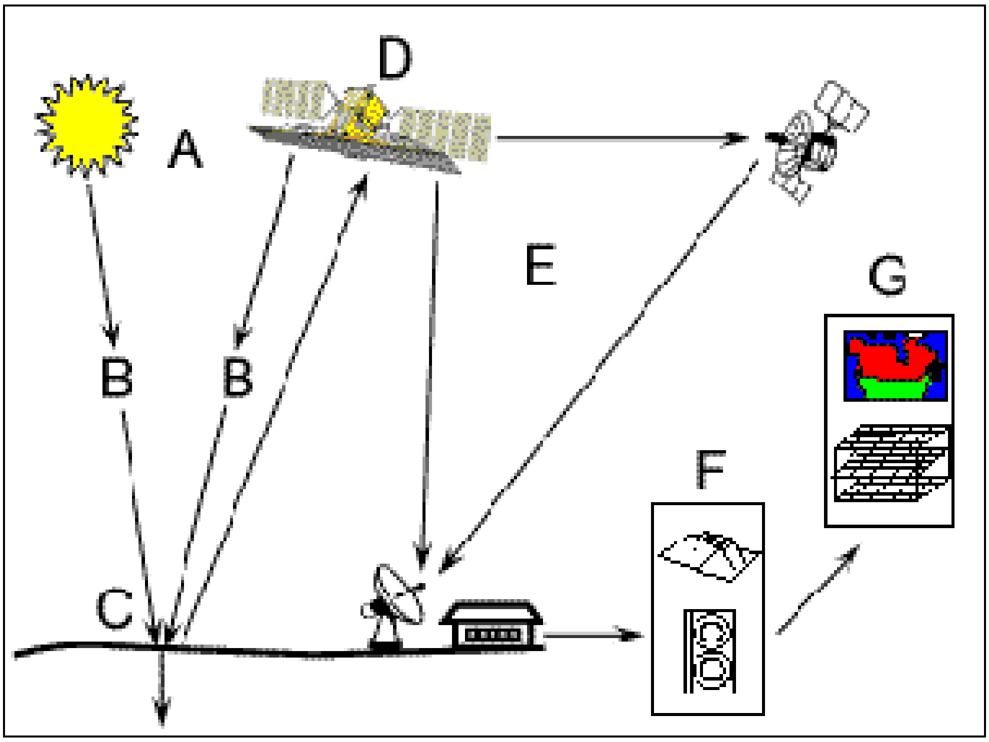
Origin of remote sensing:

The advent of aerial photography which is the origin of remote sensing techniques have provided valuable information on the earth resources. The remote sensing techniques ranges between very short wavelengths at which gamma rays are emitted to long wavelengths at which radar operates. As compared to conventional photography which is limited to the visible band of the spectrum, the aerial photography provide much more information about an area and object.

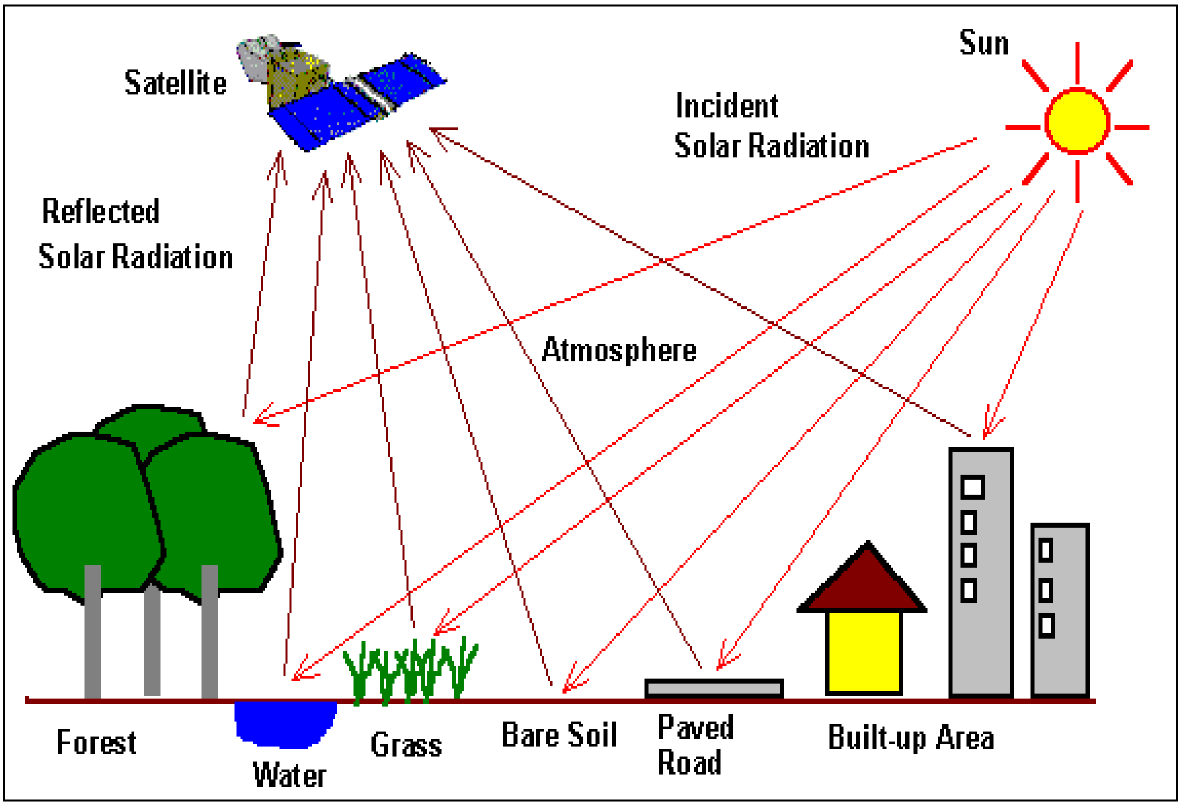
WHAT IS REMOTE SENSING?

Remote sensing is the science (and to some extent, art) of acquiring information about the earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing and applying that information. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. Remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.

Elements involved in remote sensing



1. **Energy source or illumination (A).** The first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2. **Radiation and the atmosphere (B).** As the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.
3. **Interaction with the target (C).** Once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4. **Recording of energy by the sensor (D).** After the energy has been scattered by or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.
5. **Transmission, reception and processing (E).** The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).
6. **Interpretation and analysis (F).** The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
7. **Application (G).** The final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information or assist in solving a particular problem.



Remote Sensing Process

Definitions:

- Remote sensing can be defined as the science, technology and art of acquiring information about an object which are not in physical contact with the object itself.
- Remote sensing is the technique of collecting and interpreting the information about an object or phenomena without any physical contact with the object.
- Remote sensing is defined as any process whereby information is gathered about an object, area or phenomenon without being in contact with it.
- Remote sensing is the science and art of obtaining useful information (Spectral, Spatial, and Temporal) about an object; area or phenomenon through the analysis of data acquired by a device is not in contact with the object, area or phenomenon under investigation.

Remote sensing in its broader sense refers to the activities of recording, observing, perceiving object or events at far away (Remote) places.Remote sensing actually deals with inventory, monitoring and assessment of natural resources through the analysis of data obtained by observation are synoptic, provide repetitive coverage of large areas and the data is quantifiable

Our eyes are an excellent example of a remote sensing device. We are able to collect information about our surroundings by measuring the amount of visible light energy from sun or an electric bulb. A thermometer, measuring air, soil or water temperature is in contact with the phenomenon it measures. Hence it is not a remote sensing device, whereas the infrared thermometer which measures canopy temperature is a remote sensing device.

Art and science of Remote Sensing

Remote sensing is the art and science of obtaining information from a distance about objects or phenomena without being in physical contact with them. The science of remote sensing provides the instruments and theory to understand how objects and phenomena can be detected. The art of remote sensing is in the development and use of analysis techniques to generate useful information.

Components of remote sensing:

A remote sensing system using EMR has four components:

1. A source of energy
2. Interactions of energy with the atmosphere
3. Interactions of energy with earth surface
4. A sensor with platform.

Stages of remote sensing:

The field of remote sensing encompasses techniques that obtain precise information about earth's surface. Different stages in remote sensing process are:

1. Energy source
2. Energy interaction with the atmosphere
3. Interaction of energy with earth's surface feature
4. Recording of energy by the sensor
5. Data transmission and processing
6. Image processing and analysis
7. Application

The first and for most requirement for remote sensing is the energy source which illuminates the target or objects. Sun is the natural source of energy and transmitters are the artificial source of energy to illuminate the objects.

The energy from the source comes in contact and interacts with the atmosphere, while travelling to earth surface. The energy which are not absorbed in the atmosphere reaches to earth and interacts with surface objects and features. A portion of incident energy are either reflected, transmitted or absorbed by the surface.The energy after interactions with earth's objects reaches the sensor, where it is recorded in a form which can be transmitted to and used by the users.The energy recorded by the sensor is transmitted to a receiving and a processing station where the data are processed in to an image.Then the processed image is interpreted to extract the information about the object.The extracted information is utilized to make decisions for solving problems.

Principles of Remote Sensing:

- The basic principle in remote sensing is that the different objects based on their structure, chemical and physical properties reflect or emit different amount of energy in different wavelength ranges of the electromagnetic spectrum.
- Everything in nature has its own characteristic features of reflecting, emitting and absorption of radiation.
- For example, in the atmosphere the sun's radiation are selectively scattered or absorbed depending upon the composition of the atmosphere and wavelengths.
- According to the law of conservation of energy, the energy cannot be destroyed but be converted to another form. Thus the portion of incident radiation is reflected by the surface, transmitted in to the surface and absorbed by the surface.
- However, the magnitude of each component depended on the nature of surface, the wavelength of the energy and the angle of illumination. Over water surface, majority of the radiation is either absorbed or transmitted but not reflected. Whereas over soil surface, the majority of radiation is either reflected or absorbed and little is transmitted. Over vegetated surfaces the reflectivity varied with wavelength because of its flexibility unlike soil and water.
- The underlying principle in which the whole remote sensing techniques is developed, is that "All objects on the surface of the earth have their own characteristic spectral signature".
- The responses of materials on the earth surface to incidence radiation are the energy emitted by all objects is a function of their temperature and structure. Hence, all objects have their own reflectivity depending on their own temperature and emissivity. Hence, by utilization of different reflectivity and emissivity of objects we can identify and classify them.

Very often we ask the question that how information of an object can be collected without touching it. The information from an object to the sensor is carried by the EME and recorded by the sensor. This could be encoded in the form of frequency, intensity and polarization of the electromagnetic wave.

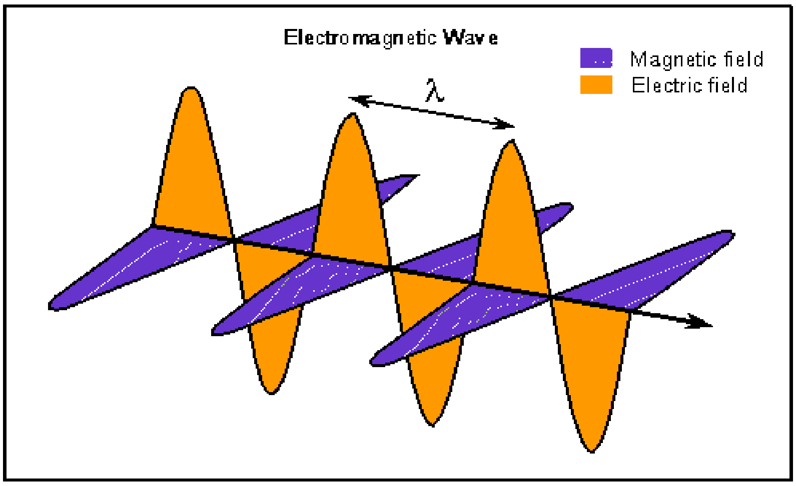
The information is propagated by electromagnetic wave at the velocity of light from the object directly through free space as well as indirectly by reflection, scattering and re-radiation by aerosols to the sensor.

Concept of Remote Sensing

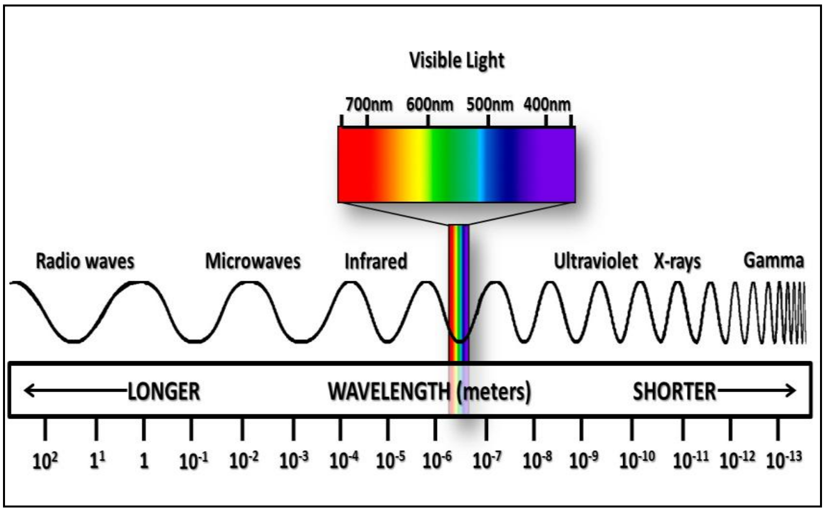
The concept of remote sensing involves six stages

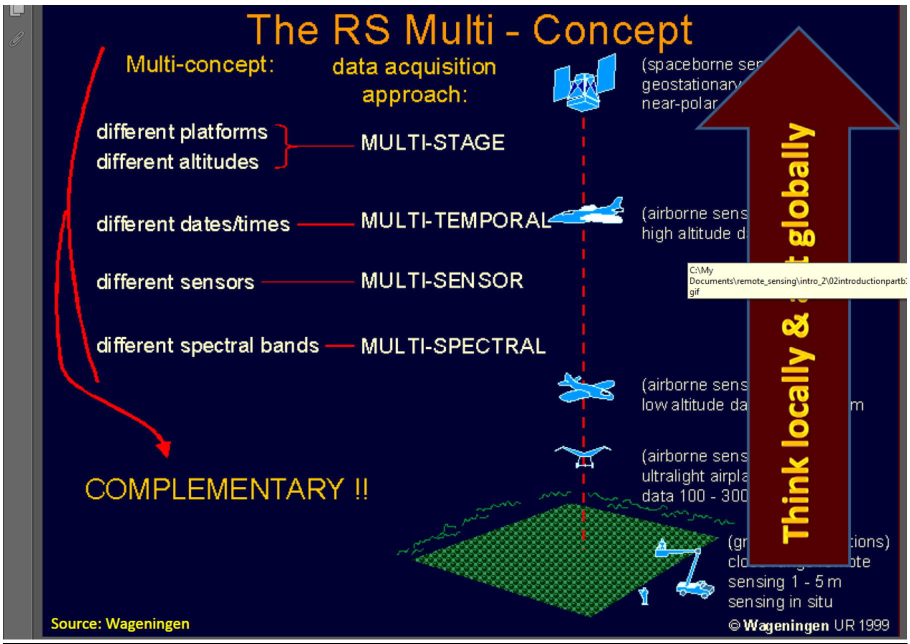
- Source of electromagnetic energy (EME), sun or transmitter is source of energy.
- Transmission of the energy from the source to the surface of earth(as well as absorption and scattering by the atmosphere)
- Interaction of energy with the objects on the surface of earth. Due to interaction the processes like reflection, absorption, transmission and emission take place.

- Transmission of energy to the remote sensing sensor.
- Generation of data in pictorial and/or digital form.



Electromagnetic Spectrum

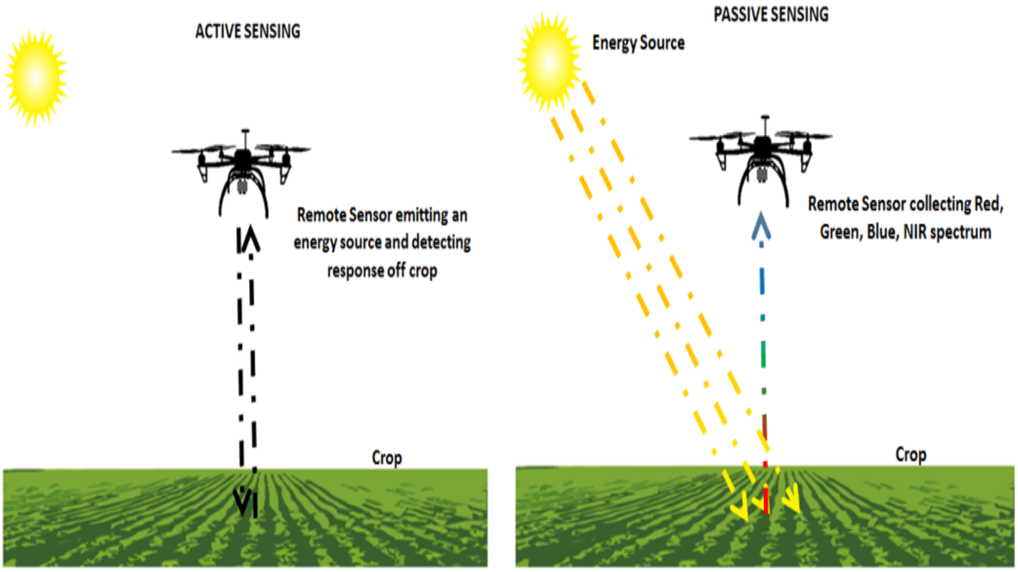




TYPES OF REMOTE SENSING:

Based on source of energy, remote sensing can be divided in to two types:

1. Passive remote sensing
2. Active remote sensing



Remote sensing systems, which use naturally available energy is called **passive remote sensing** and the remote sensing systems which provide their own source of energy is called **active remote sensing.** These sources have the advantage of obtaining data any time of day or season.

Based on range of electromagnetic spectrum there are three types of remote sensing:

1. **Optical remote sensing:** remote sensing is visible, NIR, MIR ranging from 0.3 to 3.0 µm.
2. **Thermal remote sensing:** Remote sensing of thermally emitted radiation in the range of 3 to 5 and 8 to 14 µm
3. **Microwave remote sensing**. Remote sensing in higher wavelengths from 1mm to 1 m can penetrate the clouds.

RESOLUTION

Resolution is defined as the ability of the system to render the information at the smallest discretely separable quantity in terms of distance (spatial), wavelength band of EMR (spectral), time (temporal) and/or radiation quantity (radiometric).

1. Spatial Resolution

Spatial resolution is the projection of a detector element or a slit onto the ground. In other words, scanner's spatial resolution is the ground segment sensed at any instant. It is also called ground resolution element (GRE).

2. Spectral Resolution

Spectral emissivity curves, which characterize the reflectance and/or emittance of a feature or target, over a variety of wavelengths.

3. Radiometric Resolution

This is a measure of the sensor to differentiate the smallest change in the spectral reflectance/emittance between various targets.

4. Temporal Resolution

Obtaining spatial and spectral data at certain time intervals. Temporal resolution is also called as the repetivity of the satellite; it is the capability of the satellite to image the exact same area at the same viewing angle at different periods of time.

REMOTE SENSING PLATFORMS AND SENSORS

Remote sensing is defined as the science which deals with obtaining information about objects on earth surface by analysis of data, received from a remote platform.

In the present context, information flows from an object to a receiver (sensor) in the form of radiation transmitted through the atmosphere. The interaction between the radiation and the object of interest conveys information required on the nature of the object. In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable platform away from the target or surface being observed.

Platforms

Platform is a stage to mount the camera or sensor to acquire the information about a target under investigation. Based on its altitude above earth surface, platforms may be classified as

- **Ground-based platforms:** The ground based remote sensing system for earth resources studies are mainly used for collecting the ground truth or for laboratory simulation studies.
- **Air-borne platforms:** Aircraft's are generally used to acquire aerial photographs for photo-interpretation and photogrammetric purposes. Scanners are tested against their utility and performance from these platforms before these are flown onboard satellite missions.
- **Space-borne platforms:** Platforms in space are not affected by the earth's atmosphere. The closed path of a satellite around the earth is called its orbit. These platforms are freely moving in their orbits around the earth, and entire earth or any part of the earth can be covered at specified intervals. The coverage mainly depends on the orbit of the satellite. It is through these space borne platforms, we get the enormous amount of remote sensing data.

REMOTE SENSING SENSORS

Sensor is a device that gathers energy (EMR or other), converts it into a signal and presents it in a form suitable for obtaining information about the target under investigation. These may be active or passive depending on source of energy.Sensors used for remote sensing can be broadly classified as those operating in Optical Infrared (OIR) region and those operating in the microwave region. OIR and microwave sensors can further be subdivided into passive and active.

- **Active sensors** use their own source of energy. Earth surface is illuminated through energy emitted by its own source; a part of it is reflected by the surface in the direction of the sensor, which is received to gather the information.
- **Passive sensors** receive solar electromagnetic energy reflected from the surface or energy emitted by the surface itself. These sensors do not have their own source of energy and cannot be used at nighttime, except thermal sensors. Again, sensors (active or passive) could either be imaging, like camera or sensor, which acquire images of the area and non-imaging types like non-scanning radiometer or atmospheric sounders.

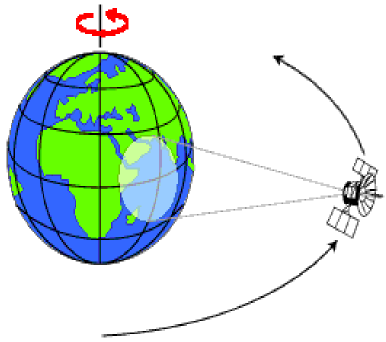
TYPES OF SATELLITE ORBITS

Satellite orbits are designed according to the capability and objective of the sensors they carry. Depending on their altitude, orientation and rotation relative to the earth satellites can be categorized as:

(1) Geostationary (2) Polar orbiting and Sun-synchronous

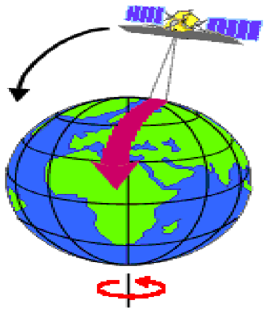
Geostationary satellites

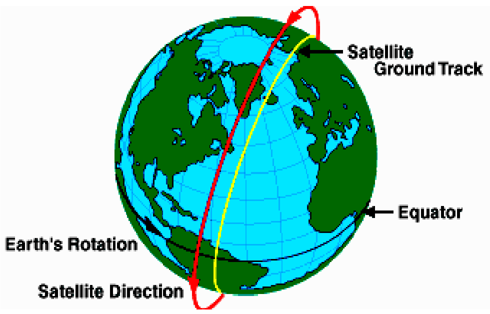
An equatorial west to east satellite orbiting the earth at an altitude of 35000 km, the altitude at which it makes one revolution in 24 hours, synchronous with the earth's rotation. These platforms are covering the same place and give continuous near hemispheric coverage over the same area day and night. These satellites are put in equatorial plane orbiting from west to east. Its coverage is limited to 70^{o}N to 70^{o}S latitudes and one satellite can view one-third globe. It mainly used for communication and meteorological applications.

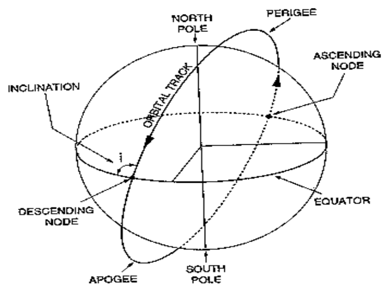


Sun-synchronous satellites

An earth satellite orbit in which the orbital plane is near polar and the altitude is such that the satellite passes over all places on earth having the same latitude twice in each orbit at the same local sun-time. This ensures similar illumination conditions when acquiring images over a particular area over a series of days.







Geostationary (GEO=Geosynchronous)	Polar Orbits (Sun synchronous)
• Orbit is one in which the satellite is always in the same position with respect to the rotating Earth. The satellite orbits at an elevation of approximately 36000 km because that produces an orbital period (time for one orbit) equal to the period of rotation of the Earth (23 hrs, 56 mins, 4.09 secs). • By orbiting at the same rate, in the same direction as Earth, the satellite appears stationary (synchronous with respect to the rotation of the Earth). • Geostationary satellites provide a "big picture" view, enabling coverage of weather events. This is especially useful for monitoring severe local storms and tropical cyclones. • *Viz*., GOES METEOSAT, INTELSAT, and INSAT satellites.	• Orbiting at an altitude of 700 to 800 km, these satellites cover best the parts of the world most difficult to cover in situ (on site). • These satellites operate in a sun-synchronous orbit. The satellite passes the equator and each latitude at the same local solar time each day, meaning the satellite passes overhead at essentially the same solar time throughout all seasons of the year. • This feature enables regular data collection at consistent times as well as long-term comparisons. The orbital plane of a sun-synchronous orbit must also rotate approximately one degree per day to keep pace with Earth's surface. • *Viz*.,SPOT, MOS, JERS, ESR, RADARSAT, IRS

Satellite	UAV (Unmanned aerial vehicle)
• No extra effort is required by user to get the data. • Continuity of data after a finite period for example 16 days, 22 days etc. • Cloud cover and state of atmospheric limits the availability of data. • Spatial resolution is coarse, making it difficult to identify small objects. • Data at important /critical stages / time cannot be acquired. • Have limited usability in regular monitoring of certain phenomenon like disease. • Economical when applied for very larger region.	• Additional efforts are required to get the data. • Data can be acquired any time by flying UAV, could be contiguous data or discrete data. • UAV can be flown below cloud cover to get data. • UAV flies close to earth for example 100-1000 m and can provides images of very high resolution. • It is in hand of user, data can be acquired any time. • It offers scope for regular monitoring of object, and phenomenon. • Comparatively expensive when applied on larger region, but its usability justifies the cost of operation.
	

SCANNING SYSTEMS

Across Track Multispectral Scanning

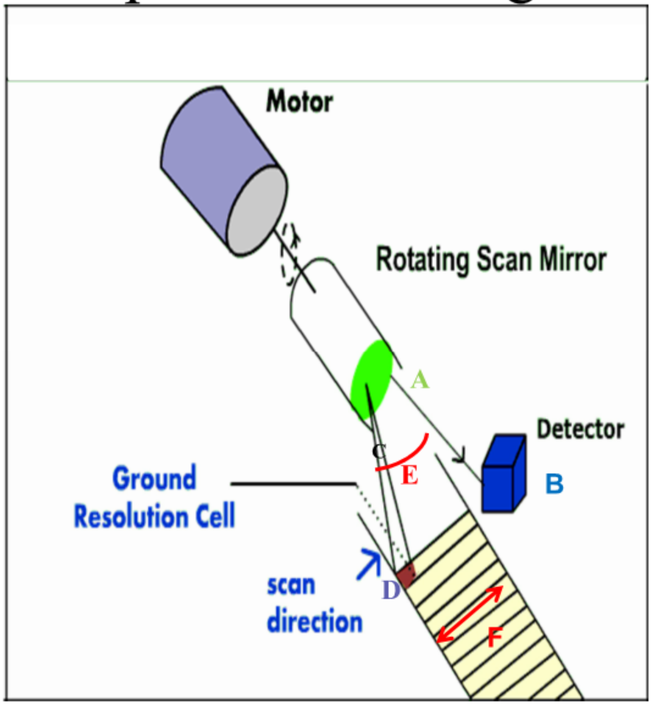
Whisk broom scanning

Scan the Earth in a series of lines.

The lines are oriented perpendicular to the direction of motion of the sensor platform (i.e. across the swath).

Data are collected within an arc below the system typically of some **90º to 120º**

Multispectral scanner (MSS) and thematic mapper (TM) of LANDSAT, and Advanced Very High Resolution Radiometer (AVHRR) of NOAA are the examples of Whisk Broom scanners



Along Track Multispectral Scanning

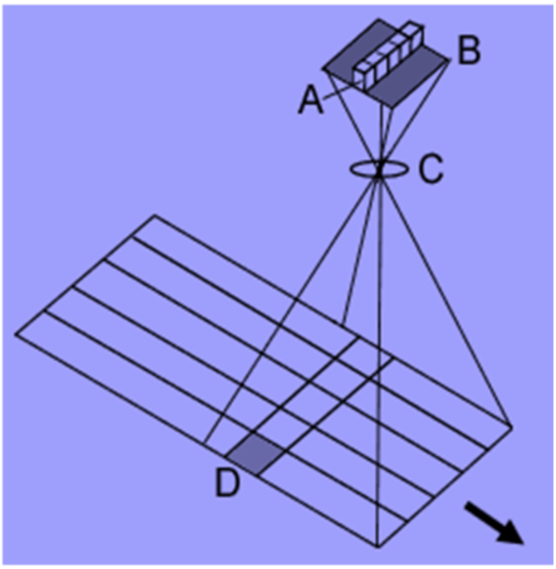
Push broom scanning

Scan the Earth in a series of lines.

This also use the forward motion of the platform to record successive scan lines and build up a two-dimensional image, perpendicular to the flight direction.

Linear arrays normally consist of numerous **charge-coupled devices (CCDs)** positioned end to end.

Linear imaging self scanning (LISS) and Wide Fielf Sensor (WiFS) of IRS Series, and High Resolution Visible (HRV) of SPOT-1 are the examples of Push broom scanners



ADVANTAGES OF REMOTE SENSING:

With growing population and rising of living standard, pressure on natural resources has been increasing day by day. Hence it has become necessary to manage the available resources. For effective management of natural resources it is essential to monitor these resources periodically with great accuracy and speedy techniques.

The main advantages of remote sensing techniques are:

- The remote sensing techniques provide the synoptic (overall) view of large area which is not possible by traditional ground survey methods.
- The data are recorded on permanent basis
- The data are very accurate and unbiased
- The data are amenable (useful) to multidisciplinary uses i.e. the same data can be used for agriculture, forestry, fishery, soil science, hydrology, geology etc.
- The process of data acquisition, analysis and communication is faster than the conventional methods.
- Remote sensing techniques have the unique capability of recording data in visible as well as invisible (UV, IR, microwave etc.) parts of the EMS.

Hence the major advantages of remote sensing are synoptic view, accessibility, accuracy, time saving and multidisciplinary applications.

SATELLITE REMOTE SENSING TECHNOLOGY is useful to gather information beyond simple visual technique with respect to extent of coverage, permanent of record, spectral and spatial resolution, speed and consistency of interpretation of data, cost effective and reliable information etc.

1. Extent of coverage

By using satellite technology information from a large area can be covered with short time with much accuracy as compared to traditional methods, for example, one LANDSAT scene covers about 185 Km × 185 Km area and takes less than 30 Seconds to record one scene from a height ranging from 550- 1600Km .

2. Permanent record

Aerial and satellite data are the permanent and reliable record of ground features present at the time of sensing by photographic camera or multispectral scanner (MSS).

3. Spectral and spatial resolution

Greater fineness of the image and the details of the objects can be obtained by using spatial resolution of any sensor. For example, spatial resolution of LANDSAT MSS is 80m and of IRS LISSS-II is 36m.

By using spectral resolution we can distinguish the different objects. We may be able to see number of terrain features like forested and denudated hills, slopping of mountains, floods, sand dunes, crops and forested area, problematic area etc. in one scene.

4. Speed and consistency of interpretation

With the use of digital image processing system we can analyses the data consistently and speedily.

5. Cost effective and reliability

Remote sensing offers cost effective and reliable monitoring systems. At times when the conventional field survey were not done honestly due to various difficulties, remote sensing offers help to cross check , verify and have more realistic and accurate data.

The advantages of remote sensing techniques over conventional methods

- The remote sensing techniques provide the synoptic view of large area which is not possible by traditional ground survey methods.
- The data are recorded on the permanent basis.
- The data are unbiased record of the objects or phenomena.
- The data are amenable to multi-disciplinary use i.e. the same data can be used for agriculture, forestry, soil science, hydrology, geology etc.
- Process of data acquisition and analysis is faster than in conventional methods.
- Satellite data are received periodically varying from 14days to 28 days depending on the satellite. This capability of satellite helps in updating the information and monitoring the changes at short intervals.
- Remote sensing technique have the unique capability of recording data in visible as well as invisible parts of the spectrum (UV, IR, Microwave etc.)

Scope of remote sensing:

The scope of remote sensing covers the application of remote sensing techniques to diverse fields. The same information can be useful to investigations of different disciplines in many ways. The data gathered by remote sensing process can be used by the users, investigators of different disciplines like agriculture, geology, forestry, hydrology, soil science, fishery, land use engineers etc.

- The oldest application of remote sensing techniques is in military operation. The infrared (IR) sensing is useful to locate an army's position.
- Geologists use remote sensing to find deposits of mineral and petroleum.
- Agriculturalists and farmers can determine the kind of crops and trees which grow in an area and can assess the growth, health and estimate the yields.
- Soil scientists can prepare soil maps based on soil characteristics.
- Hydrologists can locate useful aquifers and can estimate the volume of watersheds.
- Geographers can analyse land use pattern over large area and can study the effect of climate.
- Civil engineers use remote sensing for planning and designing large construction of roads and reservoirs.
- Oceanographers can map the movements of ocean currents.
- Meteorologists can use remote sensing for forecasting of weather.

REMOTE SENSING APPLICATION IN AGRICULTURE

- Agriculture plays a dominant role in economies of both developed and developing countries.
- Whether agriculture represents a substantial trading industry for an economically strong country or simply sustenance for a hungry, overpopulated one, it plays significant role in almost every nation.
- Production of food is important to everyone and producing food in a cost-effective manner is the goal of every farmer.
- A farmer needs to be informed to be efficient and that includes having the knowledge and information products to forge a viable strategy for farming operations.
- These tools will help him understand the health of his crop, extent of infestation or stress damage or potential yield and soil conditions.

- Commodity brokers are also very interested in how well farms are producing, as yield (both quantity and quality) estimates for all products control price and worldwide trading.

Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability and monitor farming practices. Agricultural applications of remote sensing include the following:

- **Soil properties sensing:** Soil texture, structure and physical condition, soil moisture and soil nutrients.
- **Crop sensing:** Plant population, crop stress and nutrient status.
- **Yield monitoring systems:** Crop yield, harvest swath width and moisture content of grain.
- **Variable rate technology systems:**Fertilizer flow, weed detection etc.

Crop Type Mapping

Identifying and mapping crops is important for a number of reasons. Maps of crop type are created by national and multinational agricultural agencies, insurance agencies and regional agricultural boards to prepare an inventory of what was grown in certain areas and when. This serves purpose of forecasting grain supplies (yield prediction), collecting crop production statistics, facilitating crop rotation records, mapping soil productivity, identification of factors influencing crop stress, assessment of crop damage due to storms and drought and monitoring farming activity.

Key activities include identifying the crop types and delineating their extent (often measured in acres). Traditional methods of obtaining this information are census and ground surveying. In order to standardize measurements however, particularly for multinational agencies and consortiums, remote sensing can provide common data collection and information extraction strategies.

Remote sensing offers an efficient and reliable means of collecting the information required, in order to map crop type and area. Besides providing a synoptic view, remote sensing can provide structure information about the health of the vegetation. The spectral reflection of a field will vary with respect to changes in the phenology (growth), stage type, and crop health and thus can be measured and monitored by multispectral sensors. Radar is sensitive to the structure, alignment and moisture content of the crop and thus can provide complementary information to the optical data. Combining the information from these two types of sensors increases the information available for distinguishing each target class and its respective signature and thus there is better chance of performing more accurate classification. Interpretations from remotely sensed data can be input to a geographic information system (GIS) and crop rotation systems and combined with ancillary data, to provide information of ownership, management practices etc.

Crop identification and mapping benefit from the use of multi-temporal imagery to facilitate classification by taking into account changes in reflectance as a function of plant phenology (stage of growth). This in turn requires calibrated sensors and frequent repeat imaging throughout the growing season. For example, crops like canola may be easier to identify when they are flowering, because of both the spectral reflectance change and the timing of the flowering.

Multi-sensor data are also valuable for increasing classification accuracies by contributing more information than a sole sensor could provide. The VIR sensing contributes information relating to the chlorophyll content of the plants and the canopy structure, while radar provides information relating to plant structure and moisture. In areas of persistent cloud cover or haze, radar is an excellent tool for observing and distinguishing crop type due to its active sensing capabilities and long wavelengths, capable of penetrating through atmospheric water vapour.

Crop Monitoring and Damage

Early detection and assessment of crop pest and pathogen infestations and soil moisture stress is critical in effective plant protection leading to optimum yield. This process requires that remote sensing imagery be provided on a frequent basis (at a minimum, weekly) and delivered to farmer quickly, usually within a day or two.

Also, crops do not generally, grow, evenly across the field and consequently crop yield can vary greatly from one spot in the field to another. These growth differences may be due to soil nutrient deficiencies or other forms of stress. Remote sensing allows the farmer to identify problem areas (nutrient deficiencies, pesticide and herbicide needs etc.) within a field, so that the farmer can take up timely remedial measures for improving the productivity of crops.

Many people involved in the trading, pricing and selling the produce that never actually set foot in a field. They need information regarding crop health worldwide to set prices and to negotiate trade agreements. Many of these people rely on products such as crop assessment index to compare growth rates and productivity between years and to see how well each country's agricultural industry is producing. This type of information can also help target locations of future problems. Identifying such areas facilitates in planning and directing humanitarian aid and relief efforts.

Remote sensing has a number of attributes that lend themselves to monitoring the health of crops. One advantage of optical (VIR) sensing is that it can see beyond the visible wavelengths into the infrared, where wavelengths are highly sensitive to crop vigour as well as crop stress and crop damage. Remote sensing imagery also gives the required spatial overview of the land. Recent advances in communication and technology allow a farmer to observe images of his fields and make timely decisions about managing the crops. Remote sensing can aid in identifying crops affected by conditions that are too dry or wet, affected by insect, weed or fungal infestations or weather related damage. Images can be obtained throughout the growing season to not only detect problems, but also to monitor the success of the treatment.

Healthy vegetation contains large quantities of chlorophyll, the substance that gives most vegetation its distinctive green colour. In referring to healthy crops, reflectance in the blue and red parts of the spectrum is low since chlorophyll absorbs this energy. In contrast, reflectance in the green and near-infrared spectral regions is high. Stressed or damaged crops experience a decrease in chlorophyll content and changes to the internal leaf structure. Reduction in chlorophyll content decrease reflectance in the green region and internal leaf damage results in decrease in near-infrared reflectance. These reductions in green and infrared reflectance provide early detection of crop stress. Examining the ratio of reflected infrared to red wavelengths is an excellent measure of vegetation health. This is the premise behind some vegetation indices, such as the normalized differential vegetation index (NDVI). Healthy plants have a high NDVI value because of their high reflectance of infrared light and relatively low reflectance of red light. Phenology and vigour are the main factors in affecting NDVI. An excellent example is the difference between irrigated crops and non-irrigated land. Irrigated crops appear bright green in a real-colour simulated image. Darker areas are dry rangeland with minimal vegetation. In a CIR (colour infrared simulated) image, where infrared reflectance is displayed in red, the healthy vegetation appears bright red, while the rangeland remains quite low in reflectance.

Examining variations in crop growth within one field is possible. Areas of consistently healthy and vigorous crop would appear uniformly bright. Stressed vegetation would appear dark amongst the brighter, healthier crop areas. If the data is geo-referenced and if the farmer has a GPS (global position satellite) unit, he can find the exact area of the problem very quickly, by matching the coordinates of his location to that on the image.

Detecting damage and monitoring crop health requires high-resolution imagery and multispectral imaging capabilities. One of the most critical factors in making imagery useful to farmers is a quick turnaround time from data acquisition to distribution of crop information. Receiving an image that reflects crop conditions of two weeks earlier does not help real time management or damage mitigation. Images are also required at specific times during the growing season and on a frequent basis.

Remote sensing doesn’t replace the field work performed by farmers to monitor their fields, but it does direct them to areas in need of immediate attention.

IMAGE PROCESSING AND INTERPRETATION

Image processing and interpretation/analysis can be defined as the “act of examining images for the purpose of identifying objects and judging their significance” Image analyst study the remotely sensed data and attempt through logical process in detecting, identifying, classifying, measuring and evaluating the significance of physical and cultural objects, their patterns and spatial relationship. Some procedures commonly used in analyzing/interpreting remote sensing images are briefly presented.

1. Pre-Processing

Prior to data analysis, initial processing on the raw data is usually carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions. Depending on the user’s requirement, some standard correction procedures may be carried out by the ground station operators before the data is delivered to the end-user. These procedures include radiometric correction to correct for uneven sensor response over the whole image and geometric correction to correct for geometric distortion due to earth’s rotation and other imaging conditions (such as oblique viewing). The image may also be transformed to conform to a specific map projection system. Furthermore, if accurate geographical location of an area on the image needs to be known, ground control points (GCP’s) are used to register the image to a precise map (geo-referencing).

2. Image Enhancement

In order to aid visual interpretation, visual appearance of the objects in the image can be improved by image enhancement techniques such as grey level stretching to improve the contrast and spatial filtering for enhancing the edges. A bluish tint all-over the image, producing a hazy appearance is due to scattering of sunlight by atmosphere into the field of view of the sensor. This effect also degrades the contrast between different land covers.It is useful to examine the image histograms before performing any image enhancement. The x-axis of the histogram is the range of the available digital numbers (0 to 255). The y- axis is the number of pixels in the image having a given digital number. The histograms of the three bands of this image are shown below.

3. Image Classification

Different land covers types in an image can be discriminated using some image classification algorithms using spectral features, i.e. the brightness and “colour” information contained in each pixel. Classification procedures can be “supervised” or “unsupervised”.

In supervised classification, the spectral features of some areas of known land covers types are extracted from the image. These areas are known as the training areas. Every pixel in the whole image is then classified as belonging to one of the classes depending on how close its spectral features are to the spectral features of the training areas.

In unsupervised classification, the computer program automatically groups the pixels in the image into separate clusters, depending on their spectral features. Each cluster will then be assigned a land covers type by the analyst.

Each class of land covers is referred to as a theme and the product of classification is known as a thematic map.

4. Spatial Feature Extraction

In high spatial resolution imagery, details such as buildings and roads can be seen. The amount of details depends on the image resolution. In very high resolution imagery, even road markings, vehicles, individual tree crowns and aggregates of people can be seen clearly. Pixel-based methods of image analysis will not work successfully in such imagery.

In order to fully exploit the spatial information contained in the imagery, image processing and analysis algorithms utilizing the textural, contextual and geometrical properties are required. Such algorithms make use of the relationship between neighboring pixels for information extraction. Incorporation of a-priori information is sometimes required. A multi-resolution approach (analysis at different spatial scales and combining the resolute) is also a useful strategy when dealing with very high resolution imagery. In this case, pixel- based method can be used in the lower resolution mode and merged with the contextual and textural method at higher resolutions.

5. Measurement of Bio-geophysical Parameters

Specific instruments earned on-board the satellites can be used to make measurements of the bio-geophysical parameters of the earth. Some of the examples are: atmospheric water vapor content, stratospheric ozone, land and sea surface temperature, sea water, chlorophyll concentration, forest biomass, sea surface wind field, troposphere aerosol etc. Specific satellite missions have been launched to continuously monitor the global variations of these environmental parameters that may show the causes or the effects of global climate change and the impacts of human activities on the environment.

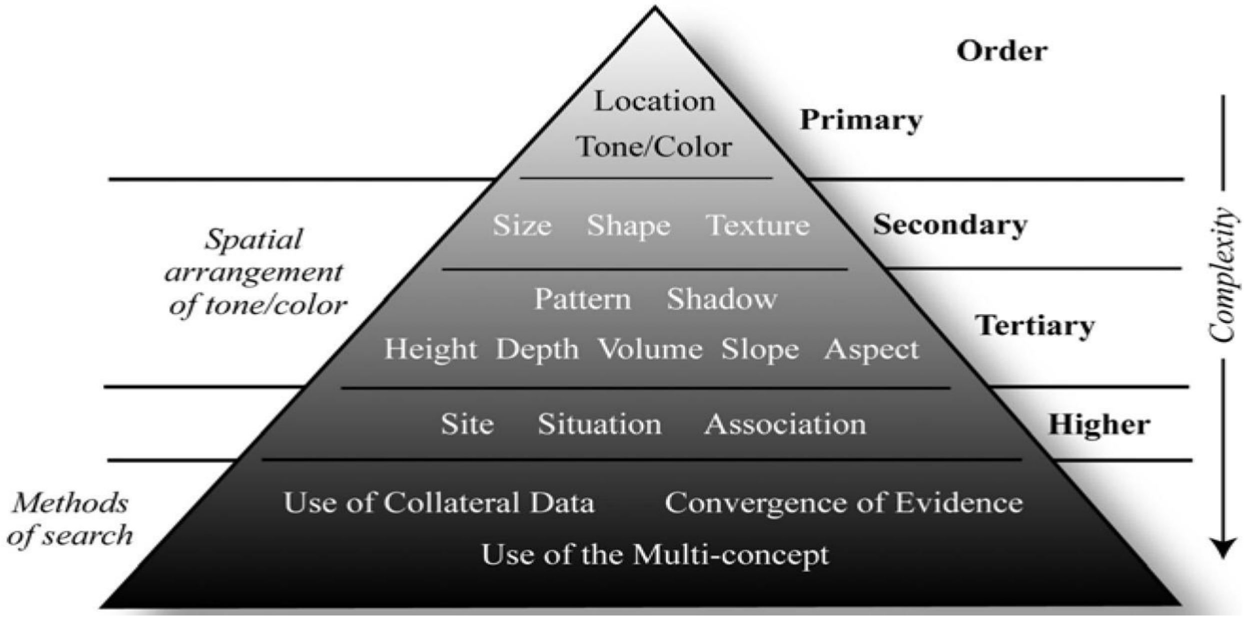
6. Geographical Information System (GIS)

Different forms of imagery such as optical and radar images provide complementary information about the land covers. More detailed information can be derived by combining several different types of images. For example, radar image can form one of the layers in combination with the visible and near infrared layers when performing classification.

Thematic information derived from the remote sensing images is often combined with other auxiliary data to form the basis for a geographic information system (GIS). A GIS is a database of different layers, where each layer contains information about a specific aspect of the same area which is used for analysis by the resource scientists.

IMAGE INTERPRETATION

Image interpretation is defined as the act of examining images to identify objects and judge their significance. An interpreter studies remotely sensed data and attempts through logical process to detect, identify, measure and evaluate the significance of environmental and cultural objects, patterns and spatial relationships. It is an information extraction process.



- **Tone/Hue**
- **Texture**
- **Pattern**
- **Shape**
- **Size**
- **Height/elevation, Shadow**
- **Association/location**

CHAPTER - 4

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

INTRODUCTION

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyse the geographic features present on the Earth surface and the events that takes place on it. The meaning to represent digitally is to convert analog into a digital form. "Every object present on the Earth can be geo-referenced", is the fundamental key of associating any database to GIS. Here, term 'database' is a collection of information about things and their relationship to each other, and 'geo-referencing' refers to the location of a layer or coverage in space defined by the co-ordinate referencing system. Evolution of GIS has transformed and revolutionized the ways in which planners, engineers, managers etc. conduct the database management and analysis.

Defining GIS

A GIS is a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. It is also defined as an information system designed to work with data referenced by spatial / geographical coordinates. In other words, GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. A Geographic Information System is a computer based system which is used to digitally reproduce and analyse the feature present on earth surface and the events that take place on it. In the light of the fact that almost 70% of the data has geographical reference as it's denominator, it becomes imperative to underline the importance of a system which can represent the given data geographically. The three perspectives of GIS are:

GIS as a Toolbox

GIS as a toolbox: if so then what kind of tools? This is classification based on functional tasks of GIS like

1. Tools for automating *spatial data* (data capture via digitizing, scanning, remote sensing, satellite geo-position system)
2. For storing spatial data (data bases and data structures)
3. For spatial data management/retrieval
4. For analysis (overlay, buffering, proximity, network functions, spatial statistics)
5. For display of spatial data and analysis results

GIS as an Information System

As Definition of GIS indicates GIS as a specialized information system stresses "spatially distributed features (points, lines, areas), activities (physical and human-invoked), and events (time).

GIS as an approach to Geographic Information Science

1. research on GIS (algorithms, analytical methods, visualization tools, user interfaces, human-computer-human interaction)

2. research with GIS: GIS as a tool used by many substantive disciplines in their own ways (anthropology, archeology, forestry, geology, engineering, business and management sciences)

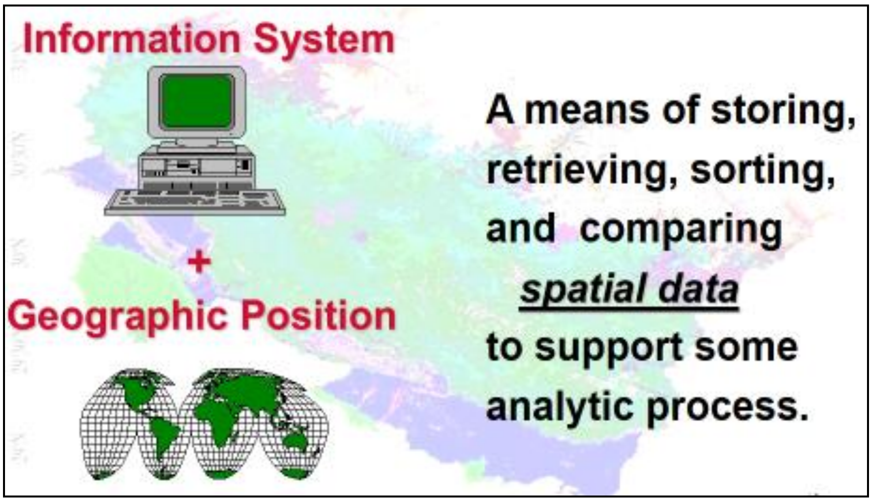
HISTORY OF GIS

Work on GIS began in 1950s, but first GIS software came only in late 1970s from the lab of the ESRI. Canada was the pioneer in the development of GIS as a result of innovations dating back to early 1960s. Much of the credit for the early development of GIS goes to Roger Tomilson. The events which took place in the development of GIS in chronological order are:

1. Early 1950s: thematic map overlay (superimposition of maps drafted at the same scale)
2. 1959: use of transparent blacked-out overlays to find suitable locations (overhead)
3. 1960s: early computer mapping packages SURFACE II, SYMAP; early spatial data banks (CIA's World Data Bank)
4. 1960s: first GIS (Canada Geographic Information System, Minnesota Land Management System)
5. 1970s: advances in algorithms and data structures to handle spatial data, Harvard Lab for Computer Graphics (first modern GIS software)
6. 1980s: introduction of PC, advances in hardware, mature mainframe GIS software
7. 1990s: desktop GIS, Internet-based GIS services, proliferation of GIS applications
8. 2000 and beyond??? omnipresent GIS, wireless, networked, every-day applications everywhere.

COMPONENTS OF GIS

GIS constitutes of five key components: Hardware, Software, Data, People, Method



Hardware

It consists of the computer system on which the GIS software will run. The choice of hardware system range from 300MHz Personal Computers to Super Computers having capability in Tera FLOPS. The computer forms the backbone of the GIS hardware, which gets it's input through the Scanner or a digitizer board. Scanner converts a picture into a digital image for further processing. The output of scanner can be stored in many formats e.g. TIFF, BMP, JPG etc. A digitizer board is flat board used for vectorisation of a given map objects. Printers and plotters are the most common output devices for a GIS hardware setup.

Software

GIS software provides the functions and tools needed to store, analyze, and display geographic information. GIS softwares in use are MapInfo, ARC GIS, AutoCAD Map, etc. The software available can be said to be application specific. When the low cost GIS work is to be carried out desktop MapInfo is the suitable option. It is easy to use and supports many GIS feature. If the user intends to carry out extensive analysis on GIS, ARC/Info is the preferred option. For the people using AutoCAD and willing to step into GIS, AutoCAD Map is a good option. The software for a geographical information system may be split into five functional groups as mentioned below**:**

1. Data input and verification
2. Data storage and database management
3. Data transformation
4. Data output and presentation
5. Interaction with the user

Data

Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. The digital map forms the basic data input for GIS. Tabular data related to the map objects can also be attached to the digital data. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organization to maintain their data, to manage spatial data.

People

GIS uses range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work. The people who use GIS can be broadly classified into two classes. The CAD/GIS operator, whose work is to vectorise the map objects. The use of this vectorised data to perform query, analysis or any other work is the responsibility of a GIS engineer/user.

Method

And above all a successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization. There are various techniques used for map creation and further usage for any project. The map creation can either be automated raster to vector creator or it can be manually vectorised using the scanned images. The source of these digital maps can be either map prepared by any survey agency or satellite imagery.

DATA IN GIS

GIS stores information about the world as a collection of thematic layers that can be used together. A layer can be anything that contains similar features such as customers, buildings, streets, lakes, or postal codes. This data contains either an explicit geographic reference, such as a latitude and longitude coordinate, or an implicit reference such as an address, postal code, census tract name, forest stand identifier, or road name. There are two components: spatial data that show where the feature is; and attribute data that provide information about the feature. These are linked by the software. The fact that there are both spatial and attribute data allows the database to be exploited in more ways than a conventional database allows, as GIS provides all the functionality of the DBMS and adds spatial functionality.

Spatial Data

Spatial data is spatially referenced data that act as a model of reality. Spatial data represent the geographical location of features for example points, lines, area etc. Spatial data typically include various kinds of maps, ground survey data and remotely sensed imagery and can be represented by points, lines or polygons.

Attribute Data

Attribute data refers to various types of administrative records, census, field sample records and collection of historical records. Attributes are either the qualitative characteristics of the spatial data or are descriptive information about the geographical location. Attributes are stored in the form of tables, where each column of the table describes one attribute and each row of the table corresponds to a feature.

THE NATURE OF GEOGRAPHICAL DATA

1. Geographical position (spatial location) of a spatial object is presented by 2-, 3- or 4-dimensional coordinates in a geographical reference system (e.g. Latitude and Longitude).
2. Attributes are descriptive information about specified spatial objects. They often have no direct information about the spatial location but can be linked to spatial objects they describe. Therefore, it is often to call attributes "*non-spatial*" or "*aspatial*" information.
3. Spatial relationship specifies inter-relationship between spatial objects (e.g. direction of object B in relation to object A, distance between object A and B, whether object A is enclosed by object B, etc.).
4. Time records the time stamp of data acquisition, specifies life of the data, and identifies the locational and attribute change of spatial objects.

REPRESENTATION OF SPATIAL DATA

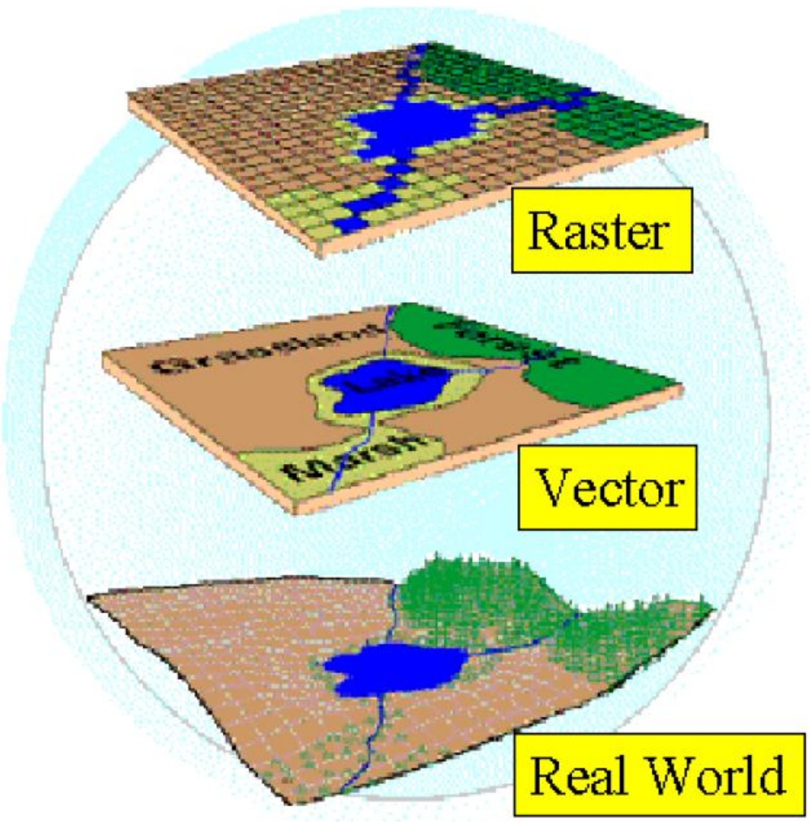
In GIS, two types of data models represent spatial data: Vector model and Raster model

Vector Models

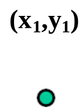
In vector models, objects are created by connecting points with straight line (or arcs) and area is defined by sets of lines. Information about points, lines and polygons is encoded and stored as a collection of x, y coordinate. Location of a point feature such as tubewell can be described by a single x, y coordinate. Linear feature such as river can be stored as a collection of point coordinates. Polygon feature, such as river catchment can be stored as a closed loop of coordinates. Vector models are very useful for describing discrete features like data represented by an area. Vector model is not much useful for describing continuously varying features such as soil type.

Raster Graphics	Vector Graphics
They are composed of pixels.	They are composed of paths.
In Raster Graphics, refresh process is independent of the complexity of the image.	Vector displays flicker when the number of primitives in the image become too large.
Graphic primitives are specified in terms of end points and must be scan converted into corresponding pixels.	Scan conversion is not required.
Raster graphics can draw mathematical curves, polygons and boundaries of curved primitives only by pixel approximation.	Vector graphics draw continuous and smooth lines.
Raster graphics cost less.	Vector graphics cost more as compared to raster graphics.
They occupy more space which depends on image quality.	They occupy less space.
File extensions: .BMP, .TIF, .GIF, .JPG	File Extensions: .SVG, .EPS, .PDF, .AI, .DXF

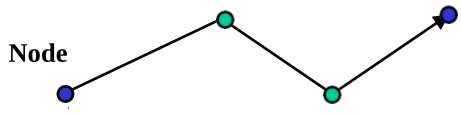
Raster-Vector Data Model



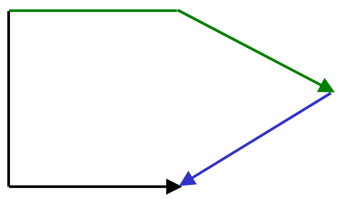
Point - **a pair of x and y coordinates**



Line - **a sequence of points**

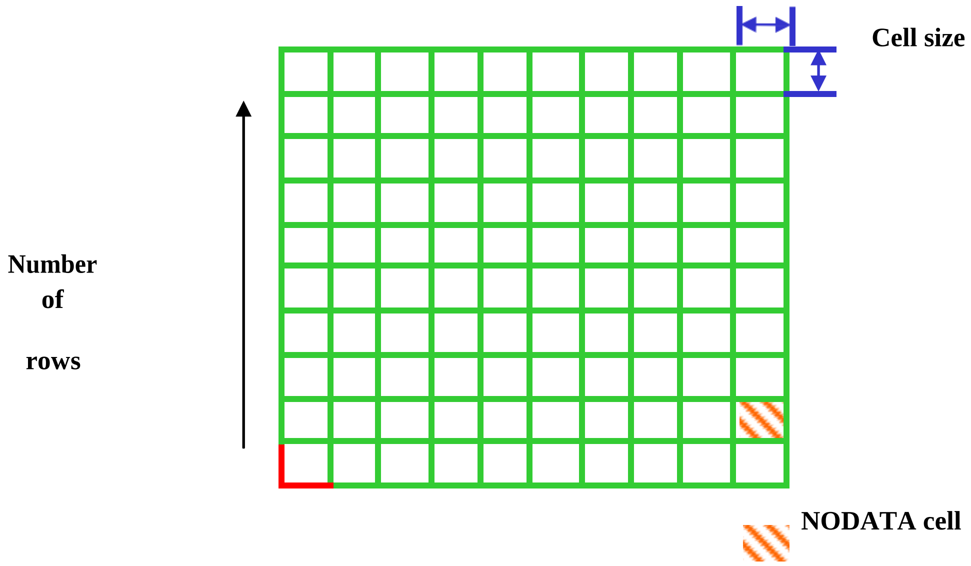


Polygon - **a closed set of lines**



Raster model

In raster model, study area is divided into a regular grid of cells in which each cell contain single value. Continuous data type, such as elevation, vegetation etc. are represented using raster model



Raster Data Model

Questions GIS can answers

Understanding GIS

WHAT GIS CAN DO?

What GIS can do?	Real World Problems
Identification	What is there?
Located	Where?
Optimum Path	What is the best route?
Patterns	What relations exists between?
Trend	What has changed? How it is changing?
Models	What if?

In the context of these innovations, geographic information systems have served an important role as an integrating technology. Rather than being completely new, GIS have evolved by linking a number of discrete technologies into a whole that is greater than the sum of its parts. GIS have emerged as very powerful technologies because they allow geographers to integrate

their data and methods in ways that support traditional forms of geographical analysis, such as map overlay analysis as well as new types of analysis and modeling that are beyond the capability of manual methods. With GIS it is possible to map, model, query, and analyze large quantities of data all held together within a single database.

The importance of GIS as an integrating technology is also evident in its pedigree. The development of GIS has relied on innovations made in many different disciplines: Geography, Cartography, Photogrammetry, Remote Sensing, Surveying, Geodesy, Civil Engineering, Statistics, Computer Science, Operations Research, Artificial Intelligence, Demography, and many other branches of the social sciences, natural sciences, and engineering have all contributed. Indeed, some of the most interesting applications of GIS technology discussed below draw upon this interdisciplinary character and heritage.

Application Areas

GIS is now used extensively in government, business, and research for a wide range of applications including environmental resource analysis, landuse planning, locational analysis, tax appraisal, utility and infrastructure planning, real estate analysis, marketing and demographic analysis, habitat studies, and archaeological analysis.

One of the first major areas of application has been in **natural resources management**, including management of

1. wildlife habitat
2. wild and scenic rivers
3. recreation resources
4. floodplains
5. wetlands
6. agricultural lands
7. aquifers

8. forests

One of the largest areas of application has been in **facilities management**. Uses for GIS in this area includes

1. locating underground pipes and cables,
2. balancing loads in electrical networks,
3. planning facility maintenance,
4. tracking energy use.

Local, state, and federal governments have found GIS particularly useful in **land management**. GIS has been commonly applied in areas like

1. zoning and subdivision planning,
2. land acquisition,
3. environmental impact policy,
4. water quality management,
5. maintenance of ownership.

More recent and innovative uses of GIS have used information based on **street-networks**. GIS has been found to be particularly useful in

1. address matching,
2. location analysis or site selection,
3. development of evacuation plans.

The range of applications for GIS is growing as systems become more efficient, more common, and less expensive.

CHAPTER - 5

GLOBAL POSITIONING SYSTEM (GPS)

INTRODUCTION

Global positioning system (GPS) is a satellite-based navigation system, consisting of more than 21 satellites and several supporting ground facilities, which provides accurate, three dimensional position, velocity and time, 24 hours a day, everywhere in the world and in al weather conditions. The global positioning system consists of three main components.

Global Positioning System (GPS) has tremendous potential for better transport management/planning. Traffic management, emergency services (fire service, accident relief, ambulance service, policing, etc.), are the few areas where GPS can play significant role due to its capability to provide near accurate location (latitude, longitude, altitude) and other details. Traffic routing, movement of vehicles, VIP movement, taxi service, fleet management for passenger and cargo services etc. becomes easier by using GPS receivers on vehicles. Use of GPS along with GIS database of the city can help to perform the above tasks more effectively. GPS is also very useful in creating accurate spatial databases.

Global positioning system is an earth-orbiting Satellite based system that provides signals anywhere on or above earth, 24 hours a day, round the year, and irrespective of weather, and that can be used to determine precise time and the position of a GPS receiver in three dimensions. This technology is increasingly used as input for GIS particularly for precise positioning of geo-spatial data and for collection of data from the field. One major advantage is its capability of forming a powerful building block in an integrated system. GPS together with a co-ordinate system and GIS produces a map and the map facilitates navigation. GPS is rapidly becoming an important tool to the GIS and Remote sensing industries.

GPS satellite constellation

CONCEPT OF GPS

GPS consists of a constellation of radio navigation satellite and a ground control segment. It manages satellite operation and users with specialized receivers who use the satellite data to satisfy a broad range of positioning requirements.

In brief, following are the key features of GPS:

- The basis of GPS is „triangulation" more precisely trilateration from satellites
- GPS receiver measures distance using the travel time of radio signals.
- To measure travel time GPS needs very accurate timing that is achieved with some techniques.
- Along with distance, one needs to know exactly where the satellites are in space.
- Finally one must correct for any delays, the signal experience as it travels through the atmosphere.

The whole idea behind GPS is to use satellites in space as reference points for location here on earth. By very accurately measuring the distances from at least three satellites, we can „triangulate" our position anywhere on the earth by resection method.

GPS COMPONENTS

Basic components of global positioning are briefly presented.

I. GPS Ground Control Stations

The ground control component includes the master control station at Falcon Air Force Base, Colorado Springs, Colorado and monitor stations at Falcon AFB, Hawaii, Ascension Island in the Atlantic, Diego Garcia in the Indian Ocean and Kwajalein Island in the South Pacific. The control segment uses measurements collected by the monitor stations to predict the behavior of each satellite's orbit and atomic clocks. Prediction data is linked up to the satellites for transmission to users. The control segment also ensures that GPS satellite orbits remain within limits and that the satellites do not drift too far from nominal orbits.

II. GPS Satellites

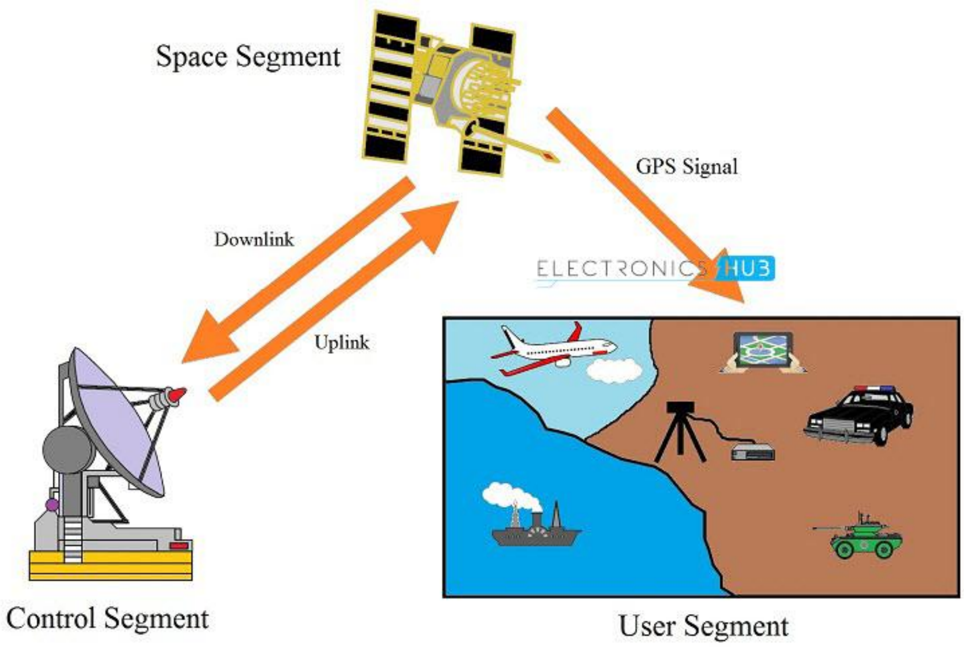
The space segment includes the satellites and the delta rockets that launch the satellites from Cape Canaveral in Florida, United States. GPS satellites orbit in circular orbits at 17,440 km altitude, each orbit lasting 12 hours. The orbits are tilted to the equator by 55 A° to ensure coverage in Polar Regions. The satellites are powered by solar cells to continually orientate themselves to point the solar panels towards the sun and the antennas towards the earth. Each satellite contains four atomic clocks.

III. GPS Receivers

When you buy a GPS, you are actually buying only GPS receiver and get free use of the other two main components, worth billions of dollars - compliments of the Government of the United States.

The ground stations send control signals to the GPS satellites. The GPS satellites transmit radio signals and the GPS receivers, receive these signals and use it to calculate its position.

Calculations used to determine your GPS receiver's position is based on very small time differences, from when the satellite transmitted the signal, to, when the GPS receiver received the signal. These small differences are then used to calculate the distance from the receiver to the satellite.



- However, when receiving only one signal, we can only calculate how far away from the satellite we are.
- When receiving two signals, we can determine two likely positions where we are.
- We need three satellite signals to determine our exact position on the earth's surface. (2D/2 dimensional positioning).
- When more than three satellites are 'visible' to the GPS receiver, it will also calculate the altitude of receiver (3D/3 dimensional positioning).
- The GPS receiver requires signals from at least three satellites to determine your unique position on the earth's surface. With a fourth signal, altitude can also be determined.
- Receiving signals from more than four different satellites, the position of the GPS receiver can more accurately be determined.
- The GPS satellite constellation is designed in such a manner as to guarantee that at least four satellites are visible from any place on earth at any moment in time.
- Most of the time (+95%) however, we should have at least six satellites visible. Many commercial GPS receivers can receive and process signals from 12 satellites for increased reliability and accuracy.

The GPS satellites carry atomic clocks that measure time to a high degree of accuracy. Time information is placed in the codes broadcast by the satellite so that a receiver can continuously determine the time the signal was broadcast. The signal contains data that a receiver uses to compute the locations of the satellites and to make other adjustments needed for accurate positioning. Receiver uses the time difference between the time of signal reception and the broadcast time to compute the range to the satellite. Receiver must account for propagation delays caused by the ionosphere and the troposphere. With three ranges to three satellites and knowing the location of the satellite when the signal was sent, the receiver can compute its three-dimensional position.

To compute ranges directly, however, the user must have an atomic clock synchronized to the global positioning system. By taking a measurement from an additional satellite, the receiver avoids the need for an atomic clock. The result is that the receiver uses four satellites to compute latitude, longitude, altitude and time.

GPS FUNCTIONS

The GPS functions include:

1. **Giving a location:** This is the whole point of a navigation system: its ability to accurately triangulate your position based on the data transmissions from multiple satellites. It will give your location in coordinates, either latitude and longitude or Universal Transverse Mercators (UTMs). Developed by the military, UTMs are used to pinpoint a location on a map. Most topographical maps have UTM gridlines printed on them.
2. **Point-to-point navigation:** This GPS navigation feature allows you to add waypoints to your trips. By using a map, the coordinates of a trailhead or road or the point where you are standing, you can create a point-to-point route to the place where you are headed. You will have trip mapped out, including any stops you add in.
3. **Plot navigation:** This feature in a global positioning system allows you to combine multiple waypoints and move point-to-point. Once you reach the first waypoint, the GPS can automatically point you on your way to the next one. The waypoint management software comes with most handheld GPS units for easy database management.
4. **Keeping track of your track:** Tracks are some of the most useful functions of portable navigation systems. You can map where you have already been. This virtual map is called a track and you can programme the GPS system to automatically drop track-points as you travel, either over intervals of time or distance. This can be done on land and allows you to retrace your steps.

WHY NEED GPS?

- Need to know the exact location where the variability exists.
- GPS provide us with the unique location information (latitude/longitude/altitude).

GPS APPLICATIONS

The GPS applications include:

A. Guidance

- Point guidance
- Swath guidance

B. Control

- Variable rate application
- Variable tillage depth
- Variable irrigation

C. Mapping

- Soil properties
- Chemical application
- Chemical prescriptions
- Tillage maps
- Yield mapping
- Pest mapping
- Topographic maps
- Planting maps

CHAPTER - 6

CROP SIMULATION MODELS

INTRODUCTION

Modeling and simulation is a discipline for developing a level of understanding of the interaction of the parts of a system and of the system as a whole. The level of understanding which may be developed via this discipline is seldom achievable via any other discipline.

Modeling and simulation is a discipline, it is also very much an art form. One can learn about riding a bicycle from reading a book. To really learn to ride a bicycle one must become actively engaged with a bicycle. Modeling and simulation follows much the same reality. You can learn much about modeling and simulation from reading books and talking with other people. Skill and talent in developing models and performing simulations is only developed through the building of models and simulating them. It is very much learn as you go process. From the interaction of the developer and the models emerges an understanding of what makes sense and what doesn't.

Simulation can be broadly defined as a technique for studying real-world dynamical systems by imitating their behavior using a mathematical model of the system implemented on a digital computer.

Simulation can also be viewed as a numerical technique for solving complicated probability models, ordinary differential equation and partial differential equation, analogously to the way in which we can use a computer to numerically evaluate the integral of a complicated function. That is why science of simulation is considered as an interdisciplinary subject as shown in Fig 5.1.

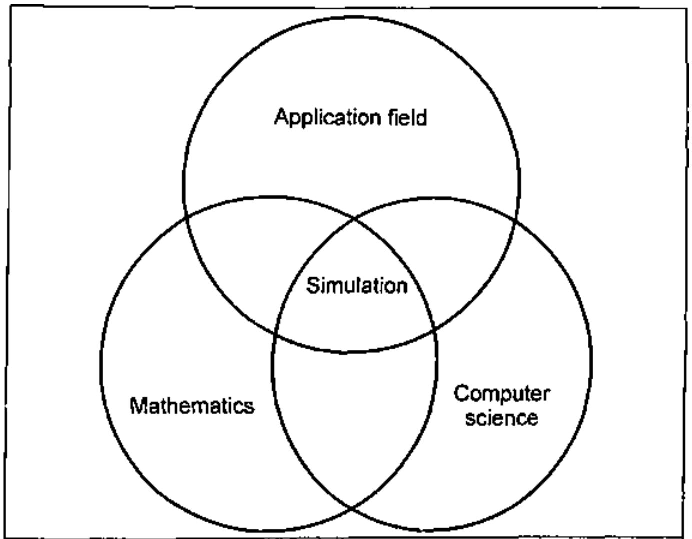


Fig 5.1. Simulation is interdisciplinary.

Computer simulation is a powerful methodology for design and analysis of complex systems. Overall approach in computer simulation is to represent the dynamic characteristics of a real-world system in a computer model. The model is subjected to experiments to obtain predictive information useful in making informed decision making about the characteristics of the real-system. Simulations are suitable for problems in which there are no closed-form analytical solutions. Since most dynamic problems in practice cannot be represented and solved fully using mathematical equations, computer simulation is a powerful and flexible methodology in complex systems analysis.

Simulations can be classified into **continuous and discrete simulations.** In continuous simulations, the state variables, i.e. the collection of variables needed to describe the system, change continuously over time and the behavior of the system is typically described by differential equations. Examples of continuous systems include the modeling of thermal or hydraulic systems. Discrete simulations are event-driven where the state variables change at discrete time points. Examples of discrete-event simulations include service industry applications such as queues in a grocery store and manufacturing applications involving material flow analysis. In general, there are three different methods to study a real-system.

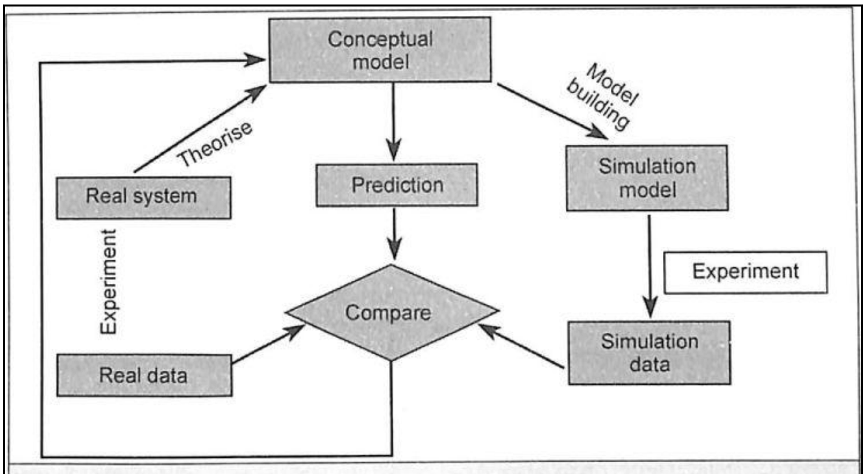


Fig 5.2. Three methods of science.

Briefly we can say that:

- Simulated system imitates operation of actual system over time.
- Artificial history of system can be generated and observed.
- Internal (perhaps unobservable) behavior of system can be studied.
- Time scale can be altered as needed.
- Conclusions about actual system characteristics can be inferred, actual system (real system) is compared with simulation.

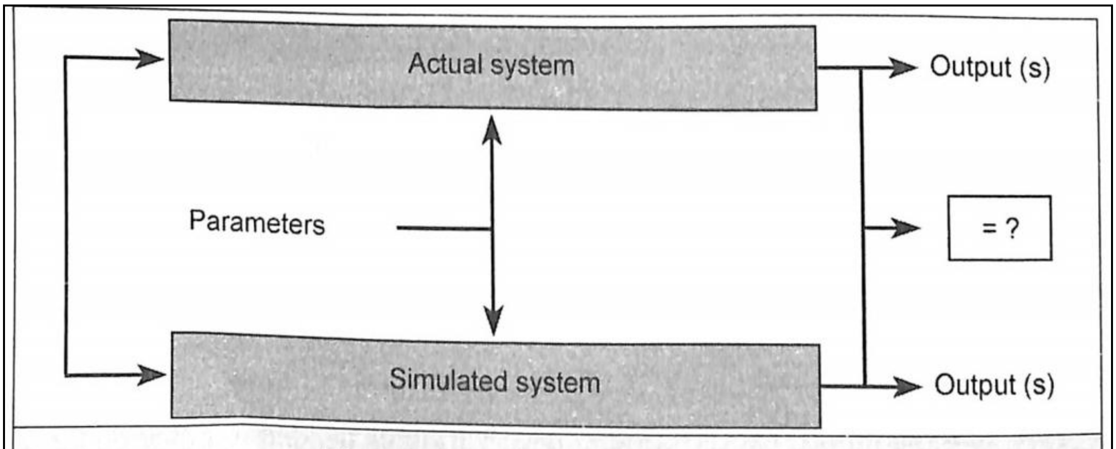


Fig 5.3. Simulation *vs* actual system.

WHEN TO USE SIMULATION?

There are several situations in which simulations can be used as indicated below: Study internals of a complex system e.g. biological system.

- Optimize an existing design e.g. routing algorithms, assembly line.
- Examine effect of environmental changes e.g. weather forecasting.

- System is dangerous or destructive e.g. atom bomb, atomic reactor, missile launching.
- Study importance of variables.
- Verify analytic solutions (theories).
- Test new designs or policies.
- Impossible to observe/influence/build the system.
- When it allows inspection of system internals that might not otherwise be observable.
- Observation of the simulation gives insights into system behaviour.
- System parameters can be adjusted in the simulation model allowing assessment of their sensitivity (scale of impact on overall system behaviour).
- Simulation verifies analysis of a complex system or can be used as a teaching tool to provide insight into analytical techniques.
- A simulator can be used for instruction, avoiding tying up or damaging an expensive, actual system (e.g. a flight simulation *v/s* use of multimillion dollar aircraft).

MODELLING CONCEPTS

There are several concepts underlying simulation. These include system and model, events, system state variables, entities and attributes, list processing, activities and delays and finally the definition of discrete-event simulation.

The process of making and testing hypotheses about models and then revising designs or theories has its foundation in the experimental sciences. Similarly, computational scientists use modeling to analyze complex, real-world problems in order to predict what might happen with some course of action. For example, Dr. Julianne Collins, a genetic epidemiologist (statistical genetics) at the Greenwood Genetics Canter, runs genetic analysis programmes and analyses epidemiological studies using the Statistical Analysis Software (SAS). Scientists are using a combination of mathematics, signal processing and scientific visualization to model, image and discover land mines.

1. System, Model and Events

A model is a representation of an actual system presents modeling and simulation concepts as introduced by Zeigler.

- A model is an abstraction of the real system.
- Simplifying assumptions are used to capture (only) important behaviors.
- Linearization, time-bound behaviors etc. may make analysis tractable.

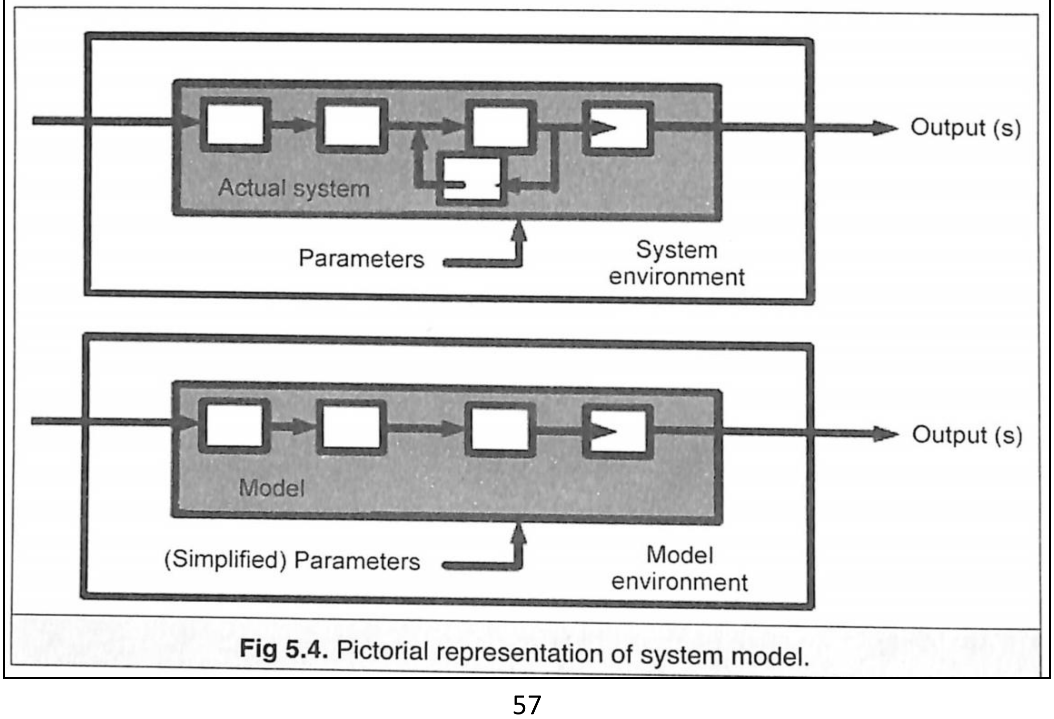


Fig 5.4. Pictorial representation of system model.

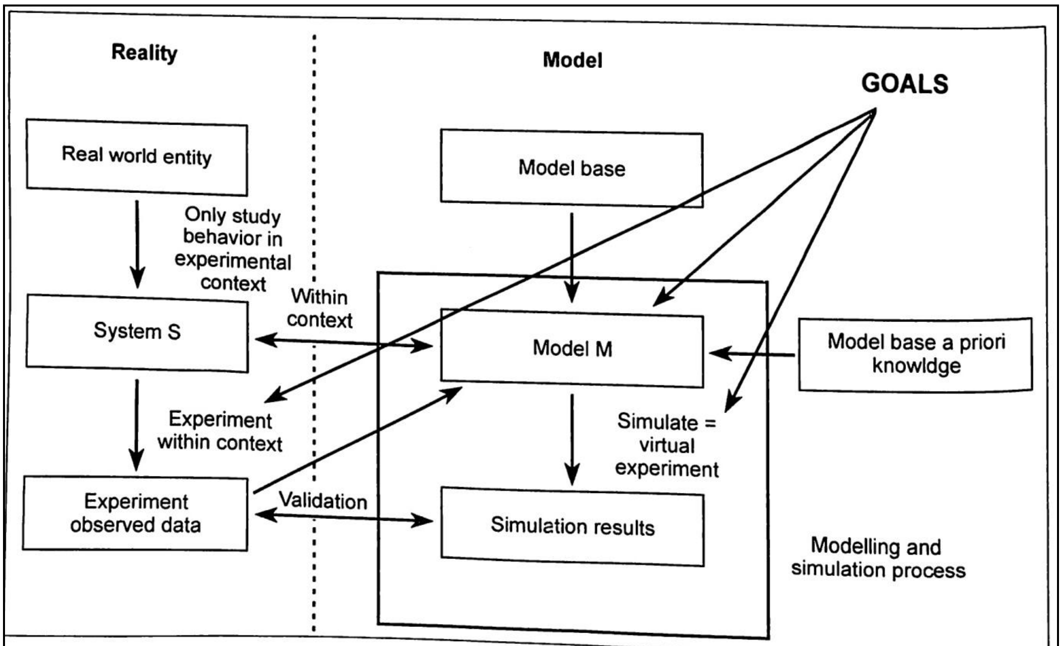


Fig 5.5. Modelling simulation.

Modeling is defined as the application of methods to analyze complex, real-world problems in order to make predictions about what might happen with various actions.

Object: It is some entity in the real-world. Such an object can exhibit widely varying behavior depending on the context in which it is studied, as well as the aspects of its behavior which are under study.

Base model: It is the hypothetical, abstract representation of the object's properties, in particular, its behavior, which is valid in all possible contexts and describes all the object's facets. A base model is hypothetical as we will never, in practice, be able to construct/represent such a total model. The question whether a base model exists at all is a philosophical one.

System: System is a well-defined object in the real-world under specific conditions, only considering specific aspects of its structure and behavior.

Experimental frame: When one studies a system in the real-world, the experimental frame (EF) describes experimental conditions (context), aspects, within which that system and corresponding models will be used. As such, the experimental frame reflects the objectives of the experimenter who performs experiments on a real system or through simulation on a model.

Immediately, there is a concern about the limits or boundaries of the model that supposedly represent the system. The model should be complex enough to answer the questions raised, but not too complex. Consider an event as an occurrence that changes the state of the system. In the example, events include the arrival of a customer for service at the bank, the beginning of service for a customer and the completion of a service. There are both internal and external events, also called endogenous and exogenous events, respectively. For example, an endogenous event in the example is the beginning of service of the customer since that is within the system being simulated. An exogenous event is the arrival of a customer for service since that occurrence is outside of the simulation. However, the arrival of a customer for service impinges on the system and must be taken into consideration.

Discrete-event simulation models are contrasted with other types of models such as mathematical models, descriptive models, statistical models and input-output models. A discrete-event model attempts to represent the components of a system and their interactions to such an extent that the objectives of the study are met. Most mathematical, statistical and input output models represent a system's inputs and outputs explicitly, but represent the internals of the model with mathematical or statistical relationships. An example is the mathematical model from physics, based on theory. Discrete-event simulation models include a detailed representation of the actual internals.

Force = Mass x Acceleration

Discrete-event models are dynamic, i.e. the passage of time plays a crucial role. Most mathematical and statistical models are static in that they represent a system at a fixed point of time. Consider the annual budget of a firm. This budget resides in a spreadsheet. Changes can be made in the budget and the spreadsheet can be recalculated, but the assage of time is usually not a critical issue. Further comments will be made about discrete-event models after several additional concepts are presented.

Models have many uses, typically:

- To understand the behavior of an existing system (why does my network performance die when more than 10 people are at work?).
- To predict the effect of changes or upgrades to the system (will spend 100,000 on a new switch cure the problem?).
- To study new or imaginary systems (let's bin the Ethernet and design our own scalable custom routing network).

2. System State Variables

System state variables are the collection of all information needed to define what is happening within the system to a sufficient level {i.e. to attain the desired output) at a given point in time. Determination of system state variables is a function of the purposes of the investigation, so what may be the system state variables in one case may not be the same in another case even though the physical system is the same.

Determining the system state variables is as much an art as a science. However, during the modelling process, any omissions will readily come to light. (And, on the other hand, unnecessary state variables may be eliminated.) Having defined system state variables, a contrast can be made between discrete-event models and continuous models based on the variables needed to track the system state. System state variables in a discrete-event model remain constant over intervals of time and change value only at certain well-defined points called event times. Continuous models have system state variables defined by differential or difference equations giving rise to variables that may change continuously over time.

Some models are mixed discrete-event and continuous. There are also continuous models that are treated as discrete-event models after some re-interpretation of system state variables and vice versa.

Entities and Attributes

An entity represents an object that requires explicit definition. An entity can be dynamic in that it "moves" through the system or it can be static in that it serves other entities. In the example, the customer is a dynamic entity, whereas the bank teller is a static entity.

An entity may have attributes that pertain to that entity alone. Thus, attributes should be considered as local values. In the example, an attribute of the entity could be the time of arrival. Attributes of interest in one investigation may not be of interest in another investigation. Thus, if red parts and blue parts are being manufactured, the colour could be an attribute. However, if the time in the system for all parts is of concern, the attribute of colour may not be of importance. From this example, it can be seen that many entities can have the same attribute or attributes (i.e. more than one part may have the attribute "red").

Resources

A resource is an entity that provides service to dynamic entities. The resource can serve one or more than one dynamic entity at the same time i.e. operates as a parallel server. A dynamic entity can request one or more units of a resource. If denied, the requesting entity joins a queue or takes some other action {i.e. diverted to another resource, ejected from the system). Other terms for queues include files, chains, buffers and waiting lines. If permitted to capture the resource, the entity remains for a time and then releases the resource.

There are many possible states of the resource. Minimally, these states are idle and busy. But other possibilities exist including failed, blocked or starved.

List Processing

Entities are managed by allocating them to resources that provide service, by attaching them to event notices thereby suspending their activity into the future or by placing them into an ordered list. Lists are used to represent queues. Lists are often processed according to FIFO (first-in first-out), but there are many other possibilities. For example, the list could be processed by LIFO (last-in-first out), according to the value of an attribute or randomly, to mention a few. An example where the value of an attribute may be important is in SPT (shortest process time) scheduling. In this case, the processing time may be stored as an attribute of each entity. The entities are ordered according to the value of that attribute with the lowest value at the head or front of the queue.

Activities and Delays

An activity is duration of time whose duration is known prior to commencement of the activity. Thus, when the duration begins, its end can be scheduled. The duration can be a constant, a random value from a statistical distribution, the result of an equation, input from a file or computed based on the event state. For example, a service time may be a constant 10 minutes for each entity, it may be a random value from an exponential distribution with a mean of 10 minutes, it could be 0.9 times a constant value from clock time 0 to clock time 4 hours, and 1.1 times the standard value after clock time 4 hours or it could be 10 minutes when the preceding queue contains at most four entities and 8 minutes when there are five or more in the preceding queue. A delay is an indefinite duration that is caused by some combination of system conditions. When an entity joins a queue for a resource, the time that it will remain in the queue may be unknown initially since that time may depend on other events that may occur. An example of another event would be the arrival of a rush order that pre-empts the resource. When pre-empt occurs, the entity using the resource relinquishes its control instantaneously. Another example is a failure necessitating repair of the resource. Discrete-event simulations contain activities that cause time to advance. Most discrete-event simulations also contain delays as entities wait. The beginning and ending of an activity or delay is an event.

MODEL CLASSIFICATIONS

Several classification categories for models exist. A system we are modeling exhibits probabilistic or stochastic behavior if an element of chance exists. For example, the path of a hurricane is probabilistic. In contrast, behavior can be deterministic, such as the position of a falling object in a vacuum. Similarly, models can be deterministic or probabilistic. A probabilistic or stochastic model exhibits random effects, while a deterministic model does not. The results of a deterministic model depend on the initial conditions and in the case of computer implementation with particular input, the output is the same for each programme execution. As we studied this and other modules, we can have a probabilistic model for a deterministic situation, such as a model that uses random numbers to estimate the area under a curve. Fig 5.6 depicts the classification of different kinds of models.

1. Discrete-Event Simulation Model

Sufficient modeling concepts have been defined so that a discrete event simulation model can be defined as one in which the state variables change only at those discrete points in time at which events occur. Events occur as a consequence of activity times and delays. Entities may compete for system resources, possibly joining queues while waiting for an available resource.

Activity and delay times may "hold" entities for durations of time. A discrete-event simulation model is conducted over time ("run") by a mechanism that moves simulated time forward. The system state is updated at each event along with capturing and freeing of resources that may occur at that time.

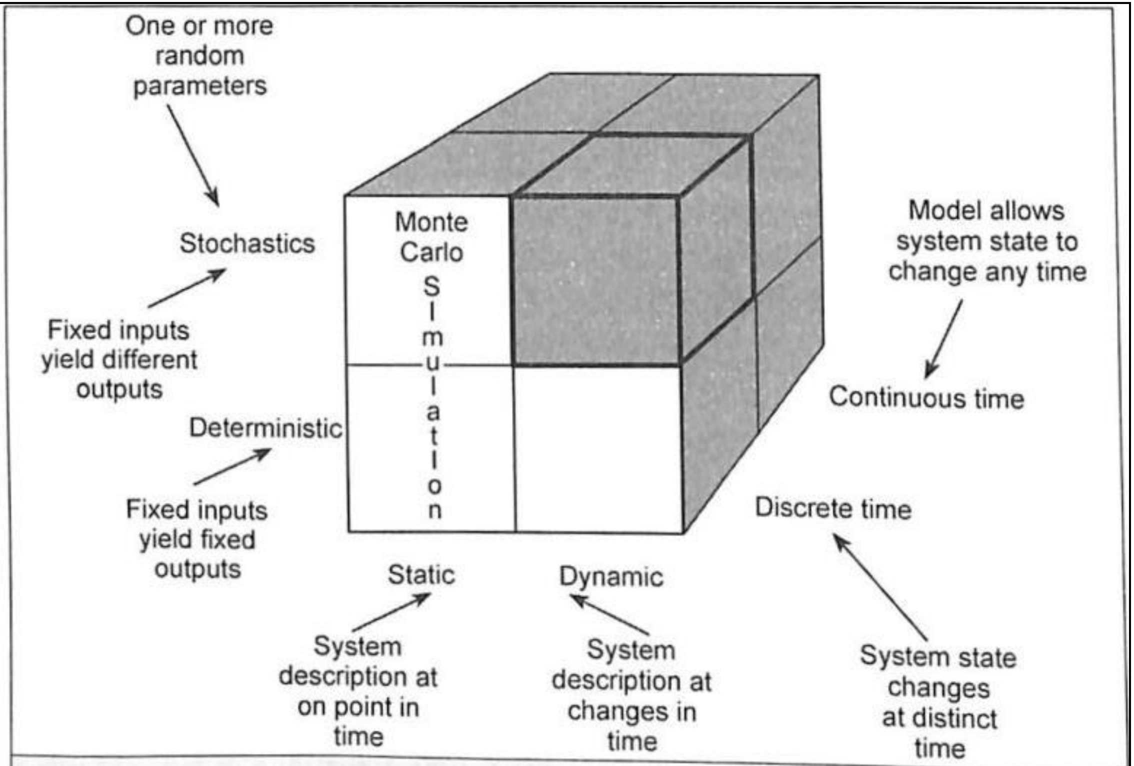


Fig 5.6. Model classifications.

Stochastic and Deterministic Systems

A system exhibits probabilistic or stochastic behavior if an element of chance exists. Otherwise, it exhibits deterministic behavior. A probabilistic or stochastic model exhibits random effects, while a deterministic model does not.

Deterministic: Randomness does not affect the behavior of the system. The output of the system is not a random variable.

Stochastic: Randomness affects the behavior of the system. The output of the system is a random variable.

2. Static and Dynamic Simulations

We can also classify models as static or dynamic. In a static model, we do not consider time, so that the model is comparable to a snapshot or a map. For example, a model of the weight of a salamander as being proportional to the cube of its length has variables for weight and length, but not for time. By contrast, in a dynamic model, time changes, so that such a model is comparable to an animated cartoon or a movie. For example, the number of salamanders in an area undergoing development changes with time; and, hence, a model of such a population is dynamic. Many of the models we consider in this text are dynamic and employ a static component as part of the dynamic model.

A static model does not consider time, while a dynamic model changes with time.

Static: A simulation of a system at one specific time or a simulation in which time is not a relevant parameter for example, Monte Carlo & steady-state simulations.

Dynamic: A simulation representing a system evolving over time for examples, the majority of simulation problems.

3. Discrete v/s Continuous Systems

When time changes continuously and smoothly, the model is continuous. If time changes in incremental steps, the model is discrete. A discrete model is analogous to a movie. A sequence of frames moves so quickly that the viewer perceives motion. However, in a live play, the action is continuous. Just as a discrete sequence of movie frames represents continuous motion of actors, we often develop discrete computer models of continuous situations.In a continuous model, time changes continuously, while in discrete model time changes in incremental steps.

Continuous state: Variables change continuously as a function of time and generally analytical method like deductive mathematical reasoning is used to define and solve the system.

State variable (SV) = /(f)

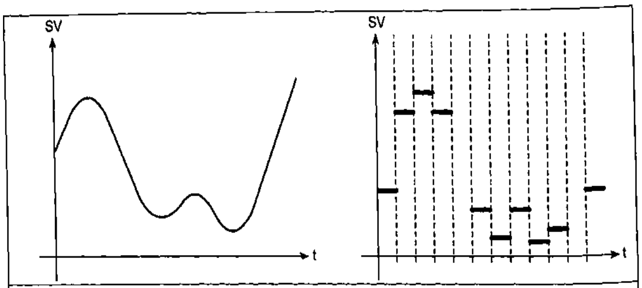


Fig 5.7. Continuous model behaviour. Fig 5.8. Discrete model behaviour.

Discrete: State variables change at discrete points in time and generally numerical method like computational procedures is used to solve mathematical models.

State variable (SV) =f(n t)

Examples of different systems

- Queue length at a cash machine: Stochastic, Discrete Time, Discrete System.
- The motion of the planets: Deterministic, Continuous Time, Discrete System.
- Logic circuit in a computer: Deterministic, Discrete Time, Discrete System.
- Flow of air around a car: Deterministic, Continuous Time, Continuous System.
- Closing prices of the 30 DAX shares: Stochastic, Discrete Time, Discrete System.

A Classic Example of Queue at Bank Counter

We see queues at everywhere. Queues are buffers to smooth out differences in arrival rates and service times. Queue Theory is well-understood. Closed-form queue-theoretic models can be used to speed up simulations. Deriving results from such models requires simulation. Here are we given an example of queue formed at bank counter. At bank counter customers arrive at random intervals and suppose there is only one cashier.

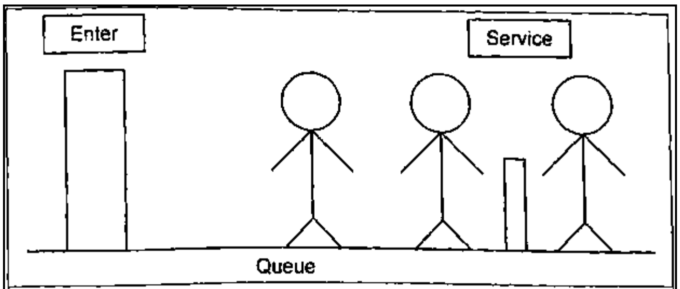


Fig 5.9. Classical example of queue.

Customers must wait in a queue. Service times at the cashier are also random measured inter-arrival times (seconds): 25, 111, 56, 232, 97, 452, 153, 45.... Measured service times (seconds): 45, 32, 11, 61, 93, 56, 30....

Now compute the average length of the queue and the probability that the cashier is busy.

PRINCIPLES OF SUCCESSFUL SIMULATION

Ten principles (10 commandments) for building a successful simulation product are briefly presented:

1. Simplicity
2. Learn from the Past
3. Create a Conceptual Model
4. Build a Prototype
5. Push the User's Desire
6. Model to Data Available
7. Separate Data from Software
8. Trust Your Creative Juices
9. Fit Universal Constraints
10. Distil Your Own Principles

1. Simplicity

When building a model, game or simulation, a good team can always envision and implement more details than are really necessary to make the product a success. Professionals can always imagine and programme much more than the customer has asked for, needs or can appreciate.

The team must be bounded by the needs of the specific product. Additional great ideas should be captured and placed on the storyboard for the next product. If allowed to render every vision into software, the final product will be a bloated and confused medley of ideas that are not clearly tied together.

2. Learn from the Past

Successful systems of the past were built by very intelligent and energetic people working with the best tools available at the time. They arrived at solutions that would fit into the computer available and applied considerable ingenuity and feats of engineering to achieve this. It is easy to look backward and smile at those primitive products. But, within each of them are nuggets of gold that should be mined when creating a new system.

Past systems are packed with good ideas that can be reused. Compact solutions to complex problems are embedded in every algorithm. However, these systems continue to grow and improve for decades. Model developers who study these are continually amazed by the complex virtual world that has been squeezed into these old machines. Creativity born of limited resources is capable of achieving what appears impossible to the general observer.

3. Create a Conceptual Model

A team of talented programmers are always eager to start programming immediately. This admirable quality must be harnessed and directed toward very difficult process of creating a conceptual model that will serve as the blueprint and foundation for the product this is part of the design process that attempts to capture the characteristics of the real-world that will be represented in the software.

Conceptual modeling consists of selecting the objects, attributes, events and interactions that will form the product. Without resorting to programming you want to identify and define a set of these that work together to form a complete, complimentary and efficient product. When creating a virtual world, there are an uncountable number of combinations of characteristics and intentions. Some are empowering, some inert and some fatal. A working conceptual model will define a virtual world that operates efficiently and appears to be complete and consistent. Designers can experiment with new ideas and trace their impacts on other algorithms within the system. Constant experimentation arrives at a package that is the best that can be found and docs so without the long development times needed to do so in software.

4. Build a Prototype

One of the reasons programmers skip the conceptual model phase is the extreme difficulty of mentally envisioning and defining an entire virtual world and the infrastructure that will support it. But, having worked through that process there are always assumptions that cannot be evaluated without working software. A prototype should be written to explore these dark comers of the conceptual model. There is no need for a prototype to look like the final product. It must enlighten the programmers who are about to jump into the problem, give them ideas, options and tools to find the best solution to the problem.

5. Push the User's Desire

Desire for a beautiful work of engineering genius that will be admired by your peers sometimes leads to products that are perfect at solving the wrong pro era. Simulation systems that are never used because they solved a problem that no one has.

Development team must be in touch with the customer and understand what gets them excited. When they use a model today, what really turns them on? What makes their job easier? What makes them recommend the product to others?

Your new product must capture the success of the old products, but overcome their limitations. Capturing success does not mean duplicating the product (though a copycat product is sometimes the solution), but requires that you achieve the same level of user excitement.

It is easy to fall into the trap of creating a product that the developer wants rather than what the customer wants. But the market base for that product is extremely small.

6. Model to Data Available

Simulations must accurately capture the performance and behavior of existing systems. These simulations may be used to direct the future structure of the models. If they are not accurate, the results can be catastrophic. Therefore, the models must be based on known characteristics and behaviors of real-systems being replicated.

Model developers need to be aware of the databases that exist in their areas. They need to understand what data exists and what data is totally unavailable. Every software model requires data that does not exist in any official or unofficial form. Every model requires that data be synthesized from what is available and from the subjective experiences of experts. But, an effort needs to be made to provide a foundation for the model based on the scarce data that does exist.

7. Separate Data from Software

In the past, the budget for CPU and memory dictated very terse implementations of models. As a result, these tended to be made up of algorithms that had been tuned to the specific situation for which it would be used. Changing the situation required changing the software. However, thanks to improvements from the hardware industry we can now afford the luxury of moving some of our assumptions and system tuning into data that can be changed by the team or by the customer. This results in a product that is much more flexible and valuable to the user.

8. Trust Your Creative Juices

When working with a new team that has not created a simulation before, they are afraid to move forward without explicit direction and definition about what they should build. They are afraid that they will head off in the wrong direction and create a product that others will criticize.

This fear of criticism is more crippling than their aversion to reworking a programme that has gone wrong.

Experienced members of the team must demonstrate and encourage the brave act of trusting your own creative juices. Team leaders must provide the vision for the entire product, but each programmer, designer and artists must have the freedom and confidence to express their vision in the product.

The fear of making mistakes results in constant repetition of requirements analysis, organizational restructuring, product research and unproductive meetings. The team avoids making concrete decisions about the design of the product. They will not allow programmers to finish a conceptual model or build a prototype.

Good leaders will not abide remaining in this trap. Experienced programmers cannot stand to vacillate around a problem they know how to solve. Self-confident programmers (new and experienced) will march somewhere of their own accord.

9. Fit Universal Constraints

Every product is bounded by the universal constraints of quality, time, money and competence. When you run out of one of these, the product is finished regardless of any software details. Managers have been taught to fit products into the bounds of the first three, but are largely unaware of the fourth.The quality, detail and capabilities of a simulation are unlimited in and of themselves. The time to produce the product dictates the level of quality in its many forms. Amount of money available limits the size of the team and is tied directly to the time factor (since we all expect to get paid every month). These three constraints are preached in multiple management courses and are applied to every form of product under the sun.

However, there is a fourth constraint - competence. Some projects require skills that are in short supply. Therefore, a generously funded project with a long schedule may still be strangled by the inability to hire people with the skills needed to do the work. Good leaders, programmers, designers and artists are not available to do all of the work that companies want done. As a result, some projects are understaffed and others are staffed with incompetent people. A successful project must fit into the boundaries formed by all four of these constraints.

10. Distil Your Own Principles

The nine principles listed above have been derived from the experiences of very talented people. However, others associated with building a simulation product have a rich pool of their own experiences. Such rich experience may be used to avoid making the same mistakes they have made in the past to create a working environment that is productive, rewarding and profitable.

MODELLING IN AGRICULTURAL SYSTEMS

The complexity of agricultural systems and models in agriculture are briefly presented.

1. Complexity of Agricultural Systems

Agricultural systems are characterized by having many organizational levels. From the individual components within a single plant, through constituent plants, to farms or a whole agricultural region or nation, lies a whole range of agricultural systems. Since the core of agriculture is concerned with plants, the level that is of main interest to the agricultural modeler is the plant. Reactions and interactions at the level of tissues and organs are combined to form a picture of the plant that is then extrapolated to the crop and their output.

2. Models in Agriculture

Efficient crop production technology is based on a right decision at right time in a right way. Traditionally, crop production functions that are used in agricultural decision making were derived from conventional experienced base agronomic research, in which crop yield were related to some defined variable based on correlation and regression or regression analysis. Crop yield were expressed as polynomial or exponential mathematical function of the defined variables, with regression coefficient. Application of correlation and regression analysis has provided some qualitative understanding of the variable and their interactions that were involved in cropping system and has contributed to the progress of agricultural sciences. However, quantitative information obtained from this type of analysis is very site specific. Information obtained can only be reliably applied to other site where climate, soil parameters and crop management are similar to those used in developing the original functions. Thus, the quantitative application of regression crop based model for decision-making is severely limited.

Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. Owing to the complexity of the system and the incomplete status of present knowledge, it becomes impossible to completely represent the system in mathematical terms and hence, agricultural models are images of the reality. Unlike in the fields of physics and engineering, universal models do not exist within the agricultural sector. Models are built for specific purposes and the level of complexity is accordingly adopted. Inevitably, different models are built for different subsystems and several models may be built to simulate a particular crop or a particular aspect of the production system.

Agriculture models are, however, only crude representations of the real-systems because of the incomplete knowledge resulting from the inherent complexity of the systems. Judicious use of such model is possible only if the user has a sound understanding of model structure, scope and limitation. Crop modeling is a new discipline and back-ground literature is scarce. Basic information about crop modeling is briefly presented.

3. Input Data Requirement for Crop Modeling

Crop modeling requires data related to weather, crop, soil, management practices and insect-pests as indicated below:

- **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.
- **Crop data:** Crop, variety, crop phenology (days to anthesis, days to maturity etc.), leaf area index, grain yield above ground biomass, 1000-grain weight.
- **Soil data:** Thickness of soil layer, pH, EC, N, P, K, soil organic carbon, soil texture, sand and clay per cent (soil moisture, saturation, field capacity and wilting point), bulk density etc.
- **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, C : N ratio of those sources has to be quantified.
- **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.

OPTIMISATION OF AGRICULTURAL INPUTS

- Optimizing models have the specific objective of devising the best option in terms of management inputs for practical operation of the system.
- For deriving solutions, they use decision rules that are consistent with some optimizing algorithm.
- This forces some rigidity into their structure resulting in restrictions in representing stochastic and dynamic aspects of agricultural systems.

- Linear and non-linear programming was used initially at farm level for enterprise selection and resource allocation.
- Later, applications to assess long-term adjustments in agriculture, regional competition, transportation studies, integrated production and distribution systems as well as policy issues in the adoption of technology, industry re-structuring and natural resources have been developed.
- Optimizing models do not allow the incorporation of many biological details and may be poor representations of reality.
- Using the simulation approach to identify a restricted set of management options that are then evaluated with the optimizing models has been reported as a useful option.

Some Crop Models Reported In Recent Literature

SOFTWARE	DETAILS
SLAM II	Forage harvesting operation
SPICE	Whole plant water flow
REALSOY	Soybean
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 sp and Leucaena sp*.
GOSSYM-COMAX	Cotton
CropSyst	Wheat and other crops
SIMCOM	Crop (CERES crop modules) and economics
LUPINMOD	Lupin
TUBERPRO	Potato and disease
SIMPOTATO	Potato
WOFOST	Wheat & maize, Water and nutrient
WAVE	Water and agrochemicals
SUCROS	Crop models
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
QCANE	Sugarcane, potential conditions
AUSCANE	Sugarcane, potential & water stress conditions, erosion
CANEGRO	Sugarcane, potential & water stress conditions.
APSIM-Sugarcane	Sugarcane, potential growth, water and nitrogen stress
NTKenaf	Kenaf, potential growth, water stress

AGRICULTURAL MODEL USES AND LIMITATIONS

Models are developed by agricultural scientists but the user-group includes the latter as well as breeders, agronomists, extension workers, policy makers and farmers. As different users possess varying degrees of expertise in the modeling field, misuse of models may occur. Since crop models are not universal, the user has to choose the most appropriate model according to his objectives. Even when a judicious choice is made, it is important that aspects of model limitations be borne in mind such that modeling studies are put in the proper perspective and successful applications are achieved.

MODEL USES

Simulation modeling is increasingly being applied in research, teaching, farm and resource management, policy analysis and production forecasts. These models can be applied into three areas, namely, research tools, crop system management tools and policy analysis tools.

A summary of some specific applications within the different groups follows:

A. AS RESEARCH TOOLS

- **Research understanding:** Model development ensures the integration of research understanding acquired through discreet disciplinary research and allows the identification of the major factors that drive the system and can highlight areas where knowledge is insufficient. Thus, adopting a modeling approach could contribute towards more targeted and efficient research planning. For example, changing the plant density in a sugar beet model resulted in model failure. This failure stimulated studies that gave additional information concerning biomass partitioning in the sugar beet.
- **Integration of knowledge across disciplines:** Adoption of a modular approach in model coding allows the scientist to pursue his discipline-oriented research in an independent manner and at a later stage to integrate the acquired knowledge into a model. For example, the modular aspect of the APSIM software allows the integration of knowledge across crops as well as. Across disciplines for a particular crop. Adoption of a modular framework also allows for the integration of basic research that is earned out in different regions, countries and continents. This ensures a reduction of research costs (e.g. through a reduction in duplication of research) as well as the collaboration between researchers at an international level.
- **Improvement in experiment documentation and data organization:** Simulation model development, testing and application demand the use of large amount of technical an observational data supplied in given units and in a particular order. Data handling forces the modeler to resort to formal data organization and database systems. The systematic organization of data enhances the efficiency of data manipulation in other research areas (e.g. productivity analysis, change in soil fertility status over time).
- **Genetic improvement:** As simulation models become more detailed and mechanistic, they can mimic the system more closely. More precise information can be obtained regarding the impact of different genetic traits on economic yields and these can be integrated in genetic improvement programs, e.g. the NTKenaf model. Researchers used the modeling approach to design crop ideotypes for specific environments.
- **Yield analysis:** When a model with a sound physiological background is adopted, it is possible to extrapolate to other environments. Use of several simulation models to assess climatically-determined yield in various crops. The CANEGRO model has been used along the same lines in the South African sugar industry. Through the modeling approach, quantification of yield reductions caused by non-climatic causes (e.g delayed sowing, soil fertility, pests and diseases) becomes possible. Almost all simulation models have been used for such purposes. Simulation models have also been reported as useful in separating yield gain into components due to changing weather trends, genetic improvements and improved technology.

B. AS CROP SYSTEM MANAGEMENT TOOLS

- **Cultural and input management:** Management decisions regarding cultural practices and inputs have major impact on yield. Simulation models, that allow the specification of management options, offer a relatively inexpensive means of evaluating a large number of strategies that would rapidly become too expensive if the traditional experimentation approach were to be adopted. Many publications are available describing the use of simulation models with respect to cultural management (planting and harvest date, irrigation, spacing, selection of variety type) and input application (water and fertilizer).
- **Risks assessment and investment support:** Using a combination of simulated yields and gross margins, economic risks and weather-related variability can be assessed. These data can then be used as an investment decision support tool.

- **Site-specific farming:** Profit maximization may be achieved by managing farms as sets of sub-units and providing the required inputs at the optimum level to match variation in soil properties across the farm. Such an Endeavour is attainable by coupling simulation models with geographic information systems (GIS) to produce maps of predicted yield over the farm. But, one of the prerequisites is a systematic characterization of units that may prove costly.

C. AS POLICY ANALYSIS TOOLS

- **Best management practices:** Models having chemical leaching or erosion components can be used to determine the best practices over the long-term. The EPIC model has been used to evaluate erosion risks due to cropping practices and tillage.
- **Yield forecasting:** Yield forecasting for industries over large areas is important to the producer (harvesting and transport), the processing agent (milling period) as well as the marketing agency. The technique uses weather records together with forecast data to estimate yield across the industry.
- **Introduction of a new crop:** Agricultural research is linked to the prevailing cropping system in a particular region. Hence, data concerning the growth and development of a new crop in that region would be lacking. Developing a simulation model based on scientific data collected elsewhere and a few datasets collected in the new environment helps in the assessment of temporal variability in yield using long-term climatic data. Running the simulations with meteorological data in a balanced network of locations also helps in locating the industry.
- **Global climate change and crop production:** Increased levels of $C0_2$ and other greenhouse gases are contributing to global warming with associated changes in rainfall pattern. Assessing the effects of these changes on crop yield is important at the producer as well as at the government level for planning purposes.

MODEL LIMITATIONS

- Agricultural systems are characterized by high levels of interaction between the components that are not completely understood.
- Models are, therefore, crude representations of reality. Wherever knowledge is lacking, the modeler usually adopts a simplified equation to describe an extensive sub-system.
- Simplifications are adopted according to the model purpose and / or the developer’s views and therefore constitute some degree of subjectivity.
- Models that do not result from strong interdisciplinary collaboration are often good in the area of the developer’s expertise but are weak in other areas.
- Model quality is related to the quality of scientific data used in model development, calibration and validation.
- When a model is applied in a new situation (e.g. switching a new variety), the calibration and validation steps are crucial for correct simulations.
- The need for model verification arises because all processes are not fully understood and even the best mechanistic model still contains some empirism making parameter adjustments vital in a new situation.
- Model performance is limited to the quality of input data.
- It is common in cropping systems to have large volumes of data relating to the above-ground crop growth and development, but data relating to root growth and soil characteristics are generally not as extensive.
- Using approximations may lead to erroneous results.
- Most simulation models require that meteorological data be reliable and complete.
- Meteorological sites may not fully represent the weather at a chosen location.
- In some cases data may be available for only one (usually rainfall) or a few (rainfall and temperature) parameters but data for solar radiation, which is important in the estimation of photosynthesis and biomass accumulation, may not be available.

- In such cases, the user would rely on generated data.
- At times, records may be incomplete and gaps have to be filled.
- Using approximations would have an impact on model performance.
- Model users need to understand the structure of the chosen model, its assumptions its limitations and its requirements before any application is initiated, e.g. using a model like QCANE, developed for cane growth under non-limiting conditions, would lead to erroneous output and analysis if it is used to simulate under water or nitrogen stress conditions.
- At times, model developers may raise the expectations of model users beyond mode capabilities.
- Users, therefore, need to judiciously assess model capabilities and limitations before it is adopted for application and decision-making purposes.
- Generally, crop models are developed by crop scientists and if interdisciplinary collaboration is not strong, the coding may not be well-structured and model documentation may be poor.
- This makes alteration and adaptation to simulate new situations difficult, especially for users with limited expertise.
- Finally, using a model for an objective for which it had not been designed or using a model in a situation that is drastically different from that for which it had been developed would lead to model failure.

CHAPTER - 7

STCR (SOIL TEST CROP RESPONSE)

SOIL MAPPING

Soil maps are required on different scales varying from 1:1 million to 1:4,000 to meet the requirements of planning at various levels. As the scale of a soil map has direct correlation with the information content and field investigations that are carried out, small scale soil maps of 1:1 million are needed for macro-level planning at national level.

Soil maps at 1:250,000 scale provide information for planning at regional or state level with generalized interpretation of soil information for determining the suitability and limitations for several agricultural uses and requires less intensity of soil observations and time.

Soil maps at 1:50,000 scale where association of soil series are depicted, serve the purpose for planning resources conservation and optimum land use at district level and require moderate intensity of observations in the field.

Large scale soil maps at 1:8,000 or 1:4,000 scale are specific purpose maps which can be generated through high intensity of field observations based on maps at 1:50,000 scale of large scale aerial photographs or very high resolution satellite data. Similarly, information on degraded lands like salt affected soils, eroded soils, waterlogged areas, *jhum* lands (shifting cultivation) etc. is required at different scales for planning strategies for reclamation and conservation of degraded lands.

Remote Sensing for Soil and Land Degradation Mapping

Though conventional soil surveys were providing information on soils they are subjective, time consuming and laborious. Remote sensing techniques have significantly contributed speeding up conventional soil survey programmes. In conventional approach approximately 80% of total work requires extensive field traverses in identification of soil types and mapping their boundaries and 20% in studying soil profiles, topographical features and for other works.

In the case of soil surveys with aerial photographs or satellite data, considerable field work with respect to locating soil types and boundaries is reduced owing to synoptic view.

Remote sensing techniques have reduced field work to a considerable extent and soil boundaries are more precisely delineated than in conventional methods. Satellite data were utilized in preparing small scale soil resource maps showing soil subgroups and their association for about three decades.

Remote sensing data from LandSat MSS are used for mapping soils and degraded lands like eroded lands, ravine lands, salt- affected soils and shifting cultivation areas.

LandSat TM, SPOT and IRS satellites enabled to map soils at 1:50,000 scale at the level of association of soil series due to higher spatial and spectral resolutions. In one of the major projects in Department of Space, Government of India - “Integrated Mission for Sustainable Development”-the soil mapping has been taken up at 1:50,000 scale for about 175 districts/blocks in the country.

With the availability of PAN data with 5.8 m spatial resolution from IRS-1C/1D satellites soil resources mapping at 1:25,000 or larger scale has been attempted using PAN merged LISS-III data. The IKONOS data has the potential for farm level soil mapping (>1:10,000).

At NRSA, the maps of salt affected soils for entire country have been prepared at 1:250,000 scale using satellite data from LandSat TM / IRS sensors with accepted nation-wide legend for mapping salt affected soils in association with Central and State government organizations.

Salt affected soils are also mapped at 1:50,000 scale on limited scale using satellite data. Multi-temporal satellite data is being used for monitoring salt affected soils on operational basis. Satellite data have also been utilized in qualitative assessment of soil erosion in north-eastern states of Manipur, Tripura and Arunachal Pradesh and to monitor eroded and shifting cultivation areas in Tripura. Similarly, remotely sensed data from TM and IRSLISS-I/II have also been used in studying ravine lands, waterlogged areas and impact of mining on forest environment.

Soil Mapping Methods

Soil surveyors consider the topographic variation as a base for depicting the soil variability. Even with the aerial photographs, only physiographic variation in terms of slope and aspects and land cover are being practiced for delineating the soil boundary. Multispectral satellite data are being used for mapping soil up to family association level (1.50,000). Methodology in most of the cases involves visual interpretation. However, computer aided digital image processing technique has also been used for mapping soil and advocated to be a potential tool.

Visual Image Interpretation

Visual interpretation is based on shape, size, tone, shadow, texture, pattern, site and association. This has the advantage of being relatively simple and inexpensive. Soil mapping needs identification of a number of elements. The elements which are of major importance for soil survey are land type, vegetation, land-use, slope and relief. Soils are surveyed and mapped, following a three-tier approach, comprising interpretation of remote sensing imagery and/or aerial photograph, field survey (including laboratory analysis of soil samples) and cartography. Several workers have concluded that the technology of remote sensing provides better efficiency than the conventional soil survey methods at the reconnaissance (1:50,000) and detailed (1:10,000) scale of mapping.

Computer-Aided Approach

Numerical analysis of remote sensing data utilizing the computers has been developed because of requirement to analyze faster and extract information from the large quantities of data. Computer aided techniques utilize the spectral variations for classification. Pattern recognition in remote sensing assists in identification of homogeneous areas, which can be used as a base for carrying out detailed field investigations and generating models between remote sensing and field parameters. Major problem with conventional soil survey and soil cartography is accurate delineation of boundary. Field observations based on conventional soil survey are tedious and time consuming. Remote sensing data in conjunction with ancillary data provide the best alternative, with a better delineation of soil mapping units. However, there is need to have an automated method for accurate soil boundary delineation with a trans-disciplinary and integrated approach.

Fertilizer recommendation using GIS

Modern frontier technologies involving system approach for efficient crop and input management is the need of present century to optimize yields and reduce pressure on natural resources leading to **sustainable agricultural management**. This vision, reflected in the concept of **precision farming**, offers the promise of increasing productivity while decreasing production costs and minimizing environmental impacts. The high-tech tools of precision farming are: an integration of several advanced technologies like geographic information system (GIS), global positioning systems (GPS), remote sensing, crop models, ground-based sensors and the internet. With the rapid pace of sensor improvement in the current satellite series (IRIS, LANDSAT, SPOT and IKONOS) and some future missions (EYE GLASS, ORB VIEW and GREENSAT), a range of high resolution both spatial and temporal would be available to map and quantify field scale crop response to variable soil, weather condition and farm management practices leading to precise crop management.

Geospatial technologies for precision farming (PF) involves an integrated technology such as GPS, GIS, remote sensing, variable rate technology (VRT), crop models, yield monitors and precision irrigation. Various configurations of these technologies are suitable for different precision farming operations. **Information technology** such as the internet is good means for some agri-business companies to deliver their services and products.

Site specific nutrient management (SSNM) approach, relatively new approach of nutrient recommendations, is mainly based on the indigenous nutrient supply from the soil and nutrient demand of the crop for achieving targeted yield. The SSNM recommendations could be evolved on the basis of solely plant analysis or soil-cum-plant analysis.

PLANT ANALYSIS BASED SSNM

It is considered that the nutrient status of the crop is the best indicator of soil nutrient supplies as well as nutrient demand of the crops. Thus, the approach is built around **plant analysis**. Initially, SSNM was tried for lowland rice, but subsequently, it proved advantageous to several contemporary approaches of fertilizer recommendations in rice, wheat and other rice-based production systems prevalent in Asian countries. Five key steps for developing field-specific fertilizer NPK recommendations have been developed for rice, through the basic principles remain the same for other crops as well.

1. Selection of the Yield Goal

A yield goal exceeding 70-80 per cent of the variety-specific potential yield (Ymax) has to be chosen. Ymax is defined as the maximum possible grain yield limited only by climatic conditions of the site, where there are no other factors limiting crop growth. The logic behind selection of the yield goal to the extent of 70-80 per cent of the Ymax is that the internal NUES decrease at very high yield levels near Ymax. Crop growth models (DSSAT) can be used to work out Ymax of crop variety under a particular climatic conditions.

2. Assessment of Crop Nutrient Requirement

The nutrient uptake requirements of a crop depend both on yield goal and Ymax. In SSNM, nutrient requirements are estimated with the help of quantitative evaluation of fertility of tropical soils (QUEFTS) models. Nutrient requirements for a particular yield goal of a crop variety may be smaller in a high yielding season than in a low yielding one.

3. Estimation of Indigenous Nutrient Supplies

Indigenous nutrient supply (INS) is defined as the total amount of a particular nutrient that is available to the crop from the soil during the cropping cycle, when other nutrients are non-limiting. The INS is derived from soil incorporated crop residues, water and atmospheric deposition. It is estimated by measuring plant nutrient uptake in an omission plot embedded in the farmers' field, wherein all other nutrients except the one (N, P or K) in question, are applied in sufficient amounts.

4. Computation of Fertilizer Nutrient Rates

Field-specific fertilizer N, P or K recommendations are calculated on the basis of above steps (1-3) and the expected **fertilizer recovery efficiency** (RE, kg of fertilizer nutrient taken up by the crop per kg of the applied nutrient). Studies indicated RE values of 40-60 % for N, 20-30 % for P and 40-50 % for K in rice under normal growing conditions, when the nutrients are applied as water soluble fertilizer sources.

5. Dynamic Adjustment of N Rates

Whereas fertilizer P and 11, as computed above, are applied basally (at the time of I sowing/planting), the N rates and application schedules can be further adjusted as per the crop demand using **chlorophyll meter** (popularly known as **SPAD**) or **leaf colour chart (LCC)**. Recent on-farm studies in India and elsewhere have revealed a significant advantage of

SPAD/LCC-based N management schedules in rice and wheat in terms of yield gain, N use efficiency and economic returns over the conventionally recommended N application involving 2 or 3 splits during crop growth irrespective of N supplying capacity of the soils. In winter season maize crop, SPAD-based ($\leq$ 37) N application resulted in a saving of 55 Kg N/ha as compared to soil test crop response equation-based N application without any yield reduction. **Agronomic efficiency** was also higher in the crop. In wheat, timing of N application at SPAD value $\leq$ 42 resulted in 9 % higher wheat yield along with 20 kg/ha N saving, than the recommended soil based N supply.

SOIL-CUM-PLANT ANALYSIS BASED SSNM

In this case, nutrient availability in the soil, plant nutrient demands for a higher target yield (not less than 80% of Ymax) and RE of applied nutrients are considered for developing fertilizer use schedule to achieve maximum economic yield of a crop variety. In order to ascertain desired crop growth, not limited by apparent or **hidden huger** of nutrients, soil is analyzed for all macro and micronutrients well-before sowing/planting. Total nutrient requirement for the **targeted yield** and RE are estimated with the help of documented information available for similar crop growing environments. **Field-specific fertilizer rates** are then suggested to meet the nutrient demand of the crop (variety) without depleting soil reserves. These **soil-test crop response (STCR)** based recommendations are now in practice to achieve desired yield targets in many field crops. Thus, recent studies with intensive cropping systems have shown that fertilizer recommendations with above approach offer greater economic gains as compared with NPK fertilizer schedules conventionally prescribed by **soil testing laboratories.**

1. Decision Support Systems

Nutrient Expert® (NE) is an easy-to-use, interactive and computer-based decision support tool that can rapidly provide nutrient recommendations for an individual farmer field in the presence or absence of **soil testing** data. NE is nutrient decision support software that uses the principles of SSNM and enables farm advisors to develop fertilizer recommendations tailored to a specific field or growing environment. NE allows users to draw required information from their own experience, farmers' knowledge of the local region and farmers' practices. NE can use experimental data but it can also estimate the required SSNM parameters using existing site information. The **algorithm** for calculating fertilizer requirements in NE is determined from a set of on-farm trial data using SSNM guidelines. The parameters needed in SSNM are usually measured in **nutrient omission trials** conducted in farmers' fields, which require at least one crop season. With NE, parameters can be estimated using proxy information, which allows farm advisors to develop fertilizer guidelines for a location without data from field trials.

2. Decision Rules to Estimate Site-Specific Nutrient Management Parameters

The NE estimates attainable yield and yield response to fertilizer from site information using decision rules developed from on-farm trials. Specifically, NE uses characteristics of the growing environment—water availability (irrigated, fully rainfed and rainfed with supplemental irrigation) and any occurrence of flooding or drought, soil fertility indicators- soil texture, soil color and organic matter content, soil test for P or K (if available), historical use of organic materials (if any) and problem soils (if any), crop sequence in farmer's cropping pattern; crop residue management and fertilizer inputs for the previous crop and farmers' current yields. Data for specific crops and specific geographic regions are required in developing the decision rules for NE. The datasets must represent diverse conditions in the growing environment characterized by variations in the amount and distribution of rainfall, crop cultivars and growth durations, soils and cropping systems.

3. Current Versions of Nutrient Expert

The NE has been developed for specific crops and geographic regions. Nutrient Expert® for hybrid maize (**NEHM**) for favorable tropical environments (South-East Asia) was developed in late 2009 and underwent field evaluation in Indonesia and the Philippines. Using NEHM as a model, the NE concept has been adapted to other crops and geographic regions or countries. In 2011, beta versions of NE for maize were developed for South Asia, China, Kenya and Zimbabwe. Likewise, beta versions of NE for wheat were developed for South Asia as well as China. In 2013, field validated versions of NE maize and NE wheat have been released for public use in South Asia and China.

PRECISION FARMING AND SITE SPECIFIC NUTRIENT MANAGEMENT

Site specific farming requires a different way of thinking about the land. Legal description of a field is defined by a surveyor and an attorney. Fields are of different shapes because of human decisions. However, soils within these boundaries are variable due to forces of nature and human activity. Nutrient properties of these soils can be different due to past nutrient application practices. Crop productivity is variable within fields due to soil property differences. Some differences between soils are small, but often the differences are large. Site specific management is used to detect and measure the differences within fields, record these differences at specific locations and then use this information to guide changes in management or inputs. Site specific farming is managing areas within fields, rather than using the same management on the entire field.

Precision Farming in Fertilizer Management

Developments in computer technology, geographic information systems (GIS), global positioning system (GPS), electronic sensors and controllers and a wide variety of communication tools during the 1990s and into the 21st century have provided exciting new technologies that can be applied in agriculture. Under the collective term, precision fanning- these technologies have opened many new opportunities for improving crop and soil management on a site-specific basis.

The SSNM fits anywhere in the world and often may be easier to implement on small scale farms where each field is more carefully monitored and managed. It is not limited to large fields and large equipment. The concept of SSNM attempts to match best management practices (BMPs) to the individual location, considering that location has unique soil and climate and the unique management skills and experience of the grower. It is matching management decisions to the resources of the site, the knowledge base of farmer about his fields and the needs ol his crops and any information about previous management responses unique to the farm. The unique combination of these resources allows each farmer to use them to his advantage in optimizing yields and profits for his production system.

A small farmer with only one field probably does not have a GPS system and probably doesn’t need one. But he can still use SSNM. His knowledge of his fields and the crops he grows and his experience and records of past production all can be used to compile the unique information he can use to meet crop needs and optimize profits. Making observations, keeping records, analyzing resources (such as soil characteristics and soil tests) and employing his best knowledge of practices for his farm are all a part of SSNM.

Building a Nutrient Management GIS Database for Each Field

Details of nutrient management and maintaining records of fertilizer use, crop yields and nutrient removal should be kept for every field on every farm in the world. The goal should be to develop a database for each field with geographically-referenced data that can be analyzed for nutrient balance, productivity, profitability and environmental impacts. Where GPS and GIS technology are not available, other methods of documenting location can be used, but GPS/GIS are the best approach for larger production areas. Important point for all is to begin keeping records to document production and fertilizer use.

The GIS analysis allows the data (years, crops, yields, soil characteristics, nutrient additions, pest problems etc.) from different layers (Fig 1.6) to be analyzed for each part of a field. This allows for interpretation of the cause-effect relationships among the various variables for which data are available. It becomes a very powerful management tool that gets better with each year of data that is added.

For the individual grower, such a database is a valuable tool to guide future management decisions. For advisers and input suppliers it can be used to summarize local activities and guide training and product supply needs.

For government agencies it can help guide policies for improving the production systems for the area. In all cases, better data, linked to GIS, has great potential for guiding better-informed decision making for all stakeholders.A variety of data management software programmes and services are available for farmers and their advisers to use in collecting, organizing and interpreting their data and range from individual farmer data systems, to data systems that allow sharing of data among many farmers. Data privacy issues, potential for marketing of data, values gained by sharing information and other factors must be considered in determining which data system is used.

Documentation of Needs, Rates of Application and Yield Responses

Soil testing, either on a uniform grid basis or based upon management zones, is the best way to determine and document variability in nutrient supplying power of the soil in a field. Along with documentation of variability in crop nutrient removal (such as by use of a yield monitor), soil test data can be used to estimate the nutrients needed from fertilizer and manure to maintain or improve the soil productivity. These data then guide the development of a site specific nutrient application map to make most efficient use of the nutrients applied and protect against over-application that can cause environmental problems and excess expense, as well as prevent under-application that can affect yield potential and also lead to environmental problems.

How Site Specific Management fits all Scales of Operation and All Parts of the World

The SSNM enables farmers to tailor nutrient management to the specific conditions of their field and provides a framework for best management practices. Total fertilizer needed to achieve a profitable target yield is determined from the anticipated yield gain, applied fertilizer and a targeted efficiency of fertilizer use. Fertilizer is supplied to match the crop's need for supplemental nutrients. The SSNM is an important nutrient management concept for all parts of the world.

Managing the right source at the right rate, right time and in the right place may be best accomplished with the right tools. Various technologies are available to help farmers and crop advisers make decisions related to nutrient management, from soil sampling to fertilizer application to yield measurement. These tools enhance the ability to fine-tune nutrient management decisions and develop the SSNM plan for each field. Farmers and the farm employees, management and agronomic advisers and input suppliers are all part of a team, each contributing to the decision process in different ways.

Right management means site specific management. Making management decisions with information collected on the specific field helps produce efficient, economical and environmentally appropriate nutrient management plans. Costs of being wrong can be high. That means the price paid for technology to fine-tune those decisions is easy to justify. Plus, the costs have gone down for many of the tools, so the components of SSNM technology do not require as much investment. Employing global positioning system (GPS) technology to geo-reference input and yield data is a good first step. In developed countries, most fertilizer and chemical dealers now have GPS-guided application equipment and harvesting equipment now comes with GPS as a standard or easily added feature. Similar GPS systems are used on planting equipment for collecting geo-referenced planting data, starter fertilizer application and other inputs. With proper controllers, variable rate application of inputs can be added to the management plan. High-accuracy guidance systems help avoids costly skips and overlaps, saving on input costs for seed, fertilizer and pesticides. Reduced operator stress and fatigue are major added benefits.

SSNM for Rice

The International Rice Research Institute (IRRI) has developed a SSNM program, based on scientific principles for supplying rice with optimum levels of essential nutrients at the critical growth stages of active tillering and panicle initiation. SSNM helps farmers apply adequate fertilizer for their rice crop in a specific field and season, for efficient nutrient use and high yields, translating to high cash value of the harvest.The concept of SSNM in rice was developed in cooperation with researchers across Asia and tested on farms in eight rice growing regions in six countries. It consists of three steps as shown in Fig.

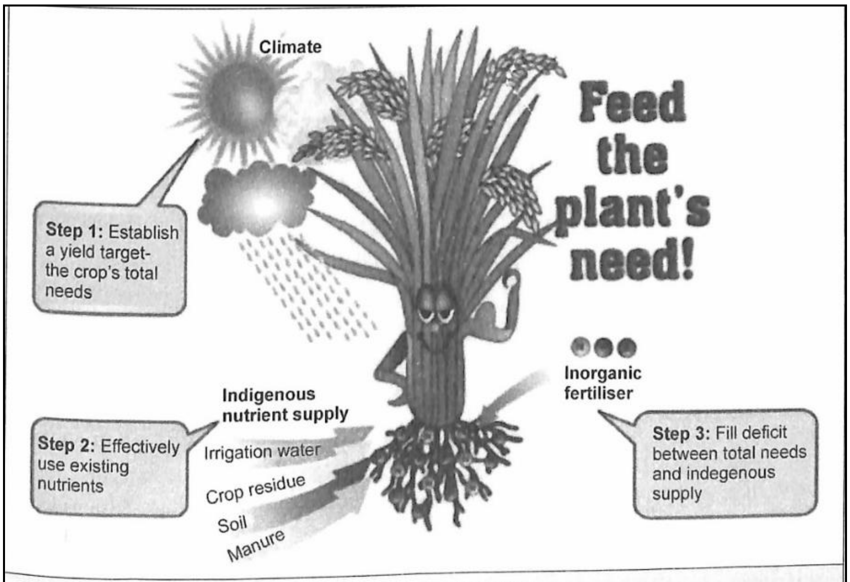


Fig 1.7. Three steps of SSNM in rice.

In the first step, an attainable yield target is established. The yield target for a given location and season is the estimated grain yield attainable when N, P and K constraints are overcome. As the amount of nutrients taken up by a rice crop is directly related to yield, the yield target indicates the total amount of nutrients that must be taken up by the crop. The second step consists of effectively using the indigenous nutrients coming from the soil, organic amendments, crop residues, and manure and irrigation water. An estimate of the nutrients taken up by the crop from indigenous sources can be obtained from the grain yield of a crop not fertilized with the nutrient of interest but fertilized with other nutrients to ensure they do not limit yield. In the third step, the quantity of required fertilizer is applied to fill the deficit between the crop’s total needs for nutrients as determined by the yield target and the supply of these nutrients from indigenous sources. The total quantity of fertilizer to be applied is determined by the efficiency of fertilizer use by the crop. The required fertilizer N is distributed in several applications during the crop growing season using tools like the leaf color chart.

STCR APPROACH FOR FERTILIZER RECOMMENDATIONS IN PRECISION AGRICULTURE

Earlier work on soil testing in India was based on the approach of correlation between test values of soil with yield, nutrient uptake or response to graded levels of applied nutrient. The approach has many limitations and its validity under field conditions has always been questioned. Currently, the targeted yield approach has become the mainstay of Coordinated Soil Test Crop Response (STCR) correlation work in India as applied to a number of crops both on research farms and at cultivator’s fields in different agro-climatic regions of the country.

What is Soil Test Crop Response Approach?

Efficient crop fertilization programme to meet the crop nutrient needs is key to sustainable agriculture. Efficient crop fertilization means optimizing crop yields, while minimizing nutrient losses to the environment, which is important economically and environmentally. Efficient nutrient application necessitates balanced fertilizer use and sound management decisions and practices.

Soil's nutrient supplying capacity (soil fertility) can be easily determined in laboratories. However, soil fertility assessment of specific locations at countrywide scale requires systematic soil sampling, delivery and feedback reporting. Crop responses to added nutrients can be tested in field experiments; nevertheless, results are site-specific and often not applicable to other locations with different soils or climate. Recognizing the lack of correlation between soil tests and crop responses to fertilizer in multi-location fertilizer-rate trials in the past and the frequent need for site-specific refinements of fertilizer prescriptions, a novel and unique field experimentation methodology was designed for soil test crop response (STCR) correlation studies at IARI (Ramamoorthy, 1968).

The STRC approach takes into account nutrient contribution from three measurable sources: (1) Soil fertility (available nutrients, based on chemical soil tests), (2) Added fertilizers and (3) Added organic manure. Over 2,000 demonstration trials in farmers' fields have validated the concept, realizing the yield targets within a 10% deviation. This novel approach has become a useful strategy to increase fertilizer use efficiency and boost food production in India.

Objective of STCR is to prescribe (recommend) fertilizer doses for a given crop based on soil test values to achieve the targeted yields in a specific agro-climatic region under irrigation or protective irrigated conditions by using mathematical equations for different crops and different agro-climatic zones separately. This takes into 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 is that this approach aims 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. Fertilizers can be recommended based on regression analysis for certain per cent of maximum yield. The STCR methodology takes in to account the three factors: nutrient requirement of the produce, percentage contribution from soil available nutrients and percentage contribution from added fertilizers, as indicated above.

The adjustment equation derived from these parameters takes the form:

F (N, P, K) = a (N, P, K) x T- b (N, P, K) x S (N, P, K)

Where,F = fertilizer nutrients (kg/ha).

S = Soil available nutrients (kg/ha).

T = Target yield (q/ha).

Nutrient requirement (NR), fertilizer efficiency (FE) and soil efficiency (SE) can be calculated from the experimental data as given below:

$$a\,(N, P, K) = \frac{NR}{FE/100}$$

$$b\,(N, P, K) = \frac{SE}{FE}$$

I. Nutrient requirement (NR) for one quintal (q) of grain:

$$NR = \frac{\text{Total nutrient uptake by grain and straw (kg/ha)}}{\text{Grain yield (q/ha)}}$$

II. Fertilizer efficiency (FE %)OR Contribution from fertilizer:

$$FE = \frac{\text{Total nutrient uptake (kg/ha)} - (\text{Soil test value in treated plot} - \text{kg/ha}) \times \text{Soil nutrient efficiency (\%)}}{\text{Fertilizer dose (kg/ha)}}$$

III. Soil efficiency (SE %)OR Contribution from soil:

$$SE = \frac{\text{Total nutrient uptake in control (kg/ha)}}{\text{Soil test value in control (kg/ha)}}$$

Calculation of Fertilizer dose:

The above basic data are transformed into workable adjustment equation as follows:

$$F = \left[\frac{NR}{E_f} \times Y\right] - \left[\frac{E_s}{E_f} \times SN\right] - \left[\frac{E_{FYM}}{E_f} \times FYM\ (t\ ha^{-1})\right]$$

Where,

F = Fertilizer (kg/ha)
NR = Nutrient requirement
Es = Percent contribution from soil
Ef = Percent contribution from fertilizer
E_{FYM} = Soil test value (kg/ha)
STV = Percent contribution from FYM
Y = Yield target (q/ha)
FYM = Farmyard manure (t/ha)

This tool is likely to have a much wider adaptability to suit the targeted yield goals by a farmer depending upon the investment capacity on nutrients and their availability in the soil, the goals to maximize the production, profit per unit area and profit per rupee invested on the fertilizer nutrients in proportion to the returns from the produce with maintenance of soil fertility.

Using the above parameters, adjustment equations have been developed for different crops in different agro-climatic regions on various soils as indicated below.

Fertilizer adjustment equations for rice:

F N = 2.83 T -0.32 SN

F $P_2 0_5$ = 2.29 T-2.98 SP

F $K_2 0$= 1.34 T-0.17 SK

Fertilizer adjustment equation for wheat:

F N = 7.54 T- 0.74 SN

F $P_2 0_5$ = 1.90 T-2.88 SP

F $K_2 0$ = 4.49 T-0.22 SK

Fertilizer adjustment equation for sorghum:

F N = 4.04 T-0.22 SN

F P_20_5 = 2.72 T - 8.26 SP

F K_20 = 3.80 T-0.17 SK

Fertilizer adjustment equation for sugarcane:

F N = 5.40 T-1.08 SN

FP_20_5 = 6.83 T-6.51 SP

FK_20= 1.90 T-0.15 SK

Based on the fertilizer adjustment equations, ready reckoner of fertilizer doses at varying soil test values for specific yield target have been prepared for different crops under different agro-climatic conditions. As an example, ready reckoner of fertilizer doses for rice at varying soil test values for specific yield target are presented in Table.

Ready reckoner of fertilizer doses at varying soil test values for specific yield target in Nandyal region.

Fertilizer adjustment equations for rice in Nandyal region:

FN = 2.83 T - 0.32 SN, FP_20_5 = 2.29 T-2.98 SP, FK_20 = 1.34 T - 0.17 SK

Soil available nutrients (kg/ha)			Fertilizer nutrient required (per ha) for yield target of					
			50 q/ha			55 q/ha		
KMn0_4 N	Olsens' P	Amn. Ac K	N	P_2O_5	K_2O	N	P_2O_5	K_2O
150	10	200	122	108	46	150	131	60
175	15	250	114	93	38	142	116	51
200	20	300	106	78	29	134	101	43
225	25	350	98	63	21	126	86	34
250	30	400	90	48	12	118	71	26
275	35	450	82	33	4	110	56	17
300	40	500	74	18	0	102	41	8
350	50	600	58	—	—	86	11	—

STCR Approach for Precision Agriculture

Agricultural production system is an outcome of a complex interaction of seed, soil, water, fertilizers and other agrochemicals. Therefore, judicious management of all the inputs is essential for sustainability of such a complex system. Focus on enhancement of the productivity during green revolution coupled with total disregard to proper management of inputs and without considering the ecological impacts, has resulted in environmental degradation. The only alternative left to enhance productivity in a sustainable manner from the limited natural resources is by maximizing resource input use efficiency. An integrated crop management system that attempts to match the kind and amount of inputs with the actual crop needs for small areas within the field appears to be precision farming.

In order to collect and utilize information effectively, it is important to be familiar with modem technological tools available indicated below:

- Global positioning system (GPS) receivers.
- Yield monitoring and mapping.
- Grid sampling and variable-rate (VRT) fertilizer.
- Remote sensing.

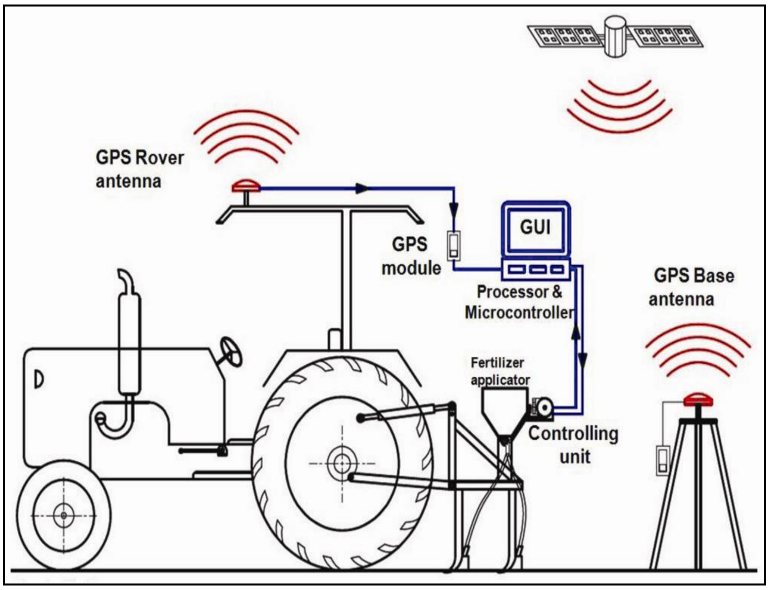
- Crop scouting.
- Geographic information system (GIS).
- Information management.
- Quantifying on-farm variability.

Grid Soil Sampling and Variable Rate Technology (VRT) for Fertilizer Application

Under normal conditions, recommended soil sampling procedure is to take samples from portions of fields that are no more than 20 acres in area. Soil cores taken from random locations in the sampling area are combined and sent to a laboratory to be tested. Crop advisors make fertilizer application recommendations from the soil test information for the 20 acre area.

Grid soil sampling uses the same principles of soil sampling but increases the intensity of sampling. For example, a 20 acre sampling area would have 10 samples using a 2 acre grid sampling system (samples are spaced 300 feet from each other) compared to one sample in the traditional recommendations.

- Soil samples collected in a systematic grid also have location information that allows the data to be mapped.
- The goal of grid soil sampling is to generate a map of nutrient requirement, called an application map.
- Grid soil samples are analyzed in the laboratory and an interpretation of crop nutrient needs is made for each soil sample.
- Fertilizer application map is plotted using the entire set of soil samples.
- Application map is loaded into a computer mounted on a variable-rate fertilizer spreader.
- Computer uses the application map and a GPS receiver to direct a product-delivery controller that changes the amount and or kind of fertilizer product, according to the application map.



VRTA (Variable Rate Applicator)

GLOSSARY OF IMPORTANT TERMS

GEO-INFORMATICS

Agro-geo-informatics: A branch of geo-informatics, is the science and technology about handling digital agro-geo-information, such as collecting (mainly through remote sensing and field investigation), processing, storing, archiving, preservation, retrieving, transmitting, accessing, visualization, analyzing, synthesizing, presenting and disseminating information.

Algorithm: An algorithm (pronounced Al-go-rith-um) is a procedure or formula for solving a problem, based on conducting a sequence of specified actions. A computer programme can be viewed as an elaborate algorithm. In mathematics and computer science, algorithm usually means a small procedure that solves a recurrent problem.

Altitude: It is the height of an object or point in relation to sea level or ground level.

Atmospheric window: Atmospheric windows are wavelengths at which electro-magnetic radiation (sunlight) from the sun will penetrate the earth's atmosphere overall constricting these spectrum bands from reaching the earth.

Attribute: A characteristic of a geographic feature, typically stored in tabular format and linked to the feature in a relational database. The attributes of a well-represented point might include an identification number, address and type.

Cluster analysis: A statistical classification technique for dividing a population or group of objects into relatively homogenous groups using more than one variable. The similarities between members of a class or cluster are high, while similarities between members of different clusters are low. Cluster analysis is frequently used in market analysis for consumer segmentation and locating customers.

Computer aided design (CAD): An automated system for the design, drafting and display of graphically oriented information.

Computer simulation: It is a powerful methodology for design and analysis of complex systems. Overall approach in computer simulation is to represent the dynamic characteristics of a real-world system in a computer model. The model is subjected to ' experiments to obtain predictive information useful in making informed decision making about the characteristics of the real-system.

Coordinate system: A reference system for defining precise locations on the earth's surface. Coordinate systems may be independent of tied to a particular map projection.

Coordinates: Coordinates are pairs (X, Y) or triplets (X, Y, Z) of values that are used to represent points and features on a two and three-dimensional space. The X-value represents the horizontal position and Y-value represents the vertical position. The Z- value generally refers to the elevation at that point location.

Crop scouting: In-season observations of crop conditions like weed patches (weed type and intensity), insect or fungal infestation (species and intensity) and crop tissue nutrient status.

Database: A logical collection of interrelated information managed and stored as a unit. GIS database includes data about the spatial location and shape of geographic features recorded as points, lines and polygons as well as their attributes.

Database design: The formal process of analyzing facts about the real-world into three structured database model. Database design is characterized by the following phases: conceptual analysis, logical design and physical design.

Database form: A database form allows you to reorganize the information in a table for display in single record view. This reorganization may include changing order and placement of fields or displaying only selected fields from existing database table.

Discrete data: Geographic features containing boundaries: Point, line or area boundaries.

Electromagnetic (EM) spectrum: The EM spectrum refers to range of energy wavelengths or frequencies from x-rays, ultraviolet, visible, infrared, microwave to radio waves.

Event: A geographic location stored in tabular rather than spatial form. Event types include address events, route events, xy events and temporal events.

Experimental frame (EF): When one studies a system in the real-world, the experimental frame describes experimental conditions (context), aspects, within which that system and corresponding models will be used. As such, the experimental frame reflects the objectives of experimenter who performs experiments on a real-system or through simulation, on a model.

Feature: A representation of a real-world object on a map. Features can be represented in a GIS as vector data (points, lines, or polygons) or as cells in a raster data format. To be displayed in GIS, features must have geometry and locational information.

Feature class: A collection of geographic features with the same geometry type (such as point, line or polygon), the same attributes and the same spatial reference. Feature classes can stand alone within a geo-database or be contained within shape files, coverage or other feature datasets. Feature classes allow homogeneous features to be grouped into a single unit for data storage purposes. For example, highways, primary roads and secondary roads can be grouped into a line feature class named “roads”.

Geocode: The process of identifying a location by one or more attributes from a base layer.

Geo-data base: An object-oriented data model introduced by ESRl (company distributing GIS) that represents geographic features and attributes as objects and the relationships between objects but is hosted inside a relational database management system. A geo-database can store objects, such as feature classes, feature datasets, non-spatial tables and relationship classes.

Geodesy: Geodesy (or geodetics) is a branch of applied mathematics and earth science of locating and assigning three-dimensional points on earth by measuring the shape of the earth.

Geographic coordinate system: A reference system that uses latitude and longitude to define the locations of points on the surface of a sphere or spheroid.

Geographic data: Information about real-world features, including their shapes, locations and descriptions. Geographic data is the composite of spatial data and attribute data. It describes an object with spatial reference on the earth's surface.

Geoid: The figure that represents the irregular spheroidal shape of the earth is called the geoid. The geoid is an equipotential surface (which means the direction of gravity is perpendicular to alt points on the surface) at mean sea level.

Geometric transformation (rectification): A process in which an image is stretched differentially so as to change its internal geometry is said to have undergone geometric transformation or rectification. A transformation specifically refers to the process of projecting an image from its plane into another plane by translation, rotation and/or scale change.

Geo-spatial data: Geospatial data, GIS data or geo-data has explicit geographic positioning information included within it, such as a road network from a GIS or a geo-referenced satellite image. Geospatial data may include attribute data that describes the features found in the dataset. There are two types of geospatial data - vector and raster.

Geo-referencing: Assigning coordinates from a known reference system, such as latitude/longitude, UTM (Universe Transverse Mercator) or State Plane, to the page coordinates of a raster (image) or a planar map. Geo-referencing raster data allows it to be viewed, queried and analyzed with other geographic data.

GIS (geographic information system): An arrangement of computer hardware, software, and geographic data that people interact with to integrate, analyses and visualize the data, identify relationships, patterns and trends and find solutions to problems. The system is designed to capture, store, update, manipulate, analyses and display the geographic information. A GIS is typically used to represent maps as data layers that can be studied and used to perform analyses.

Global positioning system (GPS): The GPS is a navigation system based on a network of satellites that helps users to record positional information (latitude, longitude and elevation) with an accuracy of between 100 and 0.01 m. GPS allows farmers to locate the exact position of field features, such as soil type, pest occurrence, weed invasion, water holes, boundaries and obstructions.

Image: A raster-based representation or description of a scene, typically produced by an optical or electronic device, such as a camera or a scanning radiometer. Common examples include remotely sensed data (for example, satellite data), scanned data and photographs. An image is stored as a raster dataset of binary or integer values that represent the intensity of reflected light, heat, sound or any other range of values on electromagnetic spectrum.

Layer: A logical set of thematic data described and stored in a map library. Layers act as digital transparencies that can be laid a top one another for viewing or spatial analysis.

Latitude and longitude: Are angles that uniquely define points on a sphere. **Latitudes** of +90 and -90 degrees correspond to the north and south geographic poles on the earth, respectively. **Longitude** is defined in terms of meridians, which are half-circles running from pole to pole.

Line: Lines represent geographic features too narrow to be displayed as an area at a given scale, such as contours, street center lines or streams.

Linear feature: A geographic feature that can be represented by a line or set of lines. For example, rivers, roads and electric and telecommunication networks are linear feature.

Model abstraction: Abstraction is the process of taking away or removing characteristics from something in order to reduce it to a set of essential characteristics. Abstraction is related to both encapsulation and data hiding.

Modelling: Modelling is defined as the application of methods to analyses complex, real- world problems in order to make predictions about what might happen with various actions.

Multispectral images: Images optically acquired in more than one spectral or wavelength interval. Each individual image is usually of the same physical area and scale but of a different spectral band. The MSS (Multi-Spectral Scanner) and TM (Thematic Mapper) sensors aboard the LANDSAT satellite both collect simultaneous multispectral images.

Network: An interconnected set of arcs representing possible paths for the movement of resources from one location to another.

Object: It is some entity in the real-world. Such an object can exhibit widely varying behavior depending on the context in which it is studied, as well as the aspects of its behavior which are under study.

Pixel depth or colour depth: The number of data bits each pixel represents. In 8-bit contexts, the pixel depth is 8 and each display pixel can be one of 256 possible colors or shades of gray. With a 24-bit raster (or with three co-registered 8-bit raster) the pixel depth is 24 and 16,777,216 colors are possible.

Pixel: The smallest element of an image that can be individually processed in a video display system. The text and images on a computer display are created by combinations of individual dots (pixels).

Point: A single x, y coordinate that represents a geographic feature too small to be displayed as a line or area at that scale.

Polygon: A polygon is a closed, connected set of lines that defines a geographic boundary with an area and perimeter. Ex. are lakes, forests and country boundaries.

Precision: It refers to the number of significant digits used to store numbers and in particular, coordinate value. Precision is important for feature representation, analysis and mapping.

Raster data: A raster is a data model used in GIS which are usually regularly-size rectangular or square shaped grid cells arranged in rows in columns.

Remote sensing: Remote sensing is the science of obtaining information about the earth without physically being there. Examples of remote sensing techniques are by satellite, unmanned aerial vehicle and aircraft.

Resolution: The detail with which a map depicts the location and shape of geographic features. The larger the map scale, the higher the possible resolution. As scale decreases, resolution diminishes and feature boundaries must be smoothed, simplified, or not shown at all; for example, small areas may have to be represented as points. The area represented by each cell or pixel in a raster.

Satellite image: A picture of the earth taken from an earth orbital satellite. Satellite images may be produced photographically or by on-board scanner (MSS).

Scale: The ratio or relationship between a distance or area on a map and the corresponding distance or area on the ground.

Simulation: Simulation can be broadly defined as a technique for studying real-world dynamical systems by imitating their behavior using a mathematical model of the system implemented on a digital computer.

Site specific management: It is used to detect and measure the differences within fields, record these differences at specific locations and then use this information to guide changes in management or inputs. Site specific farming is managing areas within fields, rather than using the same management on the entire field.

Spatial analysis: The process of modelling, examining and interpreting model results. Spatial analysis is useful for evaluating suitability and capability for estimating and predicting and for interpreting and understanding.

Spatial features: The spatial objects can be represented in object (vector) mode or image (raster) mode. In object mode, individual spatial objects can be defined as point or line or polygon.

Spatial relationship: A spatial relationship links GIS features with a table by a unique identifier all stored in a relational database management system.

Spectral band or spectral region: A well-defined, continuous wavelength range in the spectrum of reflected or radiated electromagnetic energy. Red, green and blue are all spectral regions within portion of spectrum that is visible to humans as light.

Vector data: The pints, lines and polygons that consist of vertices and paths. OR Uses co-ordinates to store the shape of spatial data objects.

Vector data model: A vector data model is a common GIS feature representation of spatial information based on defining coordinates and attribute information. Vectors are points, polylines and polygons.

Vector: A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each feature, as opposed to a raster data model, which associates attributes with grid cells. In other words, vector is any quantity that has both magnitude and direction.

PRECISION FARMING

Accuracy: In precision farming, the precision with which a positioning system can locate a point at which data is recorded or the position of a vehicle.

Biomass map: A plan that shows the variation in the crop canopy within a field, based on the data from a biomass sensor. It can indicate differences in soil fertility and therefore crop nutrient requirements, allowing fertilizer to be applied at different rates in different places.

Crop calibration: Adjustment of machinery to the characteristics of a specific crop at a specific time, such as moisture content at harvest or the different reflectance characteristics of different wheat varieties.

Crop sensing: The process of collecting information on crop characteristics such as biomass and chlorophyll content from a distance, by means of satellite, aerial or tractor-mounted remote sensors.

Crop variability: Differences in crop yields within a field caused by factors such as differences in soil type, soil fertility, compaction and previous cropping patterns.

Data logging: Automatic recording by a computer of information gathered digitally over time.

Differential global positioning system (DGPS): A system for providing very accurate position, by calculating the difference between the actual location of a fixed-position ground station and the satellite-located position of the station and providing a correction signal to a mobile user, either directly from a ground station or via a satellite. This system corrects for errors introduced by interference with the GPS signal and produces a very accurate signal of well-below one meter, which agricultural applications require.

Geo-referencing: Association of information on yield, pH, soil nitrogen or other factor with a position in a field map coordinates are assigned to an image derived by remote sensing.

Geo-statistics: Statistics used for studying spatial patterns. Geo-statistical analysis may be used to produce maps from data acquired at a relatively small set of locations.

Normalized difference vegetative index (NDVI): Relationship between visible light reflectance and near infrared reflectance of a crop canopy that allows assessment of its size, nutrient status and health. Healthy vegetation absorbs most of the visible light that it receives and reflects a lot of the near-infrared light, while unhealthy or sparse vegetation reflects more visible light and less near-infrared light.

Positioning system: A system of linked satellites that transmit radio signals to receivers on the ground, allowing a location to be accurately pin-pointed. The core satellite systems are free, as are some of the enhanced DGPS systems such as WAAS (US) and EGNOS (EU). Subscription DGPS services offering high accuracy are available from commercial providers.

Precision farming (PF): Management of farming practices that uses computers, satellite positioning systems and remote sensing devices to provide information on which enhanced decisions can be made. Sensors can determine whether crops are growing at maximum efficiency, highly specific local environmental conditions can be identified, and the nature and location of problems pinpointed. Information collected can be used to produce maps showing variation in factors such as crop yield or soil nutrient status and provides a basis for decisions on, for example, seed rates and application of fertilizers / agrochemicals as well for automatic guidance of equipment.

Precision technology (PT): Aids such as positioning systems, remote sensors and guidance control equipment that can map variability in fields and direct inputs precisely and only where they are required.

Radiometric data: Information on crop or soil conditions obtained by sensors detecting visible and invisible light reflected from surfaces.

Radiometric map: A plan created on the basis of the amount of visible and invisible light reflected from the area being studied. A radiometric map can identify differences such as those in soil fertility and crop disease.

Radiometry: The measurement of electromagnetic radiation, including visible and invisible light waves.

Real-time agronomy: The use of constantly updated data from a source such as a sensor to inform decision-making while working, for example decisions on application rates.

Real-time: Processing, updating and acting on data as soon as it is received from a source such as a sensor.

Remote sensor: These are passive sensors, in which the energy that is radiated comes from an external source such as the sun and active sensors that produce their own energy source.

Soil variability: Differences in soil type and fertility across an area, as a result of previous cropping patterns, fertilizer use, underlying soil texture or compaction.

Spatial application technology (SAT): Use of data collection devices such as remote sensors to establish which areas within fields and crops need a specific treatment and then deliver site-specific treatment to that area.

Spatial distribution: The way in which objects or features are located in an area relative to other objects or features. They may be evenly dispersed, randomly dispersed or aggregated (clumped together). Information on the spatial distribution of crop plants, weeds, diseased areas and soil types, for example, may be turned into maps on which site-specific treatments can be based.

Spatial resolution: Spacing between the points at which measurements or observations were taken in a field. The closer the sampling points are to one another, the higher the spatial resolution.

Spatial variability: The range of difference occurring in factors such as soil composition, crop yield or insect population according to position in a field.

Spatially selective treatment: Application of different rates of seed, fertilizer or agrochemicals to soil or plants in different parts of a field, according to need. Herbicide may be applied only to patches of weeds on the basis of a weed map or fertilizer to specific parts of a field on the basis of a nutrient map.

Variable rate application (VRA): Application of seeds, fertilizers or agrochemicals at different rates as required by the conditions in different parts of a field.

Variable rate input (VRI): The use of different rates of fertilizers or agrochemicals in different parts of a field. For example, fertilizer application can be increased early in the season exactly in those areas where plant density is low in order to build an optimum leaf canopy.

Variable rate technology (VRT): The devices enabling the differential application of fertilizers or agrochemicals in different parts of a field, according to an application map or real-time sensor.

Vegetation index (VI): A scale that indicates relative growth and/or vigour of green vegetation, based on a ratio and/or linear combination of measurements of reflected light in the red and near infrared regions of the spectrum.

Weed aggregation: Appearance of weeds growing in patches rather than spread evenly across a field.

Wide dynamic range vegetative index (WDRVI): An enhancement of the normalized difference vegetation index under conditions of moderate to high biomass that applies a weighting to the near infrared reflectance values.

Yield mapping: The process of using GPS and yield monitoring data to show the variation in yield across a field. Yield maps offer the possibility of identifying factors that vary across a field and potentially limit yield. Yield differences can then be addressed by applying treatments at different rates in different areas or by adjusting fertilizer rates to match previous crop off-take.

How Geo-Spatial Technologies can help?

Approaches to Agriculture using Geo Spatial Technologies
- Climate Smart Agriculture
- Precision Agriculture
- Conservation Agriculture

The objective is common to use the available information to guide agricultural production:
- To optimize the use of inputs and resources including water, land, and other inputs – which helps to reduce cost of production.
- To improve productivity through more precise use of inputs.
- To minimize agricultural risk due to pests and diseases and climatic variances.
- Hence overall improvement in farm incomes while minimizing risk.

How Geo-Spatial Technologies can help Precision Agriculture?

Precision Farming/Site-Specific Crop Management

- GIS-GPS-RS technologies are used in combination for precision farming/site-specific crop management.
- GIS analytical capabilities measures variable parameters that can affect agricultural production include,
- Yield variability & Crop variability (e.g., density, height, nutrient & water stress, chlorophyll content).
- Physical parameters of the field & Soil chemical and physical properties.
- Anomalous factors (e.g., weed, insect, and disease infestation, wind damage).
- Variations in management practices (e.g., tillage practices, crop seeding rate, fertilizer and pesticide application, irrigation patterns and frequency).

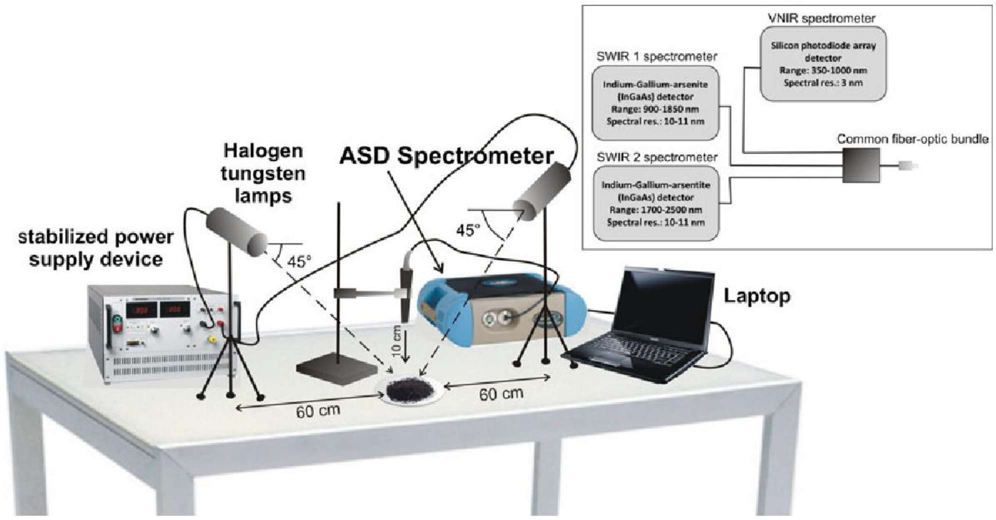
Novel Technologies for Climate-Smart Agriculture

Sensor Technologies

- Climate Smart Agriculture Mechanization Using Robotics- Driverless tractors, Portal crop scouting platform, weed mapping, weeding, micro spraying, irrigation, and selective harvesting etc.
- Drones for Climate-Smart Agriculture.
- Soil moisture sensors enables enhances water use efficiency and irrigation scheduling.

HYDRAPROBE soil moisture sensor for soil moisture, Ec and pH measurement

LeafArea and Leaf Area Index Meter (LAI meter)



Field Spectroradiometer

SOME DATA BROWSING WEBSITES

- http://earthexplorer.usgs.gov/
- http://www.nrsc.gov.in/
- http://www.spaceimaging.com
- http://www.digitalglobe.com
- http://edcimswww.cr.usgs.gov/pub/imswelcome/
- http://www.spotimage.fr/home
- http://bhuvan-noeda.nrsc.gov.in/download/download/download.php
- http://glcf.umiacs.umd.edu/data/
- http://www.usgs.gov/pubprod/
- https://cross.restec.or.jp/cross-ex/topControl.action?language=en-US

Nano-technology and Nano-scale effects

13.1 Introduction

- The word "**nano**" comes from a Greek word that means "**Dwarf**"
- $1nm=10^{-9}m$

13.2 Definition

- **Nano-science** is the study of phenomena and manipulation of materials at atomic, molecular and macro-molecular scale, where properties differ significantly from those at larger scale.
- **Nano-technologies** are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer.
- **Nanotechnology** is a process that builds controls and restructures that are the size of atoms and molecules.
- **Nano-particle** is defined as the small object that acts as a whole unit in terms of transport and properties.

13.3 Concept

- The idea of nanotechnology was for the first time introduced in 1959 by the physicist **Richard Feynman**.
- The term nanotechnology was first used in 1974 by **Norio Taniguchi**
- Nano-particle is ultrafine unit with dimensions measured in nanometers. Nano-particle exists in the nature and can be created artificially.
- Nano-particles are having the following properties
  - They are highly mobile in free state
  - They have enormous surface areas
  - They may exhibit the quantum effects
- Nano-technology is based on two main approaches
  1) **Bottom up approach**: Materials and devises are built from molecular components and which assemble themselves chemically by molecular recognition

2) **Top down approach**: Nano objects are constructed from large entities without atomic level control

13.4 Nano scale effects

- Two principal factors cause the properties of nano-material to differ significantly from other materials
    1) **Increased relative surface area**
    2) **Quantum effects**

1) **Increase relative surface area:**
    - Nano-scale materials have far larger surface areas than similar masses of larger area
    - As surface area per mass of material increases, greater amount of material can come into contact with surrounding materials, thus affecting reactivity.

Size of the cube	Number of cubes	Collective surface area
1m	1	6 m^2
0.1m	1000	60 m^2
0.01m	10^6	600 m^2
0.001m	10^9	6000 m^2
0.0^{-9}m=1nm	10^{27}	6×10^{-9} m^2

- **Quantum size effect = Electronic properties of solids are altered with reduction in particle size**
- When particle sizes of solid matter in visible scale are compared to what can be seen in a regular optical micro-scope, there is a little difference in the properties of the particle.
- When the particles are created with nano dimensions the material properties change significantly from those at larger scales
- Melting point, fluorescence, electrical conductivity, magnetic permeability and chemical reactivity change as a function of size of the particle

- Materials reduced to nano-scale can show different properties compared to that they exhibit in macro-scale enabling unique application.

  Example:

  -Opaque substances become transparent (copper)

  -Stable materials turn combustible (aluminium)

  -Solids turn into liquids at room temperature (gold)

  -Insulators become conductors (silicon)

LECTURE 14

Nano-pesticides, Nano-fertilizers and Nano-sensors

Nano-pesticides

14.1 Definition:

- Nano-pesticides are defined as any formulation that includes elements of nm size range and/or claims novel properties associated with these small size range
- Nano-pesticides are plant protection chemicals, in which either the active ingredient or the carrier molecule is developed through nanotechnology
- The major aim in the development of nano-pesticides is to lessen the environmental hazards of a pesticide active ingredient through improving the efficacy of a chemical
- The size of a nanopaticle generally ranges 1-100 nanometer and a nanometer is one billionth of a meter. When the size gets this small, particles reach a very large surface area and thus more volume of pesticides get contact with the pests.

14.2 Formulations of Nano-pesticides

- Nano-pesticides are formulated according to their intended purpose as formulations improving solubility, slow release of active ingredients, prevent degradation etc.
- Some foremost nano-formulations are:
  - **Nano-emulsions:** In this formulation active ingredient of the chemical is dispersed as nanosized droplets in water, with surfactant molecules confined at the pesticide-water interface
  - **Nano-suspension:** Nano-suspensions, also termed as nano-dispersions, are formulated by dispersing the pesticide as solid nanosized particles in aqueous media
  - **Polymer based nano-particles:** Polymer-based pesticide nanocarriers are majorly deployed in the slow and controlled release of active ingredients to the target site
  - **Nano-encapsulation:** This confines the hydrophobic or hydrophilic active ingredient, surrounded by a polymer coating or membrane.

- **Nanospheres:** These are homogeneous vesicular structures, in which the bioactive ingredient is uniformly dispersed throughout the polymer matrix.
- **Nanogels:** These are also known also hydrogel nanopartciles. These are formulated by cross linking of polymeric particles having hydrophilic groups
- **Nano-fibres:** Nano-fibres are developed through electrospinning, thermal induced phase separation

14.3 Advantages of Nano-pesticides

- Improved solubility of active ingredients
- Better stability of formulation
- Slow release of active ingredient
- Improved mobility
- Higher surface area
- Uniform leaf coverage
- Improve pesticide utilization
- Nano-formulations improve adhesion of droplets to plant surface
- Eco-friendly approach

Nano-fertilizers

14.4 Definition

- Nano-fertilizers are nutrient carriers of Nano-dimensions capable of holding bountiful of nutrient ions due to their high surface area and release it slowly and steadily that commensurate with crop demand
- Nutrient use efficiencies of conventional fertilizers hardly exceed 30-35 %, 18-20 % and 35-40 % for N, P and K respectively. The data remain constant for the past several decade
- Nano particles have extensive surface area and capable of holding abundance of nutrients and release it slowly and steadily such that it facilitates uptake of nutrients matching the crop requirement without any associated illeffects of customized fertilizer inputs.
- Encapsulation of fertilizers within a nano particle is one of these new facilities which are done in three ways :
  - The nutrient can be encapsulated inside nanoporous materials

- Coated with thin polymer film
- Delivered as particle or emulsions of nano scales dimensions

- In addition, nanofertilizers will combine nano devices in order to synchronize the release of fertilizer-N and -P with their uptake by crops, so preventing undesirable nutrient losses to soil, water and air via direct internalization by crops, and avoiding the interaction of nutrients with soil, microorganisms, water, and air.
- Types of nano devices available are:
  - Nano-porous zeolites
  - Controlled release nano fertilizers

14.5 *Advantages related to transformed formulation of* conventional fertilizer using technology

Desirable Properties	Examples of Nano fertilizers-Enabled Technologies
Controlled release formulation	So-called smart fertilizers might become reality through transformed formulation of conventional products using nanotechnology. The Nano structured formulation might permit fertilizer intelligently control the release speed of nutrients to match the uptake pattern of crop.
Solubility and dispersion for mineral micronutrients	Nano sized formulation of mineral micronutrients may improve solubility and dispersion of insoluble nutrients in soil, reduce soil absorption and fixation and increase the bio-availability.
Nutrient uptake efficiency	Nano structured formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production, and save fertilizer resource.
Effective duration of nutrient release	Nano structured formulation can extend effective duration of nutrient supply of fertilizers into soil
Loss rate of fertilizer nutrients	Nano structured formulation can reduce loss rate of fertilizer nutrients into soil by leaching.

Nano-sensors

14.6 Definition and Types

- Nano-sensors are any biological, chemical or surgical sensory points used to convey information about nanoparticles to the macroscopic world.
- Different types include
  - Sensors using semi-conductor nanowire detection elements
  - Semi-conducting carbon nano tubes

- Carbon nanotubes and nanowires detect bacteria and viruses
- Nanocantilevers

LECTURE 15

Nano-biosensors

15.1 Introduction

- Nanobiosensor is a modified version of a biosensor which may be defined as a compact analytical device/ unit incorporating a biological or biologically derived sensitized element linked to a physico-chemical transducer
- Nanosensors with immobilized bioreceptor probes that are selective for target analyte molecules are called nanobiosensors.
- A nanobiosensor is usually built on the nanoscale to obtain process and analyze the data at the level of atomic scale
- Their applications include detection of analytes like urea, glucose, pesticides etc., monitoring of metabolites and detection of various microorganisms / pathogens.

15.2 Characteristics of ideal biosensor

- Highly specific for the purpose of the analyses i.e. a sensor must be able to distinguish between analyte and any 'other' material.
- Stable under normal storage conditions.
- Specific interaction between analytes should be independent of any physical parameters such as stirring, pH and temperature.
- Reaction time should be minimal.
- The responses obtained should be accurate, precise, reproducible and linear over the useful analytical range and also be free from electrical noise.
- The nanobiosensor must be tiny, biocompatible, nontoxic and non-antigenic.
- Should be cheap, portable and capable of being used by semi-skilled operators.

15.3 Constituents of Nanobiosensors

- A typical nanobiosensor comprises of 3 components; biologically sensitized elements (probe), transducer and detector
  1) The biologically sensitized elements (probe) including receptors, enzymes, antibodies, nucleic acids, molecular imprints, lectins, tissue, microorganisms, organelles etc., which are either a biologically derived material or bio-mimic component that receives signals from the analytes (sample) of interest and transmits it to transducer. And such nano-receptor may play a vital role in the development of future nanobiosensors.
  2) The transducer acts as an interface, measuring the physical change that occurs with the reaction at the bioreceptor/sensitive biological element then transforming that energy into measurable electrical output.
  3) The detector element traps the signals from the transducer, which are then passed to a microprocessor where they are amplified and analyzed; the data is then transferred to user friendly output and displayed/stored

15.4 Types of Nanobiosensors

- **Mechanical Nanobiosensors**: Nanoscale mechanical forces between biomolecules provide an exciting ground to measure the biomolecular interaction. This helps in the development of minute, sensitive and label free biosensors
- **Optical Nanobiosensors:** Optical biosensors are based on the arrangement of optics where beam of light is circulated in a closed path and the change is recorded in resonant frequency when the analyte binds to the resonator
- **Nanowire Biosensors:** Nanowire biosensor is a hybrid of two molecules that are extremely sensitive to outside signals: single stranded DNA, (serving as the 'detector') and a carbon nanotube, (serving as the transmitter). The surface properties of nanowires can be easily modified using chemical or biological molecular ligands, which make them analyte independent, This transduces the chemical binding event on their surface into a change in conductance of the nanowire with extreme sensitivity, real time and quantitative fashion

- **Ion Channel Switch Biosensor Technologies:** The Ion Channel Switch (ICS) is based on a synthetic self-assembling membrane that acts as a biological switch for detecting the signals i.e. the presence of specific molecules by triggering an electrical current
- **Electronic Nanobiosensors:** Electronic nanobiosensors work by electronically detecting the binding of a target DNA that actually forms a bridge between two electrically separated wires on a microchip
- **Viral nanobiosensors:** Virus particles are essentially biological nanoparticles. Herpes simplex virus (HSV) and adenovirus have been used to trigger the assembly of magnetic nanobeads as a nanosensor for clinically relevant viruses
- **Nanoshell Biosensors:** Positioning gold nanoshells are used in a rapid immunoassay for detecting analytes within complex biological media without any sample preparation
- **PEBBLE Nanobiosensors:** Probes Encapsulated by Biologically Localized Embedding (PEBBLE) nanobiosensors consist of sensor molecules entrapped in a chemically inert matrix by a microemulsion polymerization process that produces spherical sensors in the size range of 20 to 200 nm. These nanosensors are capable of monitoring real-time inter- and intra-cellular imaging of ions and molecules.

15.5 Role of Nano-Biosensors in Agriculture

Presently, nanomaterial-based biosensors exhibit fascinating prospects over traditional biosensors. Nanobiosensors have marked advantages such as enhanced detection sensitivity/ specificity and possess great potential for its applications in different fields including environmental and bioprocess control, quality control of food, agriculture, bio defence, and, particularly, medical applications. But here we are concerned with the role of nano biosensor in agriculture and agro-products. Some of the potential applications of nanobiosensors are listed below:

- As Diagnostic Tool for Soil Quality and Disease Assessment
- As an Agent to Promote Sustainable Agriculture
- As a Device to Detect Contaminants and Other Molecule
- As Tool for Effective Detection of DNA and Protein

LECTURE 16

Use of Nano-technology in Agriculture

16.1 Introduction

- Agriculture has always been the backbone of the developing countries
- Nanotechnology is now emerging and fast growing field of science which is being exploited over a wide range of scientific disciplines including Agriculture
- A smarter way for sustainable agriculture appears to be nanotechnology

16.2 Potential applications of Nanotechnology in Agriculture

- Increase the productivity using nanopesticides and nanofertilizers
- Improve the soil quality using nanozeolites and hydrogels
- Stimulate crop growth using nanomaterials
- Provide smart monitoring using nanosensors by wireless communication devises

16.3 Nanotechnology in tillage

- Mechanical tillage practices improve soil structure and increase porosity leading to better distribution of soil aggregates and eventually modify the physical properties of soil.
- Nanomaterials usage increase soil pH and soil structure
- It also reduces mobility, availability and toxicity of heavy metals besides reducing soil erosion
- Nanoparticles in soil reduce cohesion and internal friction besides reducing the shear strength of the soil. Reduction in adhesion of soil particles allows easy crushing of lumps with less energy

16.4 Nanotechnology in Seed Science

- Seed is nature's nano-gift to man. It is self perpetuating biological entity that is able to survive in harsh environment on its own.
- Nanotechnology can be used to harness the full potential of seed.
- Seed production is a tedious process especially in wind pollinated crops.

- Detecting pollen load that will cause contamination is a sure method to ensure genetic purity.
- Pollen flight is determined by air temperature, humidity, wind velocity and pollen production of the crop.
- Use of nanobiosensors specific to contaminating pollen can help alert the possible contamination and thus reduces contamination.
- The same method can also be used to prevent pollen from Genetically, modified crop from contaminating field crops.
- Novel genes are being incorporated into /seeds and sold in the market.
- Tracking of sold seeds could be done with the help of nanobarcodes that are encodable, machine - readable, durable and sub-micron sized taggants.
- Disease spread through seeds and many times stored seeds are killed by pathogens.
- Nano-coating of seeds using elemental forms of Zn, Mn, Pa, Pt, Au, Ag will not only protect seeds but used in far less quantities than done today.
- Technologies such as encapsulation and controlled release methods have revolutionized the use of pesticides and herbicides. Seeds can also be imbibed with nanoencapsulations with specific bacterial strain termed as Smart seed.
- It will thus reduce seed rate, ensure right field stand and improved crop performance.
- A smart seed can be programmed to germinate when adequate moisture is available.
- Coating seeds with nanomembrane, which senses the availability of water and allow seeds to imbibe only when time is right for germination, aerial broadcating of seeds embedded with magnetic particle, detecting the moisture content during storage to take appropriate measure to reduce the damage and use of bioanalytical nanosensors to determine ageing of seeds are some possible thrust areas of research.
- Carbon nanotubes (CNTs) can also be used as new pores for water permeation by penetration of seed coat and act as a passage to channelize the water from the

substrate into the seeds. These processes facilitate germination which can be exploited in rainfed agricultural system.

16.5 Nanotechnology in Water Use

- Water purification using nanotechnology exploits nanoscopic materials such as carbon nanotubes and alumina filters for nanofiltration
- It utilizes the existence of nanoscopic pores in zeolite filtration membranes, nanocatalysts and magnetic nanoparticles
- Carbon nanotube membranes and Nanofibrous alumina filters can remove almost all kinds of water contaminants including turbidity, oil bacteria, viruses and organic contaminants

16.6 Nanotechnology in Fertilizers

- Fertilizers have played a pivotal role in enhancing the food grain production in India
- Despite the resounding success in grain yield, it has been observed that yields of many crops have begun to stagnate as a consequence of imbalanced fertilization and decline in organic matter content of soils.
- Excessive use of nitrogenous fertilizer affects the groundwater and also causes eutrophication in aquatic ecosystems.
- A disturbing fact is that the fertilizer use efficiency is 20-50 per cent for nitrogen and 10-25 per cent for phosphorus.
- Elimination of eutrophication and drinking water with possible build up of nutrients in soil is possible only by adoping nano fertilizers an emerging alternative to conventional fertilizers
- Additionally, nano-technology has improved nutrient use efficiency,and minimize costs of environmental protection.
- Slow-release of nano-fertilizers and nanocomposites are excellent alternatives to soluble fertilizers. Nutrients are released at a slower rate throughout the crop growth; plants are able to take up most of the nutrients without any waste.
- Slow release of nutrients in the environments could be achieved by using zeolites that are a group of naturally occurring minerals having a honeycomb-like layered

crystal structure. Its network of interconnected tunnels and cages can be loaded with nitrogen and potassium, combined with other slowly dissolving ingredients containing hosphorous, calcium and a complete suite of minor and trace nutrients. Zeolite acts as a reservoir for nutrients that are slowly released “on demand.”

- Fertilizer particles can be coated with nanomembranes that facilitate slow and steady release of nutrients.
- The Nano-composites being contemplated to supply all the nutrients in right proportions through the “Smart” delivery systems also needs to be examined closely.
- Currently, the nutrient use efficiency is low due to the loss of 50-70% of the nitrogen supplied in conventional fertilizers.
- Encapsulation of fertilizers within a nanoparticle is one of these new facilities which are done in three ways
  a) the nutrient can be encapsulated inside nanoporous materials,
  b) coated with thin polymer film
  c) delivered as particle or emulsions of nanoscales dimensions

16.7 Nanotechnology in Plant protection

- Persistence of pesticides in the initial stage of crop growth helps in bringing down the pest population below the economic threshold level and to have an effective control for a longer period. Hence, the use of active ingredients in the applied surface remains one of the most cost-effective and versatile means of controlling insect pests.
- To protect the active ingredient from the adverse environmental conditions and to promote persistence, a nanotechnology approach, namely “nano-encapsulation” can be used to improve the insecticidal value.
- Nanoencapsulation comprises nano-sized particles of the active ingredients being sealed by a thin-walled sac or shell (protective coating).
- Nanoencapsulation of insecticides, fungicides or nematicides will help in producing a formulation which offers effective control of pests while preventing accumulation of residues in soil.

- In order to protect the active ingredient from degradation and to increase persistence, a nanotechnology approach of "controlled release of the active ingredient" may be used to improve effectiveness of the formulation that may greatly decrease amount of pesticide input and associated environmental hazards.
- Nano-pesticides will reduce the rate of application because the quantity of product actually being effective is at least 10-15 times smaller than that applied with classical formulations, hence a much smaller than the normal amount could be required to have much better and prolonged management.
- Recently,clay nanotubes (halloysite) have been developed as carriers of pesticides at low cost, for extended release and better contact with plants, and they will reduce the amount of pesticides by 70-80%, thereby reducing the cost of pesticide with minimum impact on water streams.

16.8 Nanotechnology in Weed Management

- Multi-species approach with single herbicide in the cropped environment resulted in poor control and herbicide resistance
- Continuous exposure of plant community having mild susceptibility to herbicide in one season and different herbicide in other season develops resistance in due course and become uncontrollable through chemicals
- Developing a target specific herbicide molecule encapsulated with nanoparticle is aimed at specific receptor in the roots of target weeds, which enter into roots system and translocated to parts that inhibit glycolysis of food reserve in the root system. This will make the specific weed plant to starve for food and gets killed
- In rainfed areas, application of herbicides with insufficient soil moisture may lead to loss as vapour so controlled release of encapsulated herbicides is expected to take care of the competing weeds with crops.
- Now a days, adjuvants for herbicide application are currently available that claim to include nanomaterials.
- Excessive use of herbicides leave residue in the soil and cause damage to the succeeding crops. continuous use of single herbicide leads to evolution of herbicide resistant weed species and shift in weed flora.

- For example, Atrazine, an s-triazine-ring herbicide, is used globally for the control of pre-and postemergence broadleaf and grassy weeds, which has high persistence (half life-125 days) and mobility in some types of soils. Residual problems due to the application of atrazine herbicide pose a threat towards widespread use of herbicide and limit the choice of crops in rotation.
- To remediate the atrazine residue from soil within a short span of time, application of silver modified with nanoparticles of magnetite stabilized with Carboxy Methyl Cellulose (CMC) nanoparticles recorded 88% degradation of herbicide atrazine residue under controlled environment found to be a potential remedy