

**GEO-INFORMATICS AND  
NANOTECHNOLOGY FOR PRECISION  
FARMING**

**SUBJECT CODE – ASAG 3110**

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## Precision Agriculture

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### 1.1 Definition

- 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).
- Precision agriculture can be defined as the application of principles and technologies to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality (Pierce and Nowak, 1999).
- Precision Farming is generally defined as an information and technology based farm management system to identify, analyze and manage variability within fields by doing all practices of crop production in right place at right time and in right way for optimum profitability, sustainability and protection of the land resource. Precision agriculture is a systems approach to farming for maximizing the effectiveness of crop inputs..

### 1.2 Objectives of precision farming

- To develop a methodology for identifying the causes of within field variation in crop performance.
- To develop practical guidelines required to implement precision farming technology to achieve best management.
- To explore the possibility of using remote-sensing methods and GIS to enable management decisions to be made in real time during the growth of the crop
- To determine the potential economic and environmental benefits of using precision farming technology in cropping system.

### 1.3 Need of precision farming

- To increase production efficiency
- To improve product quality
- Use of chemicals more efficiently
- Energy conservation

- To increase input use efficiency
- Soil and ground water protection
- Improve soil structure

## 1.4 Components of precision farming

### ➤ Information or data base

- **Soil:** Soil Texture, Structure, Physical Condition, Soil Moisture; Soil Nutrients, etc.
- **Crop:** Plant Population; Crop Tissue Nutrient Status, Crop Stress, Weed patches (weed type and intensity); Insect or fungal infestation (species and intensity), Crop Yield; Harvest Swath Width etc.
- **Climate:** Temperature, humidity, rainfall, solar radiation, wind velocity, etc.

In-fields variability, spatially or temporally, in soil-related properties, crop characteristics, weed and insect-pest population and harvest data are important databases that need to be developed to realize the potential of precision farming.

- **Technology:** Technologies include a vast array of tools of hardware, software and equipments.
  - **Global Positioning System (GPS) receivers:** GPS provides continuous position information in real time, while in motion. Having precise location information at any time allows soil and crop measurements to be mapped. GPS receivers, either carried to the field or mounted on implements allow users to return to specific locations to sample or treat those areas.
  - **Differential Global Positioning System (DGPS):** A technique to improve GPS accuracy that uses pseudo range errors measured at a known location to improve the measurements made by other GPS receivers within the same general geographic area.
  - **Geographic information systems (GIS):** Geographic information systems (GIS) are computer hardware and software that use feature attributes and location data to produce maps. An important function of an agricultural GIS is to store layers of information, such as yields, soil

survey maps, remotely sensed data, crop scouting reports and soil nutrient levels.

- **Remote sensing:** It is the collection of data from a distance. Data sensors can simply be hand-held devices, mounted on aircraft or satellite-based. Remotely-sensed data provide a tool for evaluating crop health. Plant stress related to moisture, nutrients, compaction, crop diseases and other plant health concerns are often easily detected in overhead images. Remote sensing can reveal in-season variability that affects crop yield, and can be timely enough to make management decisions that improve profitability for the current crop.
- **Variable Rate Applicator:**  
The variable rate applicator has three components:
  - a. Control computer
  - b. Locator and
  - c. Actuator

The application map is loaded into a computer mounted on a variable-rate applicator. The computer uses the application map and a GPS receiver to direct a product-delivery controller that changes the amount and/or kind of product, according to the application map.

- **Combine harvesters with yield monitors:** Yield monitors continuously measure and record the flow of grain in the clean grain elevator of a combine. When linked with a GPS receiver, yield monitors can provide data necessary for yield maps.

#### ➤ **Management**

- **Information management:** The adoption of precision agriculture requires the joint development of management skills and pertinent information databases. A farmer must have clear idea of objectives of precision farming and crucial information necessary to make decisions effectively. Effective information management requires many more than just keeping analysis

tools. It requires an entrepreneurial attitude toward education and experimentation.

- **Decision support system (DSS):** Combination of information and technology into a comprehensive and operational system gives farmers a decision to treat the field. For this purpose, DSS can be developed, utilizing GIS, agronomic, economic and environmental software, to help farmers manage their fields.
- **Identifying a precision agriculture service provider:** It is also advisable for farmers to consider the availability of custom services when making decisions about adopting precise/site specific crop management. Purchasing the equipments and learning the necessary skills for precision farming is a significant up-front cost that can not be affordable for many farmers.

## 1.5 Steps in precision farming

### ➤ Identification and assessment of variability

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

➤ **Management of variability**

- **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 the observed yields are 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 lands based on personal observation and could already be modifying their management accordingly. Appropriate technologies here might take this task easier or more efficient. Larger farmers may find the more advanced technologies

necessary to collect and properly analyse data for better management decisions.

➤ **Evaluation of precision farming**

- Economic analysis: Whether it is cost effective?
- Environmental assessment: Does it improve the quality of environment or at least not harm?
- Rate of ToT (Transfer of Technology): Do farmers adopt it rapidly?

## **1.6 Scope of precision farming in India**

- The concept of precision farming is not new for India. Farmers try their best to do the things for getting maximum possible yield with information and technologies available to them but unless & until total information about his field and advanced technologies are available, they cannot do precision farming in perfect sense.
- In India, major problem is the small field size. More than 58 percent of operational holdings in the country have size less than 1ha.
- Only in the states of Punjab, Rajasthan, Haryana and Gujarat more than 20 per cent of agricultural lands have operational holding size of more than four hectare.
- When contiguous fields with the same crop are considered, it is possible to obtain fields of over 15 ha extent in which similar crop management are followed. Such fields can be considered for the purpose of initiating the implementation of precision farming. Similar implementation can also be carried out on the state farms.
- There is a scope of implementing precision agriculture for crops like, rice and wheat especially in the states of Punjab and Haryana. Commercial as well as horticultural crops also show a wider scope for precision agriculture in the cooperative farms. Nearly two-third arable land in India is rain-fed. The crop yields are very low ( $\approx 1\text{t ha}^{-1}$ ) and very good potential exists for increasing productivity of rain-fed Cropping systems.

## **1.7 Advantages of precision farming**

- Overall yield increase

- Efficiency improvement
- Reduced production costs
- Better decision making in Agricultural management
- Reduced environmental impact
- Accumulation of farmer's knowledge for better management with time

## **1.8 Drawbacks of Precision Farming**

- High costs
- Lack of technical expertise knowledge and technology
- Not applicable or difficult/costly for small land holdings
- Heterogeneity of cropping systems and market imperfections

## Geo-informatics in Precision Agriculture

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### 2.1 Introduction

- **Geoinformatics** is 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.
- It is an integral tool to collect process and generate information from spatial and non spatial data.
- Geoinformatics is an appropriate blending of modules like remote sensing, global positioning system, geographical information system and relational database management system

### 2.2 Tools and techniques in Geoinformatics

#### 2.2.1 Global positioning system

- The Global Positioning System (GPS) is a satellite-based navigation system that can be used to locate positions anywhere on the earth.
- GPS provides continuous (24 hours/day), real-time, 3-dimensional positioning, navigation and timing worldwide in any weather condition.
- As a tool of precision Agriculture, Global Positioning System satellites broadcast signals that allow GPS receivers to calculate their position. This information is provided in real time, meaning that continuous position information is provided while in motion. Having precise location information at any time allows crop, soil and water measurements to be mapped
- GPS makes use of a series of satellites that identify the location of farm equipment within a 3 meter of an actual site in the field.
- The most common use of GPS in agriculture is for yield mapping and variable rate fertilizer/pesticide applicator.

- GPS are important to find out the exact location in the field to assess the spatial variability and site-specific application of the inputs
- The positional (horizontal) accuracy of the GPS can be of the order of 20 m
- In order to achieve the required accuracies, especially needed for precision agriculture, the GPS has to be operated in a differentially corrected positioning mode, i.e. DGPS. In the DGPS

### **2.2.2 Remote Sensing Technique**

- Remote sensing (RS) is the science of making inferences about material objects from measurements, made at distance, without coming into physical contact with the objects under study
- A remote sensing system consists of a sensor to collect the radiation and a platform – an aircraft, balloon, rocket, satellite or even a ground-based sensor-supporting stand - on which a sensor can be mounted
- Currently a number of aircraft and spacecraft imaging systems are operating using remote sensing sensors. Some of the current image systems from spacecraft platform include Indian Remote Sensing Satellites (IRS), French National Earth Observation Satellite (SPOT), IKONOS etc
- Detection, identification, measurement and monitoring of agricultural phenomena are predicted on assumption that agricultural landscape features have consistently identifiable signatures on the type of remote sensing data.
- These identifiable signatures are reflection of crop type, state of maturity, crop density, crop geometry, crop vigour, crop moisture etc.
- The detection of features to a large extent depends on the type of sensor used and the portion of the electromagnetic spectrum used in sensing

### **2.2.3 Geographical Information System**

- GIS is a computerized data storage and retrieval system, which can be used to manage and analyze spatial data relating crop productivity and agronomic factors
- GIS can display analyzed information in maps that allow better understanding of interactions among yield, fertility, pests, weeds and other factors, and decision-making based on such spatial relationships
- Many farm information systems (FIS) are available, which use simple programmes to create a farm level database. One example of such FIS is LORIS. LORIS (Local Resources Information System) consists of several modules, which enable the data import; generation of raster files by different gridding methods; the storage of raster information in a database; the generation of digital agro-resource maps; the creation of operational maps etc.
- A comprehensive farm GIS contains base maps such as topography, soil type, N, P, K and other nutrient levels, soil moisture, pH, etc. Data on crop rotations, tillage, nutrient and pesticide applications, yields, etc. can also be stored.
- GIS is useful to create fertility, weed and pest intensity maps, which can then be used for making maps that show recommended application rates of nutrients or pesticides

### **2.3 Application of Geoinformatics in precision Agriculture**

- 1) Precision farming employs a system engineering approach to crop production where inputs are made on an "as needed basis," and was made possible by recent innovation in information and technology such as microcomputers, geographic information systems, remote sensing, positioning technologies (Global Positioning System), and automatic control of farm machinery.
- 2) It is a holistic approach to manage spatial and temporal variability in agricultural lands at micro level based on integrated soil, plant, information, and engineering management technologies as well as economics.

- 3) It is well known that soil resources and weather vary across space and over time. Given this inherent variability, management decisions should be specific to time and place rather than rigidly scheduled and uniform.
- 4) Precision agriculture provides tools for tailoring production inputs to specific plots within a field, thus potentially reducing input costs, increasing yields, and reducing environmental impacts by better matching inputs applied to crop needs.
- 5) Modern technologies used in precision agriculture cover three aspects of production: (a) data collection or information input, (b) analysis or processing of the precision information, and (c) recommendations or application of the information.
- 6) Data collection for soil is done basically to understand inherent variability factors controlling crop growth and yield.
- 7) Conventional approach for soil variability mapping is commonly done through manual grid sampling and interpolation through geostatistical techniques for whole agricultural landscape.
- 8) The inherent variability can be correlated with the variability map of yield to develop cause and effect relationships. This may help to develop relatively homogenous management zones. Such samplings are costly and time consuming.
- 9) The scope of remote sensing data has been widely studied and looking more closely at how the spectral response of soil can be linked to various soil properties and characteristics.
- 10) As an alternate to conventional laboratory soil analysis, hyperspectral remote sensing which is non-destructive, cost effective and capable of spatial prediction has been investigated for surface soil characterization.
- 11) Hyperspectral image data or imaging spectrometry technique, which many narrow and contiguous bands, provides near-laboratory-quality reflectance information, has the capability to obtain non-visible information over a spatial view in large scales.

## Crop Discrimination and Spectral Features for Crop Classification

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### 3.1 Introduction

- Currently computers are being used automation and to expand decision support system (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.
- 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
- With the use of these imaging and non-imaging data, we can easily characterise the different species
- Different crops show distinct phenological 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 phenological stage can differ between the varieties, which introduce data variability for crop type discrimination with imaging systems.
- Agricultural crops are significantly better characterised, classified, modelled and mapped using hyperspectral data.

#### 3.1.1 Feature Extraction

- Feature extraction is the process of defining image characteristics or features which effectively provides meaningful information for image interpretation or classification.
- The ultimate goals of feature extraction are:
  - Effectiveness and efficiency in classification.
  - Avoiding redundancy of data.
  - Identifying useful spatial as well as spectral features.

- Maximising the pattern discrimination.
- For crop type discrimination, spatial features are useful. Crops are planted in rows. either multiple or single rows, as per the crop types for convenience and to maximise yields
- Different spatial arrangement of the crops gives better spatial information, but it requires high spatial resolution images.
- In spatial image classification, spatial image elements are combined with spectral properties in reaching a classification decision. Most commonly' used elements are texture, contexture and geometry (shape).

### **3.1.2 Role of texture in classification**

- As it is possible to distinguish between regular textures manifested by man made objects hence, this texture characteristic is used to discriminate between divergent objects
- Grey value relationship is obtained from segmentation both by conventional texture analysis and grey level co-occurrence matrix (GLCM)
- GLCM method analyses within GLCM space not from original grey values

### **3.1.3 Grey Level Co-occurrence Matrix (GLCM)**

- The **GLCM** can be viewed as two dimensional histogram of the frequency with which pairs of grey level pixels occur in a given spatial relationship, defined by specific inter-pixel distance and a given pixel orientation
- Hence this segmentation of urban objects , texture analysis are usually performed by GLCM

### **3.1.4 Local Binary Pattern (LBP)**

- It is a simple yet very efficient texture operator which labels the pixels of an image by thresholding the neighbourhood of each pixel and considers the result as a binary number.
- Due to its discriminative power and computational plainness, LBP texture operator become a popular approach
- Spacial feature extraction for crop type discrimination works well if we have high spatial resolution satellite imagery. Rather than this spatial information is

also useful in spectral based classification for visual interpretation in supervised learning

## 3.2 Spectral Features for Crop Classification

- Band selection
- Narrow band vegetation indices

### 3.2.1 Band Selection

- Band selection is one of the important steps in hyperspectral remote sensing.
- There are two conceptually different approaches of band selection like Unsupervised and supervised.
- Due to a 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 band by studying the reflectance behaviour of crops.

### 3.2.2 Narrow Band 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 hyperspectral systems is their ability to create new indices that integrate not sampled by any broadband system and to quantify absorptions that *are* Specific to important biochemical and biophysical quantities of vegetation.
- Vegetation properties measured with hyperspectral vegetation indices (HVIs) can be divided into three main categories. (1) Structure, (2) biochemistry and (3) plant physiology/stress.

### **3.3 Importance of Hyperspectral Remote Sensing**

- Spectrum allows us to study very specific characteristics of agricultural crops
- Non-imaging sensors gave spectral signatures with approximate 1-10 nm sampling rate which is very effective for distinct feature identification
- Narrow band vegetation indices play an important role for mapping plant biophysical and biochemical properties of agricultural crops
- It gives detailed information about crops but it is necessary to select appropriate bands

## Yield Monitoring and Soil Mapping

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### 4.1 Introduction on Yield Monitoring

- To enable decision makers and planners to predict the amount of crop import and export yield estimation well before harvest is imperative
- But conventional methods are expensive, time consuming and are prone to large errors due to incomplete and inaccurate ground observations
- Data captured through remote sensing has the prospective, capacity and the potential to exhibit spatial information at global scale
- Different approaches include
  - Aerial photography
  - Multispectral scanners
  - Radar
  - Satellite Data

#### 4.1.1. Aerial Photography

- This is used for optimized use of resources for agriculture and crop inventory
- Black and white photography has been used for crop identification, primarily based on ground appearance and the equivalent aerial photographic form of selected fields at nine intervals during growing season

#### 4.1.2. Multispectral Scanners

- It uses pattern recognition techniques using a computer format to differentiate specific crop from other agricultural crops
- It also helps in species identification

#### 4.1.3. Radar

- It helps in monitoring the yield concentrating on seasonal change between the crops and numerous variables which are considered in making simplest determinations

#### 4.1.4. Satellite Data

- Predicting crop yields with conventional models proved to be unsuccessful in present day World

- Remote sensing has proved effective in predicting crop yield and provide representative and spatially exhaustive information on the development of the model
- India's marked the beginning of remote sensing with the launch of IRS satellite in 1988.
- Yield estimates through remote sensing is indirect in nature
- Recently, researchers are using coarse resolution data as a sampling tool to estimate the yield through remote sensing for increased precision

## 4.2. 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 generalised 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.

## 4.3 Applications of soil mapping through remote sensing

### ➤ Remote Sensing for Soil and Land Degradation Mapping

- Conventional surveys are subjective, time consuming and laborious
- Remote sensing speeded up the conventional soil survey programmes
- Aerial photography and satellite data reduced the field work with respect to locating soil types and boundaries owing to synoptic view

### ➤ Soil Mapping methods

- Topographic variations as the base for depicting soil variability
- Multispectral satellite data is being used for mapping soil upto family association level (1:50000)

### ➤ Visual Image Interpretation

- It is based on shape, size, tone, shadow, texture, pattern, site and association
- This is relatively simple and inexpensive
- Several workers have concluded that remote sensing technology provides better efficiency at 1:50000 and detailed at 1:10000 scale of mapping

### ➤ Computer Aided Approach

- Numerical analysis of remote sensing data utilising the Computers has been developed because of requirement to analyse faster and extract information from the large quantities of data
- Computer aided techniques utilise 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.

## Site Specific Nutrient Management (SSNM)

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### 5.1 Introduction

- 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
- The SSNM helps in improving NUE as it provides an approach for feeding crops like rice, maize, wheat, etc. with nutrients as and when needed.
- The major benefit for farmers from improved nutrient management strategy is an increase in the profitability.
- The SSNM eliminates the wastage of fertilizers by preventing excessive rates of fertilization and by avoiding fertilizer application when the crop does not require nutrient inputs.

### 5.2 Importance of SSNM

- Optimal use of existing indigenous nutrient sources such as crop residues and measures.
- Application of N, P and K fertilizers is adjusted to the location and season-specific needs of the crop.
  - Use of the leaf color chart ensures that nitrogen is applied at the right time and in the amount needed by the crop which prevents wastage of fertilizer.
  - Use of nitrogen omission plots to determine the P & K fertilizers required to meet the crop needs. This ensures that P and K are applied in the ratio required by the rice crop.
- Local randomization for application of Zn, S and micronutrients are followed.
- Selection of most economic combination of available fertilizer sources.

- Integration with other integrated crop management (ICM) practices such as the use of quality seeds, optimum plant density, integrated pest management and good water management.

### **5.3 SSNM Approaches**

- The 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

### **5.4 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 low-land 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 are

#### **1) Selection of the Yield Goal**

- A yield goal exceeding 70–80% of the variety-specific potential yield ( $Y_{max}$ ) has to be chosen.
- $Y_{max}$  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% of the  $Y_{max}$  is that the internal NUEs decrease at very high yield levels near  $Y_{max}$ .
- Crop growth models (eg. DSSAT) can be used to work out  $Y_{max}$  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  $Y_{max}$ .
- In SSNM, nutrient requirements are estimated with the help of quantitative evaluation of fertility of tropical soils (QUEFTS) models.
- The 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 K, as computed above, are applied basally i.e., at the time of 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 color 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 grain, 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.

### **5.5 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  $Y_{max}$ ), and RE of applied nutrients are considered for developing fertilizer use schedule to achieve maximum economic yield of a crop variety.
- 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-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

### **5.6 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

## **5.7 Decision Rules to Estimate Site-Specific Nutrient Management Parameters**

- NE estimates the 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

## **5.8 Current Versions of Nutrient Expert**

- NE has been developed for specific crops and geographic regions. Nutrient Expert® for Hybrid Maize (NEHM) for favourable tropical environments (e.g., 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.

## Spatial data and its management in GIS

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### 6.1 Introduction

- Geospatial data has significantly different structure and function. It includes structure data about objects in the spatial universe- their identity, location, shape and orientation and other things we may know about them
- In geographical data all the objects are described in terms of points, lines, tables and polygons constituting the tabular portion of geospatial data
- GIS technology accommodates some kinds of unstructured data (usually raster imagery) that can be tagged and geocoded and integrated by GIS software the other kinds of map data
- Raw GIS data is generally meaning less for human eye until converted into a map. This is what GIS software does.

### 6.2 What is a GIS

- A geographic information system (GIS) is a computer-based tool for mapping and analysing things that exist and events that happen on earth.
- GIS technology integrates common database operations such as query and statistical analysis with the unique visualisation and geographic analysis benefits offered by maps
- These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes and planning strategies.
- Mapmaking and geographic analysis are not new, but a GIS performs these tasks better and faster than do the old manual methods.

### 6.3 Importance of GIS

- Perform Geographic Queries and Analysis
- Improve Organisational Integration
- Make Better Decisions

- Making Maps much more

## 6.4 How GIS works

- A GIS stores information about the world as a collection of thematic layers that can be linked together by geography.
- This simple but extremely powerful and versatile concept has proven valuable for solving many real-world problems from tracking delivery vehicles, to recording details of planning applications, to modelling global atmospheric circulation

## 6.5 Geographic References

- Geographic information contains either an explicit geographic reference, such as a latitude and longitude or national grid coordinate or an implicit reference such as an address, postal code, census tract name, forest stand identifier or road name.
- An automated process called geo-coding is used to create explicit geographic references (multiple locations) from implicit references (descriptions such as addresses).
- These geographic references allow location of features, such as a business or forest stand and events, such as an earthquake, on the earth's surface for analysis.

## 6.6 Vector and Raster Models

- Geographic information systems work with two fundamentally different types of geographic models - the "vector" model and the "raster" model.
- In the vector model, information about points, lines and polygons is encoded and stored as a collection of x, y coordinates. The location of a point feature, such as a bore-hole, can be described by a single collection of point x, y coordinate
- Linear features, such as roads and rivers, can be stored as a be stored Coordinates. Polygonal features, such as sales territories and river catchm as a closed loop of coordinates.
- The **vector** model is extremely useful for describing discrete features, but less useful for describing Continuously varying features such as soil type or accessibility costs for hospitals.

- The **raster** model has evolved to model such continuous features. A raster image comprises a collection of grid *cells* rather like a scanned map or picture. Both the vector and raster for storing geographic data have unique advantages and disadvantages

## 6.7 Components of GIS

A working GIS integrates five key components: Hardware, software, data, people and methods.

### Hardware

It is the computer on which a GIS operates. Today, GIS software runs a wide range of hardware types, from centralised computer servers to desktop computers used in stand alone or networked configurations.

### Software

The GIS software provides the functions and tools needed to store, analyse and display geographic information. Key software components are:

- Tools for the input and manipulation of geographic information.
- A database management system (DBMS).
- Tools that support geographic query, analysis and visualisation.
- A graphical user interface (GUI) for easy access to tools.

### Data

Possibly, the most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organisations to organise and maintain their data, to manage spatial data.

### People

The GIS technology is of limited value without the people who manage the system and develop plans for applying it to real-world problems. The GIS users range from technical specialists who design and maintain the System to those who use it to help them perform the everyday work.

**Methods**

A successful GIS operates according to a well-designed plan and business rules, are the models and operating practices Unique to each organisation

## Geodesy and its Basic principles

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### 7.1 Introduction

- Geodesy also known as geodetics, geodetic engineering or geodetics engineering- a branch of applied mathematics and earth sciences, is the scientific discipline that deals with the measurement and representation of the earth (or any planet), including its gravitational field
- Geodesy is defined as the science of measurement and mapping of the earth's surface.
- Geodesists also study geodynamical phenomena such as crustal motion, tides and polar motion
- For this, they design global and national control networks, using space and terrestrial techniques while relying on datums and coordinate systems

### 7.2 Principles of Geodesy

- Coordinates and Coordinate Reference Systems
- Earth and the Geoid
- Ellipsoids (Spheroids)
- Geodetic Datums
- Geographical Coordinates (Latitude and Longitude)
- Latitude and Longitude are not Unique
- Global Positioning System (GPS)
- Coordinate Transformations

#### 7.2.1 Coordinates and Coordinate Reference Systems

- Coordinates belong to a coordinate system
- A coordinate system (CS) describes the mathematical rules governing the Coordinate space including: the number of axes, their name, their direction, their units and their order
- A coordinate reference system (CRS) is a coordinate system which is referenced to the earth.

- Surface of the earth is irregular and is therefore difficult to calculate on directly.
- Numerous models exist and any one model may have several variations in position or orientation relative to the earth. Each variation leads to a different CRS.
- Consequently, coordinates describe location unambiguously only when the CRS to which they are referenced has been fully identified.

### **7.2.2 Earth and the Geoid**

- Surface of the earth with its topography is far too irregular to be a convenient basis for computing position.
- Surveyors reduce their observations to the gravitational surface, which approximates mean sea level.
- This equi-potential surface is known as the geoid. It is approximately spherical but because of the rotation of the earth, there is slight bulge at the equator and flattening at the poles.
- In addition, because of the variations in rock density that impact the gravitational field, there are many local irregularities. These factors make the geoid a complex surface.

### **7.2.3 Ellipsoids (Spheroids)**

- To simplify computing of position, the geoid is approximated by the nearest mathematically definable figure, the ellipsoid. The ellipsoid is effectively a ‘best fit’ to the geoid.
- Approximation of the geoid by a reference ellipsoid could traditionally only be done locally, not globally and this limitation led to the existence of many ellipsoids, each with different size and shape
- Ellipsoids determine shape and provide a best fit of the geoid.

### **7.2.4 Geodetic Datums**

- A geodetic datum defines the position and orientation of the reference ellipsoid relative to the centre of the earth and the meridian used as zero longitude - the prime meridian

- Size and shape of the ellipsoid are traditionally chosen to best fit the geoid in area of interest. A local best fit will attempt to align the minor axis of the ellipsoid with the earth's rotational axis.
- It will also ensure that the zero longitude of the ellipsoid coincides with a defined prime meridian.
- The prime meridian is usually that through Greenwich, England, but historically, countries used the meridian through their national astronomic observatory.
- A geodetic datum is inextricably linked to the generation of geographical coordinates.

### **7.2.5 Geographical Coordinates (Latitude and Longitude)**

- Position of a point relative to a geographical coordinate reference system is described by the CRS ellipsoid and is generally expressed by means of geographical coordinates
- It is very important to appreciate that latitude and longitude are not unique and are therefore entirely dependent on the chosen geodetic datum. Conversely, any given values of latitude and longitude can refer to any geodetic datum
- Each of the many models (ellipsoids) may have several determinations of its reference to the earth, each resulting in a different geodetic datum.
- Because of the irregularities of the geoid, a point has coordinates referenced to European datum that differ by several meters from coordinates referenced to Monte Mario datum, despite both datum using the same ellipsoid
- Similarly, if the model is changed (a different ellipsoid adopted), even when the reference point is retained, coordinates of positions away from the reference point will differ

### **7.2.6 Latitude and Longitude are not Unique**

- Latitude and longitude are not unique without the associated CRS being identified.

### **7.2.7 Global Positioning System (GPS)**

- The GPS is a worldwide navigation system operated by the US Department of Defense and formed by a constellation of 24 satellites and their ground stations.
- Its receivers use these satellites as reference points to calculate positions accurate to a matter of meters, on or above the earth's surface.
- These “black box” units generate a 3D coordinate, which can be used for navigation (amongst other numerous purposes) and ultimately determine your position in terms of a latitude and longitude.
- In addition, they compute a height above the ellipsoid for that associated position.
- The coordinate **reference system** used by the GPS system is known as WGS 84. The WGS 84 CRS has its own ellipsoid, confusingly also known as WGS 84.
- There is no single datum origin point for the WGS 84 datum and geographic coordinates are derived from a world adjustment of several geodetic markers surveyed by GPS

## 7.2.8 Coordinate Transformations

- In order to merge points such as surface well locations (whose geographical coordinates are referenced to one particular CRS) with other points based on a different CRS, one of the two datasets must be transformed it is possible to measure and calculate the displacements, rotations and scale differences between them.
- There are numerous different methods of transforming coordinates Various **E&P** companies adopt different CRS to store geo-referencing data in their corporate databases
- It is therefore quite common to have to transform data sets to suit the recipient's prescribed CRS, prior to sharing data with other operators or submitting information to regulatory bodies.

## Remote sensing and its applications in Agriculture

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### 8.1 Introduction

- 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.

### 8.2 Components of Remote Sensing

- **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.
- **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.
- **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.
- **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
- **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).

- **Interpretation and Analysis (F)** - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
- **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.

### 8.3 Types of Remote Sensing

- **Active Remote Sensing:** when remote sensing work is carried out with a man made source of radiations which is used to illuminate a body and to detect the signal reflected from. eg. Radar and Lidar remote sensing
- **Passive Remote Sensing:** when remote sensing work is carried out with the help of electromagnetic radiations (signals) reflected by a natural body (sun and earth). eg visible, NIR and Microwave remote sensing.

### 8.4 Application of Remote Sensing in Agriculture

- **Crop Identification:**
  - It is very important for a national government to know what crops the country is going to produce in the current growing season
  - This knowledge has financial benefits for the country, as it allows the budget planning for importing and exporting of food products
  - To identify the crop we need to know in advance, how the crops reflect the near-infrared at each of their various growth stages. Using the different near infrared reflectance is one of the tools we have to discriminate between two crops.
  - Having the knowledge of when each crop is planted and harvested, we can estimate the percentage of vegetation cover through the growth period, assuming no external factors (stress, disease, etc.) affect its growth.
  - By using multi-date data (data from different dates) from one growing period, it is possible to identify the different crop types, because the vegetation cover of each crop changes at different rates.

- By combining this information with remote sensing data, we can discriminate between different crops and also identify them. This information serves to predict grain crop yield, collecting crop production statistics, facilitating crop rotation records, mapping soil productivity, identification of factors influencing crop stress, assessment of crop damage and monitoring farming activity
- **Detection, diagnosis and control of plant diseases**
  - Remote sensing assist in protecting the plants from potential attacks of pests, fungi or bacteria
  - By combining agricultural knowledge with remotely sensed data, it is possible to have early warning and prevent a pest or a disease from affecting the crops, by taking appropriate action at an early stage.
  - Detection of diseases at early stage is a lot easier less costly than currently used impractical human scouting techniques. It is also possible to assess the extent of the damage caused by pests and diseases, by using similar methods to those used to identify stressed plants
  - The symptoms of such attacks usually cause the break-down of chlorophyll, and we can identify the reduction of chlorophyll concentration in the plants through remote sensing.
  - In addition to loss of chlorophyll, pest and diseases can cause the destruction of whole leaves. This leads to a reduction in the total leaf area and as a result, the reduction of the plant's capacity for photosynthesis
- **Yield estimation**
  - Remote sensing has been used to forecast crop yields based primarily upon statistical–empirical relationships between yield and vegetation indices
- **Yield maps**
  - Yield maps created on the basis of satellite images acquired in many seasons represent the spatial variability in crops yield regardless of plant species
- **Soil Analysis**

- A major breakthrough in these studies has been the use of visible-near infrared spectroscopy to develop quantitative calibrations for rapid characterization of soil nutrients and various physical properties of soils.
- The coupling of this technology with remote sensing data, geo-referenced ground surveys, and new spatial statistical methods has resulted in the improved capability for large area soil assessments

➤ **Soil Mapping**

- Soil maps are another type of maps developed using remote sensing data. These maps can be compiled on the basis of airborne or satellite images acquired when the degree of soil coverage by plants is less than 30-50%.
- Soil maps present homogeneous soil zones with similar properties and conditions for plant growth. These maps are useful in determining soil sampling locations for detailed studies of soil, soil moisture sensors location or developing irrigation plans
- Remote sensing is a good method for mapping and prediction of soil degradation. Soil layers that rise to the surface during erosion have different color, tone and structure than non eroded soils thus the eroded parts of soil can be easily identify on the images. Using multi-temporal images we can study and map dynamical features – the, expansion of erosion, soil moisture.

➤ **Land cover mapping**

- It is one of the most important and typical applications of remote sensing data. Land cover corresponds to the physical condition of the ground surface, for example, forest, grassland, concrete pavement etc., while land use reflects human activities such as the use of the land, for example, industrial zones, residential zones, agricultural fields etc Initially the land cover classification system should be established, which is usually defined as levels and classes.

## Image processing and Interpretation

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### 9.1 Definition

- Image Processing and Interpretation can be defined as act of examining images for the purpose of identifying objects and judging their significance

### 9.2 Common image processing functions

#### 9.2.1 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**).

#### 9.2.2 Image Enhancement

- It is to improve the appearance of the imagery to assist in visual interpretation and analysis.
- Examples of enhancement functions include contrast stretching to increase the tonal distinction between various features in a scene, and spatial filtering to enhance (or suppress) specific spatial patterns in an image

### 9.2.3 Image Classification

- Different landcover 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. The classification procedures can be "supervised" or "unsupervised".
- In **supervised classification**, the spectral features of some areas of known landcover 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 landcover type by the analyst.
- Each class of landcover is referred to as a "**theme**" and the product of classification is known as a "**thematic map**".

### 9.2.4 Spatial Feature Extraction

- In high spatial resolution imagery, details such as buildings and roads can be seen.
- The amount of details depend 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 utilising the textural, contextual and geometrical properties are required.
- Such algorithms make use of the relationship between neighbouring pixels for information extraction.
- Incorporation of a-priori information is sometimes required.

- A multi-resolutional approach (i.e. analysis at different spatial scales and combining the results) 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.

### 9.2.5 Measurement of Bio-geophysical Parameters

- Specific instruments carried 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 vapour content, stratospheric ozone, land and sea surface temperature, sea water chlorophyll concentration, forest biomass, sea surface wind field, tropospheric 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.

### 9.2.6 Geographical Information System (GIS)

- Different forms of imagery such as optical and radar images provide **complementary information** about the landcover.
- 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.
- The thematic information derived from the remote sensing images are 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.

## Global positioning system, components and its functions

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### 10.1 Definition

- **Global Positioning System (GPS)** is a satellite based navigation system consisting of more than 20 satellites and several supporting ground facilities, which provide accurate, three dimensional position, velocity and time, 24 hours a day, everywhere in the world and in all weather conditions

### 10.2 Components of GPS

- **GPS Ground control stations.**
  - The ground control component 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.
  - The control segment uses measurements collected by the monitor stations to predict the behavior of each satellite's orbit and atomic clocks.
  - The 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.
- **GPS satellites**
  - GPS satellites orbit in circular orbits at 17,440 km altitude, each orbit lasting 12 hours.
  - The orbits are tilted to the equator by  $55^\circ$  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 which measure time to a high degree of accuracy.

- The 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.
  - The receiver uses the time difference between the time of signal reception and the broadcast time to compute the range to the satellite
- **GPS receivers**
- When you buy a GPS, you are actually buying only the GPS receiver and get free use of the other two main components.
  - GPS receivers are smaller to carry, easier to handle, much more versatile and updateable.
  - Personal navigation with a GPS also means you can customize maps as you go along - plotting points of interest and marking all those wonderful places in an easy, neat and ordered manner.

### 10.3 Functions of GPS

- **Giving a location:**
- 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).
- **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're standing, you can create a point-to point route to the place where you're headed.
- **Route navigation:**
- By combining multiple waypoints on a trail, you can move point-to-point with intermediate bearing and distance guides. Once you reach the first

predetermined waypoint, the GPS receiver can automatically point you to the next one or you can manually do this.

➤ **Keep a Track:**

- Tracks are some of the most useful functions of navigation systems. You can map where you've already been. This virtual map is called a track, and you can program the GPS system to automatically drop track-points as you travel, either over intervals of time or distance. This can be done on land or in a nautical setting and allows you to retrace your steps

## Simulation and Crop Modelling

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### 11.1 Introduction

- Simulation is defined as a technique for studying real world dynamical systems by imitating their behaviour using a mathematical model of the system implemented on a digital computer
- A simulation is the manipulation of a model in such a way that it operates on time or space to compress it, thus enabling one to perceive the interactions that would not otherwise be apparent because of their separation in time or space.
- Simulation can 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
- A model is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behavior of a system. Also, a model is “A representation of an object, system or idea in some form other than that of the entity itself”. Its purpose is usually to aid in explaining, understanding or improving performance of a system.
- 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.
- A system is understood to be an entity which maintains its existence through the interaction of its parts. A model is a simplified representation of the actual system intended to promote understanding. Whether a model is a good model or not depends on the extent to which it promotes understanding. Since all models are simplifications of reality there is always a trade-off as to what level of detail is included in the model.
- If too little detail is included in the model one runs the risk of missing relevant interactions and the resultant model does not promote understanding. If too much detail is included in the model the model may become overly complicated and actually preclude the development of understanding.

## 11.2 TYPES OF MODELS

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

**a. Statistical models:** These models express the relationship between yield or yield components and weather parameters. In these models relationships are measured in a system using statistical techniques. Example: Step down regressions, correlation, etc.

**b. Mechanistic models:** These models explain not only the relationship between weather parameters and yield, but also the mechanism of these models (explains the relationship of influencing dependent variables). These models are based on physical selection.

**c. Deterministic models:** These models estimate the exact value of the yield or dependent variable. These models also have defined coefficients.

**d. Stochastic models:** A probability element is attached to each output. For each set of inputs different outputs are given along with probabilities. These models define yield or state of dependent variable at a given rate.

**e. Dynamic models:** Time is included as a variable. Both dependent and independent variables are having values which remain constant over a given period of time.

**f. Static:** Time is not included as a variable. Dependent and independent variables having values remain constant over a given period of time. 5

**g. Simulation models:** Computer models, in general, are a mathematical representation of a real world system. One of the main goals of crop simulation models is to estimate agricultural production as a function of weather and soil conditions as well as crop management. These models use one or more sets of differential equations, and calculate both rate and state variables over time, normally from planting until harvest maturity or final harvest.

**h. Descriptive model:** A descriptive model defines the behaviour of a system in a simple manner. The model reflects little or none of the mechanisms that are the causes of phenomena. But, consists of one or more mathematical equations. An example of such an equation is the one derived from successively measured

weights of a crop. The equation is helpful to determine quickly the weight of the crop where no observation was made.

**i. Explanatory model:** This consists of quantitative description of the mechanisms and processes that cause the behaviour of the system. To create this model, a system is analyzed and its processes and mechanisms are quantified separately. The model is built by integrating these descriptions for the entire system. It contains descriptions of distinct processes such as leaf area expansion, tiller production, etc. Crop growth is a consequence of these processes.

### 11.3 Model Development

➤ **Model Calibration:**

Calibration is the adjustment of the system parameters so that simulation results reach a pre-determined level, usually that of an observation. In many instances, even if a model is based on observed data, simulated values do not exactly comply with the observed data and minor adjustments have to be made for some parameters

➤ **Model Validation**

The model validation stage involves the confirmation that the calibrated model closely represents the real situation. The procedure consists of a comparison of simulated output and observed data. Ideally, all mechanistic models should be validated. However, validation of all the components is not possible due to lack of detailed datasets and the option of validating only the determinant ones is adopted.

### 11.4 Steps of Modelling Process

The modeling process is cyclic and closely parallels the scientific method and the software life cycle for the development of a major software project. The process is cyclic because at any step we might return to an earlier stage to make revisions and continue the process from that point. The steps of the modeling process are as follows:

- **Analyze the problem** We must first study the situation sufficiently to identify the problem precisely and understand its fundamental questions clearly. At this stage, we determine the problem's objective and decide on the problem's classification,

such as deterministic or stochastic. Only with a clear, precise problem identification can we translate the problem into mathematical symbols and develop and solve the model.

- **Formulate a model** In this stage, we design the model, forming an abstraction of the system we are modeling. Some of the tasks of this step are as follows:
  - **Gather data** We collect relevant data to gain information about the system's behavior.
  - **Make simplifying assumptions and document them** In **formulating a model** we should attempt to be as simple as reasonably possible. Thus, frequently we decide to simplify some of the factors and to ignore other factors that do not seem as important. Most problems are entirely too complex to consider every detail, and doing so would only make the model impossible to solve or to run in a reasonable amount of time on a computer. Moreover, factors often exist that do not appreciably affect outcomes. Besides simplifying factors, we may decide to return to Step 1 to restrict further the problem under investigation.
  - **Determine variables and units** We must determine and name the variables. An independent variable is the variable on which others depend. In many applications, time is an independent variable. The model will try to explain the dependent variables. For example, in simulating the trajectory of a ball, time is an independent variable; and the height and the horizontal distance from the initial position are dependent variables whose values depend on the time. To simplify the model, we may decide to neglect some variables (such as air resistance), treat certain variables as constants, or aggregate several variables into one. While deciding on the variables, we must also establish their units, such as days as the unit for time.
  - **Establish relationships among variables and submodels** If possible, we should draw a diagram of the model, breaking it into submodels and indicating relationships among variables. To simplify the model, we may assume that some of the relationships are simpler than they really are. For

example, we might assume that two variables are related in a linear manner instead of in a more complex way

- **Determine equations and functions** While establishing relationships between variables, we determine equations and functions for these variables. For example, we might decide that two variables are proportional to each other, or we might establish that a known scientific formula or equation applies to the model. Many computational science models involve differential equations, or equations involving a derivative, which we introduce in Module 2.3 on “Rate of Change.”
- **Solve the model** This stage implements the model. It is important not to jump to this step before thoroughly understanding the problem and designing the model. Otherwise, we might waste much time, which can be most frustrating. Some of the techniques and tools that the solution might employ are algebra, calculus, graphs, computer programs, and computer packages. Our solution might produce an exact answer or might simulate the situation. If the model is too complex to solve, we must return to Step 2 to make additional simplifying assumptions or to Step 1 to reformulate the problem
- **Verify and interpret the model’s solution** Once we have a solution, we should carefully examine the results to make sure that they make sense (verification) and that the solution solves the original problem (validation) and is usable. The process of verification determines if the solution works correctly, while the process of validation establishes if the system satisfies the problem’s requirements. Thus, verification concerns “solving the problem right,” and validation concerns “solving the right problem.” Testing the solution to see if predictions agree with real data is important for verification. We must be careful to apply our model only in the appropriate ranges for the independent data. For example, our model might be accurate for time periods of a few days but grossly inaccurate when applied to time periods of several years. We should analyze the model’s solution to determine its implications. If the model solution shows weaknesses, we should return to Step 1 or 2 to determine if it is feasible to refine the model. If so, we cycle back through the process. Hence, the cyclic modeling

process is a trade-off between simplification and refinement. For refinement, we may need to extend the scope of the problem in Step 1. In Step 2, while refining, we often need to reconsider our simplifying assumptions, include more variables, assume more complex relationships among the variables and submodels, and use more sophisticated techniques.

➤ **Report on the model** Reporting on a model is important for its utility. Perhaps the scientific report will be written for colleagues at a laboratory or will be presented at a scientific conference. A report contains the following components, which parallel the steps of the modeling process:

- **Analysis of the problem** Usually, assuming that the audience is intelligent but not aware of the situation, we need to describe the circumstances in which the problem arises. Then, we must clearly explain the problem and the objectives of the study.
- **Model design** The amount of detail with which we explain the model depends on the situation. In a comprehensive technical report, we can incorporate much more detail than in a conference talk. For example, in the former case, we often include the source code for our programs. In either case, we should state the simplifying assumptions and the rationale for employing them. Usually, we will present some of the data in tables or graphs. Such figures should contain titles, sources, and labels for columns and axes. Clearly labeled diagrams of the relationships among variables and submodels are usually very helpful in understanding the model.
- **Model solution** In this section, we describe the techniques for solving the problem and the solution. We should give as much detail as necessary for the audience to understand the material without becoming mired in technical minutia. For a written report, appendices may contain more detail, such as source code of programs and additional information about the solutions of equations.
- **Results and conclusions** Our report should include results, interpretations, implications, recommendations, and conclusions of the model's solution. We may also include suggestions for future work.

- **Maintain the model:** As the model's solution is used, it may be necessary or desirable to make corrections, improvements, or enhancements. In this case, the modeler again cycles through the modeling process to develop a revised solution.

## 11.5 Modelling in Agricultural Systems

- **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 modeller 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.

- **Models in agriculture**

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 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.

## 11.6 Principles of Successful simulation

- Simplicity
- Learn from the past
- Create a conceptual model
- Build a prototype
- Push the user's desire
- Model to data available

- Separate data from software
- Trust your creative juices
- Fit universal constraints
- Distil your own principles

## **11.7 Model Uses**

- Crop system management: to evaluate optimum management production for cultural practice.
- Helps in evaluating weather risk.
- Investment decisions become qualitative
- These are resource conserving tools

## **11.8 Model Limitations**

- Models and simulations can't ever completely re-create real life situations
- Not every possible situation have been included in the model
- The equipment and software are expensive to purchase
- The result depends on how good the model is and how much data was used to create it in the first place

## Soil Test Crop Response (STCR)

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### 12.1 Introduction

- Fertilizer is one of the costliest inputs in agriculture and the use of right amount of fertilizer is fundamental for farm profitability and environmental protection.
- Imbalanced use of fertilizers by farmers not only reduces the yield of the crops but also deteriorate the quality of soil and water resources.
- To enhance farm profitability under different soil-climate conditions, it is necessary to have information on optimum fertilizer doses for every crops. For determining the optimum fertilizer doses, the most appropriate method is Soil Test Based Integrated Fertilizer Recommendation for different crop which are based on the soil test and crop response studies.
- High yielding, fertilizer responsive varieties of crop and high cost of fertilizers have necessitated the development of a quantitative basis for making fertilizer recommendations according to soil fertility status of field for obtaining economic yield.
- Soil test crop response (STCR) study based on soil test based fertilizer recommendation should be carried out to develop quantitative basis for calculating the profit maximizing dose of fertilizers based on soil test for any crop.
- STCR approach is based on soil contribution and yield level is used for recommending fertilizer dose.
- STCR concept is more quantitative, precise and meaningful. Among various methods of fertilizer recommendation such as general recommended dose (GRD), soil test based recommendation, critical value approach, *etc.*, the soil test crop response (STCR) approach for targeted yield is unique in indicating both soil test based fertilizer dose and the level of yield that can be achieved with good agronomic practices.

## 12.2 What is Soil Test Crop Response

- Soil testing is a rapid chemical analysis to assess available nutrient status of the soil and includes interpretation, evaluation and fertilizer recommendation based on the result of chemical analysis and other considerations.
- A chemical method for estimating the nutrient supplying capacity of a soil.
- It can determine soil's nutrient status before a crop (field, vegetable, ornamental) is planted.

## 12.3 Objectives of STCR

- To study the relationship between soil test values for available N, P, K and yield response to important crops.
- To derive yield targeting equations for important crops for making fertilizer recommendations.
- To evaluate various soil test methods for their suitability under field conditions.
- To evaluate the extent to which fertilizer needs of crop can be reduced in relation with conjunctive use of organic manure

## 12.4 Targeted Yield Approach

- Targeted yield concept is an approach that comes under STCR.
- For obtaining a given yield a definite quantity of the nutrients must be taken up by the crop.
- Once this requirement is known for a given yield, the requirement of fertilizer can be estimated by taking into account efficiency of the soil available nutrient pool and that of fertilizer requirement.

## 12.5 Concept of STCR

- ICAR established the AICRP on STCR in 1967 and the STCR concept was developed by Ramamoorthy in 1987.

- STCR approach is aiming at obtaining a basis for precise quantitative adjustment of fertilizer doses under varying soil test values and response for targeted levels of crop production.
- STCR provides the relationship between a soil test value and crop yield.
- 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

## 12.6 Methods of STCR

- **Gradient experiment:** in this phase artificial soil fertility gradient is created at experiment site by following procedure:
  - Divided the experiment field into 3 or 4 equal strips according to size of field.
  - In 1<sup>st</sup> strip – no fertilization, 2<sup>nd</sup> strip -single fertilization, 3<sup>rd</sup> strip – double fertilization likely increasing fertilizer dose with increase in number of strips
  - Grow exhaustive crop like maize, sorghum fodder crops.
  - Pre sowing and post harvest soil samples were collected from each strips and analysis.
  - Plant analysis after harvest of exhaustive crop
- **Test crop experiment:** after confirming the establishment of fertility gradients in the experiment field this phase of field experiment conducted with the following procedure:
  - Each strip is divided in number of plots which is equal to treatments
  - Initial soil sample is collected from each plot and analyzed
  - The experiment is layout as per statistical design
  - Test crop experiment is taken with different level of fertilizers
  - After maturity of crop to calculated yield from each plot
  - Soil and plant sample is collected from each plot and analyzed
  - Using the yield and nutrient uptake data, soil test values and applied fertilizer doses of treated and control plots, the basic data viz. nutrient

requirement (kg/q), soil, fertilizer and organic manure efficiencies (%) for making fertilizer recommendation can be worked out.

## 12.7 Target Yield Equation

- Liebig's law of minimum is the basis of this concept.
- First advocated by **Truog** (1960), **Ramamoorthy** and coworkers in 1967 established the theoretical basis and experimental proof for the fact that Liebig's law of the minimum operates equally well for N, P and K.
- Among the various methods of fertilizer recommendation, the one based on yield targeting is unique in the sense that this method not only indicates soil test based fertilizer dose but also the level of yield.
- Targeted yield concept is a balance between applied nutrients and the available nutrients in the soil.

$$\text{Fertiliser dose FN/ F P}_2\text{O}_5 / \text{FK}_2\text{O} = \frac{\text{NR} \times \text{T} \times 100}{\% \text{ CF}} - \frac{\% \text{ CS}}{\% \text{ CF}} \times \text{Soil test value}$$

Where,

$$\text{Nutrient requirement (kg of nutrient required Per quintal of grain Production) (NR)} = \frac{\text{Uptake of nutrient kg/ha from grain and Straw}}{\text{Grain yield quintal /ha}}$$

$$\text{Percent Contribution from soil to total Nutrient uptake (C.S)} = \frac{\text{Uptake of nutrient in kg/ha from grain and straw}}{\text{Available soil test values for Nutrient from controlled plots (kg/ha)}} \times 100$$

$$\text{Percent nutrient contribution from fertilizer to total uptake (C.F)} = \frac{\text{Total nutrient uptake in treated plot - soil test values}}{\text{Fertilizer dose}} \times \text{CS}$$

## 12.8 Conditions for yield targeting equation

- Used for similar soils of particular agro-eco region.
- Maximum targets should not exceed 75-80% of highest yield achieved for the crop in the area.
- Fertilizer N recommendations for legumes should be same as general dose of the crop of the area.

- Adjustment equations must be made within experimental range of soil test values.
- If the targeted yield was achieved within  $\pm 10$  per cent variation, then the equations are found to be valid.

## **12.9 STCR Approach for Precision Agriculture**

- Agricultural production system is an outcome of 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
- Under normal conditions, recommended soil sampling procedure is to take samples from portions of fields are no more than 20 acres in area
- Grid soil sampling uses the same principles of soil sampling but increases the intensity of sampling
- The goal of grid soil sampling is to generate a map of nutrient requirement called an application map
- Application map is loaded into the computer mounted on variable rate fertilizer spreader
- Computer uses the application map and GPS receiver to direct a product delivery controller that changes the amount and kind of fertilizer product according to application map

## Nano-technology and Nano-scale effects

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### 13.1 Introduction

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

### 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 devices 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 <sup>2</sup>
0.1m	1000	60 m <sup>2</sup>
0.01m	10 <sup>6</sup>	600 m <sup>2</sup>
0.001m	10 <sup>9</sup>	6000 m <sup>2</sup>
0.0 <sup>-9</sup> m=1nm	10 <sup>27</sup>	6×10 <sup>-9</sup> m <sup>2</sup>

- **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)

## Nano-pesticides, Nano-fertilizers and Nano-sensors

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### 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 nanoparticle 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 as hydrogel nanoparticles. 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 decades
- 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

## Nano-biosensors

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### 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

## Use of Nano-technology in Agriculture

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### 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 devices

### 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 imbided 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 broadcasting 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 adopting 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 phosphorous, 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 nematocides 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