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CROP MANAGEMENT

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Precision Farming

24/01/06.

By

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(2005-21-103)

SEMINAR REPORT

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Certificate

Certified that this seminar report entitled "**Precision Farming**" is a record of work done independently by **Rathish. S.T.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Place : Vellanikkara

Date : 23 05 06

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DECLARATION

I, Rathish, S.T. (2005-21-103) hereby declare that the seminar entitled "*Precision farming*" has been prepared by me, after going through the various references cited here and has not been copied from my fellow students.

S.T. Rathish

Vellanikkara
23.05.06

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PRECISION FARMING

Introduction

"Agriculture is the backbone of the Indian Economy"- said Mahatma Gandhi five decades ago. Even today, as we enter the new millennium, the situation is still the same, with almost the entire economy being sustained by agriculture, which is the mainstay of the villages. Not only the economy, but also every one of us looks up to agriculture for our sustenance too. Therefore, it is no surprise if agriculture gets the celebrity status in the name of *Precision Farming* (PF).

Precision agriculture is the fact that land is heterogenous in nature. Consider the state of Kerala. It is divided into twenty agroclimatic zones. This has identified by super imposing soil moisture availability regimes over seven soil groups (KAU, 1996). For all these agroclimatic zones, there is only a single blanket recommendation. The variability in soil type, fertility status, soil moisture availability etc., among these agroclimatic zones is not considered. Soil fertility status i.e., nutrient content varies from one place to another even in the same field. Work conducted in Vellanikkara, Horticulture College Campus revealed that within an area of 380 ha itself, wide variability can be seen in soil physical properties, fertility status etc. (Seena, 2000). The population of weeds is never uniform throughout the crop field and the population dynamics of insect pests also shows a variable pattern. When a pathogen attacks a crop, the disease intensity may not be same throughout the field. Sometimes disease appears in patches leaving many disease free zones. But in conventional agriculture, without considering these variables, fertilizers, herbicides, insecticides and fungicides are applied at a uniform rate through out the crop field. Precision agriculture emphasizes on this aspect and deals with judicious crop management at micro level wherein only required amount of inputs are applied (Biswas and Subbarao, 2000). It is here the challenge arises considering the implementation of the technology at various levels in the global community. The need of the hour is not application of the technology but the adoption of *appropriate technology*, which would suit the particular level of the global community. In India, the farming practices are too haphazard and non-scientific and hence need some forethought before implementing any new technology.

Such an approach in agriculture production management give rise to what is now termed as Precision Farming (PF), Precision Agriculture (PA), Prescription Farming (PF), Site Specific Agriculture (SSA), Soil Specific Crop Management (SSCH), Spatially Variable Crop Production (SVCP) etc.

Definition

1. It is defined as the application of technologies and principle to manage spatial and temporal variability associated with all aspects of agricultural production. (Pierce and Nowak, 1999).

2. It is defined as information and technology based farm management system to identify, analyze and manage field variability within the fields for optimum profitability, sustainability, and protection of land resources.

Statistically, the precision farming P = 1 – SD, where SD is standard deviation; P = 1, indicates highly homogenous field and P = 0, is a complex system, describes maximum variability of field (Mandal and Ghosh, 2000).

Objectives

- Increased production efficiency
- Improved product quality
- More efficient chemical use
- Energy conservation
- Soil and ground water protection

Principles

- Ability to generate yield maps
- Control and selective delivery of materials to crops
- Ability to control equipment applying materials selectively in response to information
- Detailed knowledge about crop growth, protection management

Practical problems for following precision farming in Indian agriculture

- ✓ Small land holdings
- ✓ Cost/benefit aspect of PF system
- ✓ Heterogeneity of cropping system
- ✓ Lack of local technical expertise

✓ Knowledge and technological gaps

Out of these, the two major problems for implementing PF in Indian agriculture are **small land holdings** and **cost of PF system**. In India more than 57.8 per cent of operational holdings has size less than 1 ha. (Ray *et al.*, 2001). With this field size, and the farming being mostly subsistent farming, it is difficult task to adopt the techniques of PF at individual field level. However, for adoption of PF, one can consider, instead of individual fields, contiguous fields, with same crop under similar management practices. Since management practices, like seed rate fertilizer rates etc. are mostly based upon the agroclimatological units, they remain similar for a larger area. In these cases the PF can be adopted as information based agricultural system, i.e. at least the farmer has the information about the soil of his field before adopting the fertilizer practices.

Fig. 1. General Concept of Precision Farming

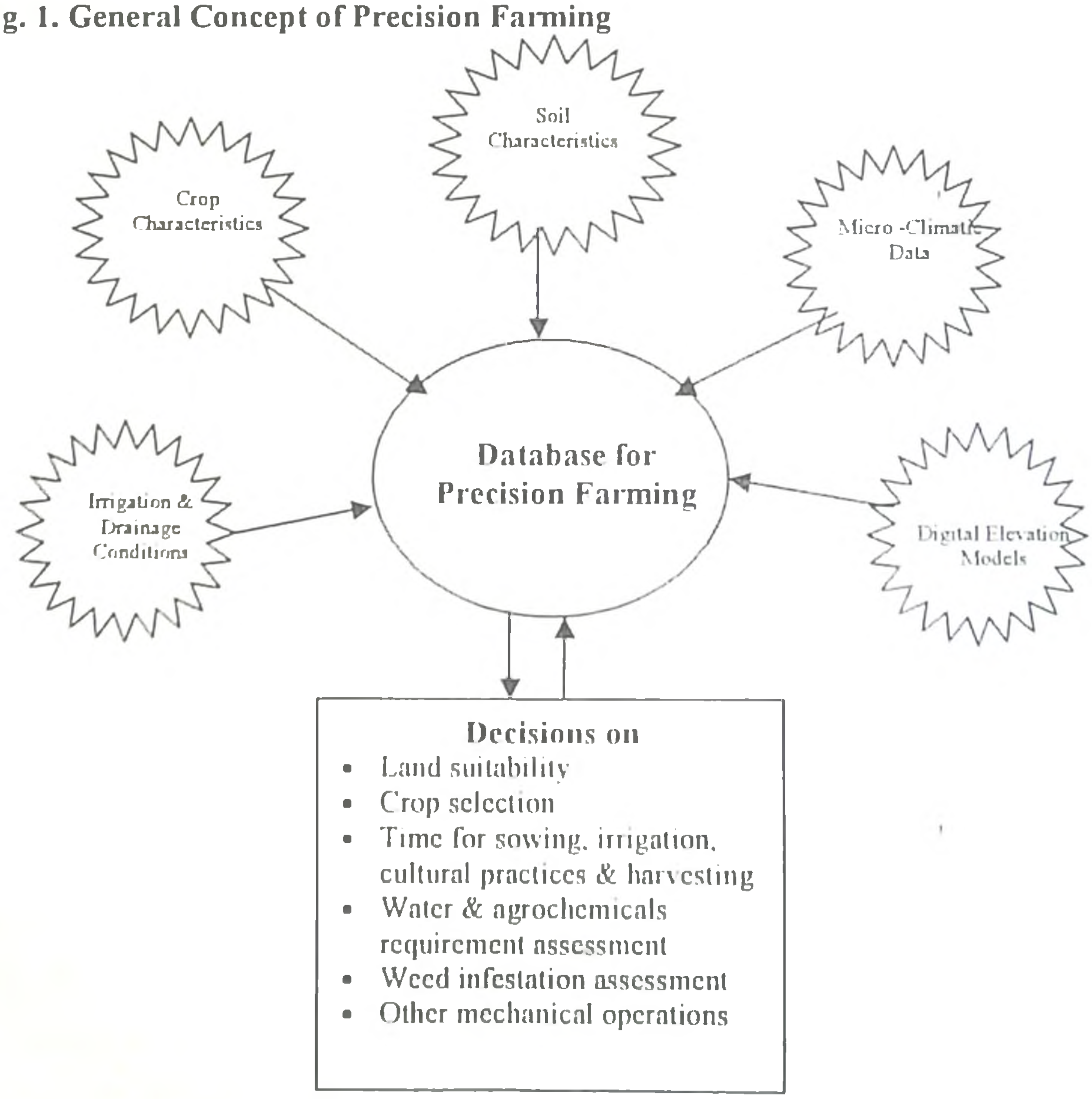
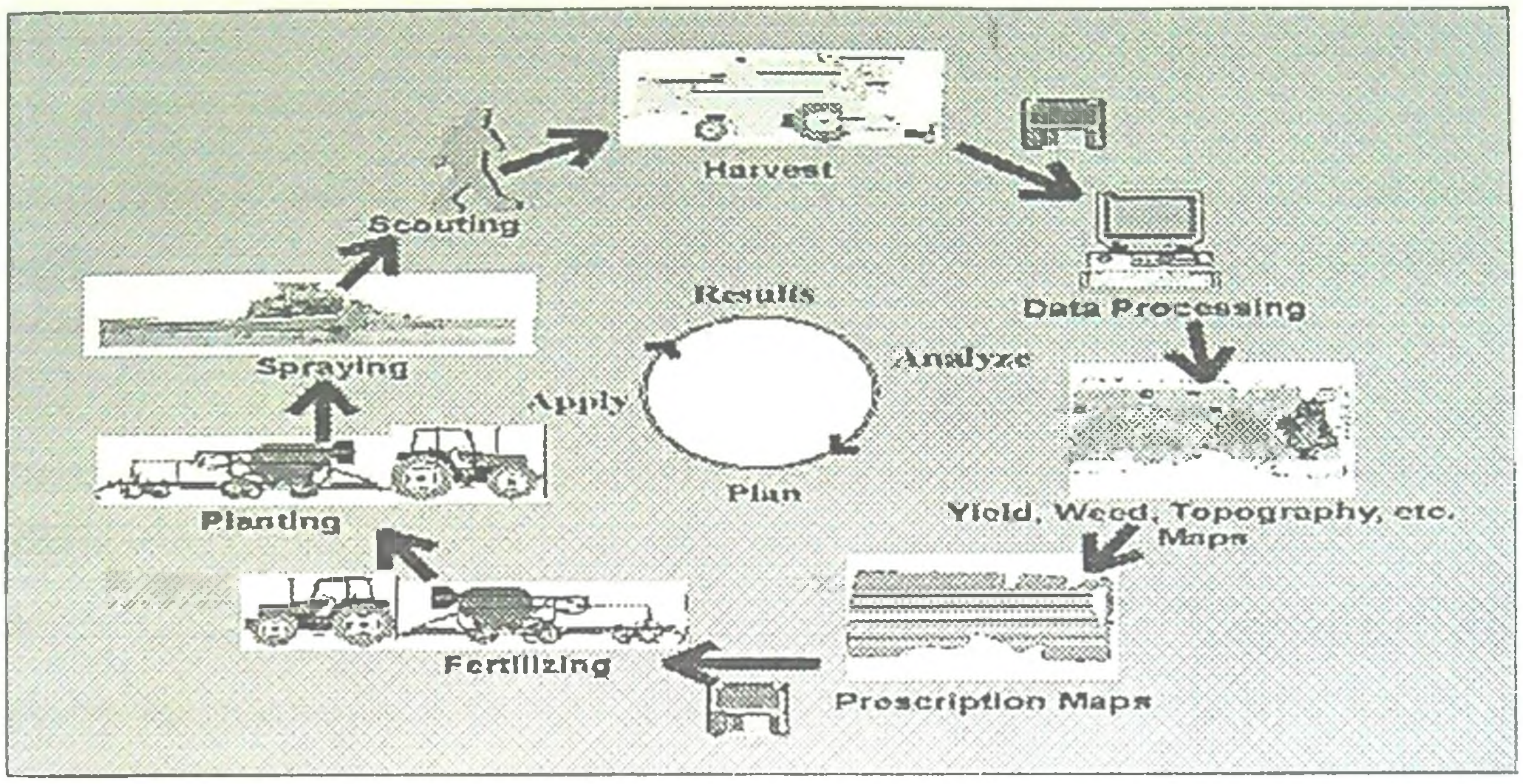


Fig. 2. Precision farming cycle



Precision farming technologies

There are five major components of technology used for precision management practices. They are

- Computers
- Remote Sensing (RS)
- Geographical Information System (GIS)
- Global Positioning Systems (GPS)
- Variable Rate Technology (VRT)
- Yield Monitoring (YM)

1. Computers

Many technologies support precision agriculture, but none is more important than computers in making precision agriculture possible. Precision agriculture requires the acquisition, management, analysis and output of large amounts of spatial and temporal data. Therefore, the computers will derive significant technological development to enable precision agriculture in the foreseeable future. Mobile computing systems were needed to function on the go in farming operations. The extent to which agriculture can utilize computer technology is important to the success of agriculture in general (Holt, 1985). It appears that computer hardware will be more than adequate for precision agriculture; the same cannot be said for the software.

2. Remote sensing

Remote sensing has shown potential for use in agricultural management for a number of years however; the availability of fine spatial resolution, near real-time data has limited its application in the past. New companies that provide aircraft based imaginary to meet the resolution and temporal requirements for agricultural management are now emerging the promise of commercially available, high-resolution satellite imaginary will also provide additional sources of remotely sensed data (Fritz, 1996).

Advances in precision farming technology (GIS, GPS, and variable rate equipment) provide the tools need to apply information from multi-spectral images to management problems. There is still considerable work to be done before the full benefits of remotely sensed data can be realized, but there are applications that can transmit from this data at the present time. Following are a few examples of how remote sensing can currently meet some of the information needs in the precision agriculture.

(i). Soil properties

Soil physical properties such as organic matter have been correlated to specific spectral responses (Dalal and Henry, 1986). Therefore, multi-spectral images have shown potential for the automated classification of soil mapping units (Leone *et al.*, 1995). Such direct applications of remote sensing for soil mapping are limited because several other variables can impact soil reflectance such as tillage practices and moisture content.

In conventional agriculture with considering these variables fertilizers, herbicides, insecticidies and fungicidies are applied at an uniform rate throughout the crop field. Precision agriculture emphasizes on the aspect and deals with judicious crop management at micro level wherein only required amount of inputs are applied (Patil and Chaudhari, 2006).

(ii). Pest detection

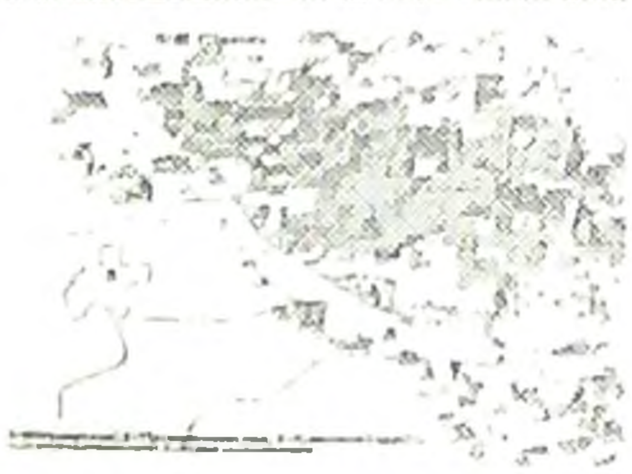
Carlson *et al.* (1995) developed a method to use digitized color infrared photographs to classify weeds in a no-fill cornfield. The classified data were placed in a GIS, and a decision support system was then used to determine appropriate herbicide amount to apply. Penuelas *et al.* (1995) used reflectance measurements to assess the mite attacks on apple trees. Powdery mildew has also shown to be detectable with reflectance measurements in the visible portion of the spectrum (Lorenzen and Jensen, 1989). The ability to detect and map insect damage with remotely sensed imaginary implies that methods can be developed to focus pesticide applications in the areas of field most infected, thus decreasing the damage to beneficial insects.

(iii). Water stress

The difference between remotely sensed surface temperature and ground-based measurements of air temperature has been a established as a method to detect water stress in plants (Jackson *et al.*, 1981). More recently, methods to integrate spectral vegetation indices with temperature have been used to improve remotely sensed estimates of evapotranspiration. Moran *et al.* (1994) defined a water deficit index which uses the response of the vegetation index of account for partial canopy conditions, so that false indications of water stress due to high soil back ground temperature were minimized. Spectral indices have also been used to determine "real time" crop co-efficient to improve irrigation scheduling (Baucsh, 1995). Variable irrigation is coupled with precision nutrient and pest management via. Chemigation, in part because variable irrigation facilities increased management precision in space and time (Senthil *et al.*, 2001).

Fig.3. Soil spectral variability map of Sriramapuram village, Dindigul District, Tamilnadu

Soil variability map of Sriramapuram village, Dindigul District: IRS LISS III image (false colour composite) of area surrounding the Sriramapuram village (yellow circle), of 16 May 2000.



The soil map derived from the merged data of IRS Pan and LISS III. There are three soil classes, marked in three different colour. The area marked white is either cropped, vegetation or settlement area. Also overlaid are the road network and village boundaries, derived from satellite data.

The figure 3. Shows Soil spectral variability map of Sriramapuram village, Dindigul District, Tamilnadu. Even at the first level of classification of merged data IRS LISS III (23 m resolution) and Pan (5.8 m resolution) shows that there are at least four types of soil in this village. However the whole village used to apply a similar fertilizer dose for the only crop grown in the rabi season, i.e. Bengal gram. Presently, this village has been adopted by MS Swaminathan Research foundation for implementing variable rate application technology.

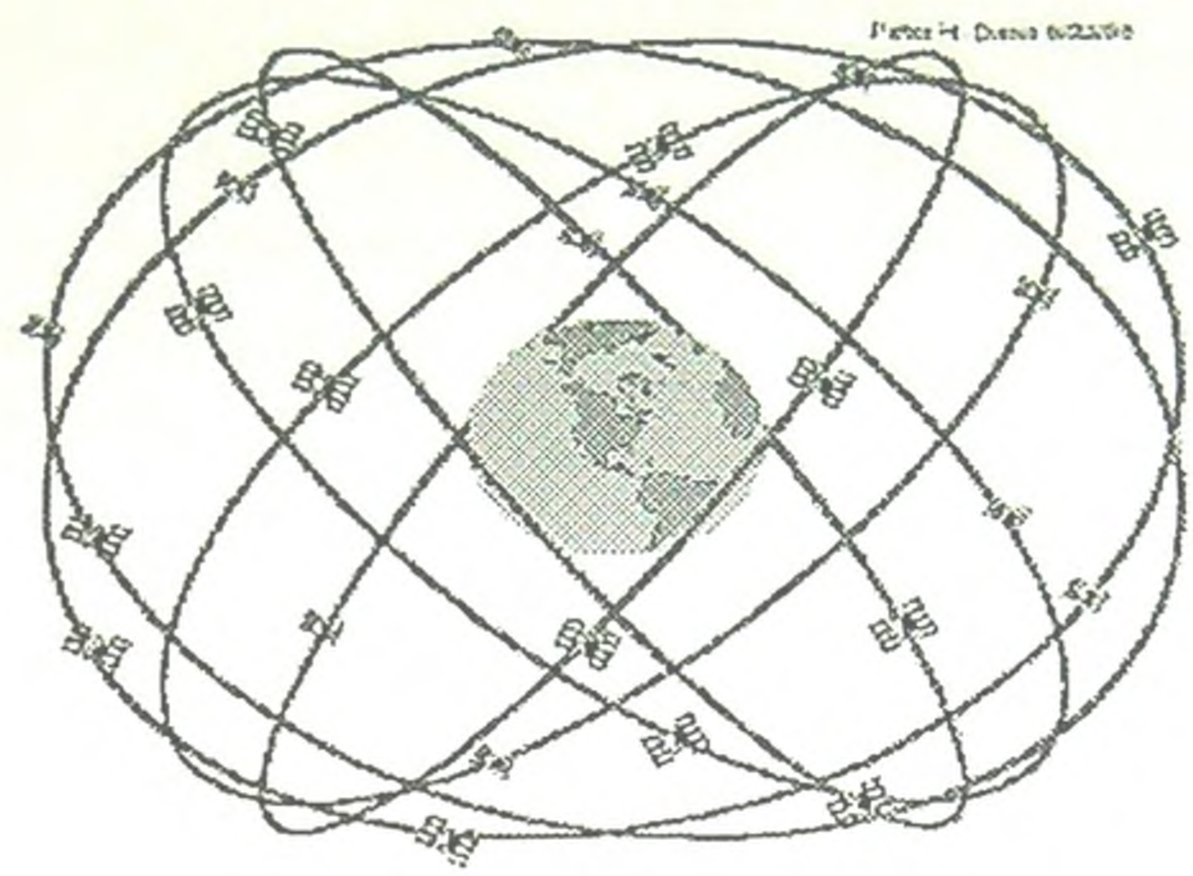
3. Geographic Information Systems (GIS)

GIS is an organized collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information. The ability to perform spatial operations on the data distinguishes a true GIS from the many software programs that do thematic mapping and database management. Because precision agriculture is concerned with spatial and temporal variability and because it is information based and decision focused, it is the spatial analysis capabilities of GIS that enable precision agriculture. Computer simulation modeling can help derive the needed understanding of variability and linking GIS to models will be important to precision agriculture.

4. Global Positioning Systems (GPS)

The GPS technology enables precision agriculture because all phases of precision agriculture require positioning information. GPS is able to provide the positioning in a practical and efficient manner for a few thousand dollars. Expensive high precision differential GPS (DGPS) systems are available that achieve centimeter accuracies, allow for automated machinery guidance and kinematic mapping of topography (Clark, 1996) and are useful in the creation of digital elevation models needed for terrain analysis. The GPS known as NAVSTAR (NAVigational System with Time And Ranging) was becoming available for general civilian use including agriculture by the early 1990s.

GPS is the heart of precision agriculture. The Global position system (GPS) uses satellites to calculate and find the accurate position any where on the earth. GPS was initially funded by the Department of Defence (DOD) and is currently a joint project between DOD and DOT (Department of Transportation). The GPS satellites are called NAVSTAR and orbit at an altitude of 10,900 nautical miles. (fig.4)



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

The United States department of defence has implemented a network of 24 satellites, resulting in virtually all the USA having two-dimensional coverage for 24 hours per day. GPS satellites rotate the earth twice a day therefore their location relative to a given ground point is constantly changing and so the satellites that are in view of a GPS receiver are constantly changing. If at least four GPS satellites are visible it is possible to obtain three-dimensional coverage. The GPS satellites transmit radio signals that can be picked up by receivers on the ground. With 3 satellites signals, accurate latitude and longitude can be determined through triangulation; four satellites signals allow for measurement of elevation.

For security reasons, the US government sometimes intentionally degrades the GPS signal from the satellites through a process called selective availability. So that the accuracy is limited to about 100 meters. This is not a major problem for most navigation uses, but is not acceptable for many mapping applications, such as site-specific crop management system. To compensate for this degradation, and to generally improve positioning accuracy, agricultural users need to provide for a fixed-point reference system, or differential global position system.

The accuracy of GPS is also depends upon the type of receiver. The system generally provides accuracy within a range of 100 meters. This is not accurate enough for meet agricultural operation; differential GPS must be used to get accuracy of less than a meter.

In a DGPS, a receiver can be mounted on a precisely known, fixed portion located at a known surveyed location, which also knows the true portion of each satellite, when it calculates the distance to each satellite in its view, it also determines,the error in each portion. The difference between the true distance and the GPS-measured distance then designates the differential correction distance.

The differential corrections are broadcast from base stations using radio frequency beacomes transmitting near the AM radio band. Differential GPS (DGPS) is the blanket term for a number of different system that have evolved to overcome the inaccuracies occurred by selective ability and physics involved in sending radio signals through the earth's atmosphere. These system are separated into two classification

i. Post processed differential GPS

ii. Real Time differential GPS

Post-Processed Differential GPS

Post processing works on the principle that if the exact location of place is known, then the size of selective ability distortion can be determined for each GPS signal. If correction information is then broadcast to local receivers set up to deal with it, significant improvement in accuracy can be achieved by storing GPS recording for subsequent computational correction.

Real time differential GPS

Real time differential correction requires a receiver designed for use with a real time differential service. Real time differential service broadcast an extra signal, which allows a GPS receiver to cancel out many of the errors inherent in GPS signals. Some of these services use their own satellites, and some have ground stations sprinted around the covered area. Some services combine two.

DGPS receivers can be used in a wide range of situation to provide the latitude and longitude of machine operation in a field, or of a field scout who is making observations and taking samples. Field images or maps can be made by recording parameter such as yield or fertilizer application along with portion in the field.

5. Variable rate technology

Variable rate technology, or VRT is a technology that allows variable rates of fertilizer application, seeding, chemical application and tillage throughout a single paddock. The rate is changed according to a preset map or through information gathers "on the go" sensors. Two approaches to VRT.

Map based VRT (Fig.5.): It involves creating application maps that describe the varying amounts of input needed throughout a paddock. Application maps are produced from yield, topography, soil, nutrient or weed maps, which have been 'ground truthed' to give specific details of inputs required throughout a paddock. The application maps are interpreted by small computers called controllers that increase and decrease the amount of input according to the map.

Map based VRT allows farmers to make decisions based on the detailed maps and knowledge of the paddocks before they are in the field. Map based VRT gives farmers precise control over how much of a given input is applied to specific areas within any paddocks. However, it does involve collecting and processing certain amounts of data, greater amounts of data collected over longer periods of time can create more accurate maps.

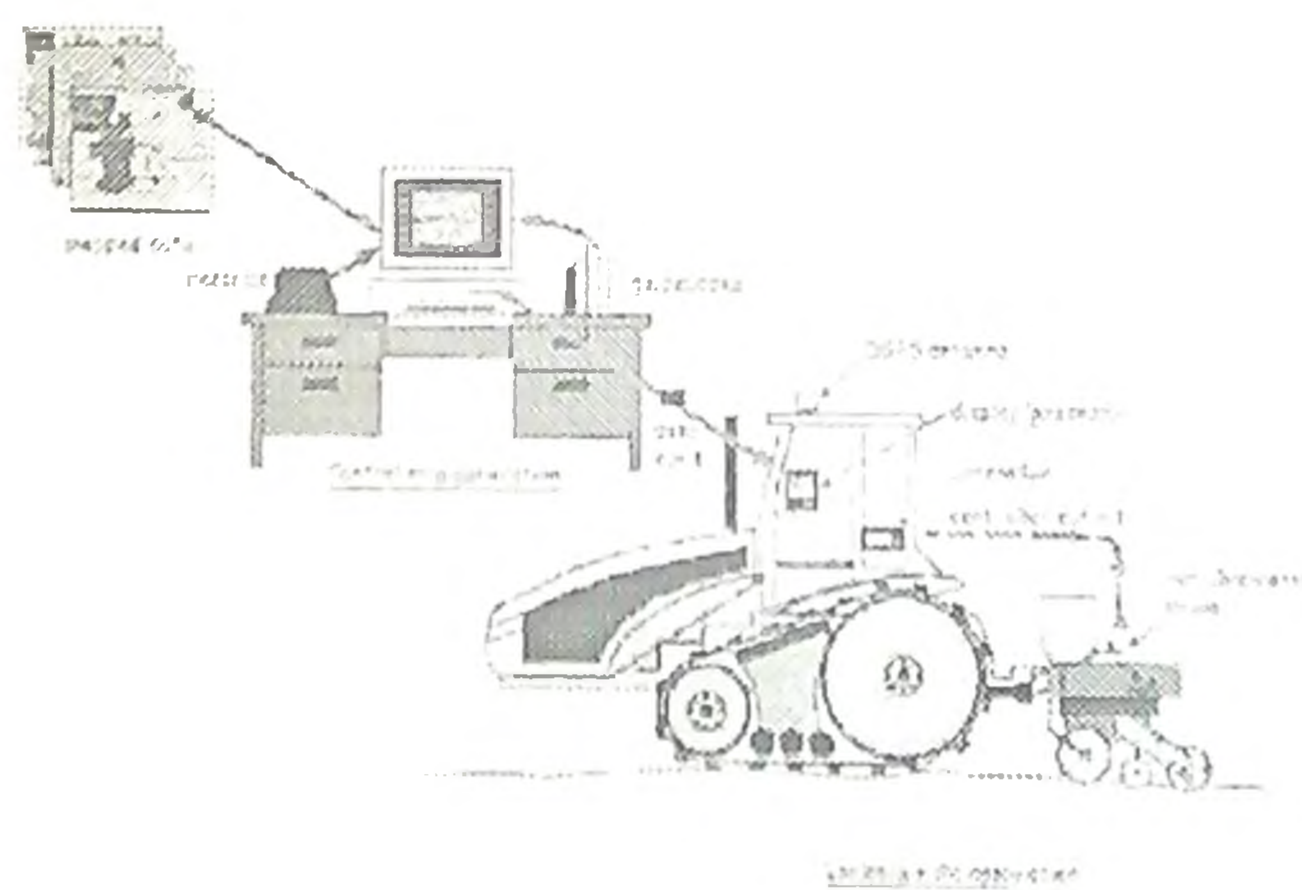


Figure 5. Map based VRT

Sensor based VRT: It utilizes sensors to collect data, such as soil properties or crop characteristics, "on the go". This information is processed and used to vary the amount of input applied. This technology does not require detailed maps or extensive decision making prior to application. Sensor based VRT can be utilized with or without precision farming practices.

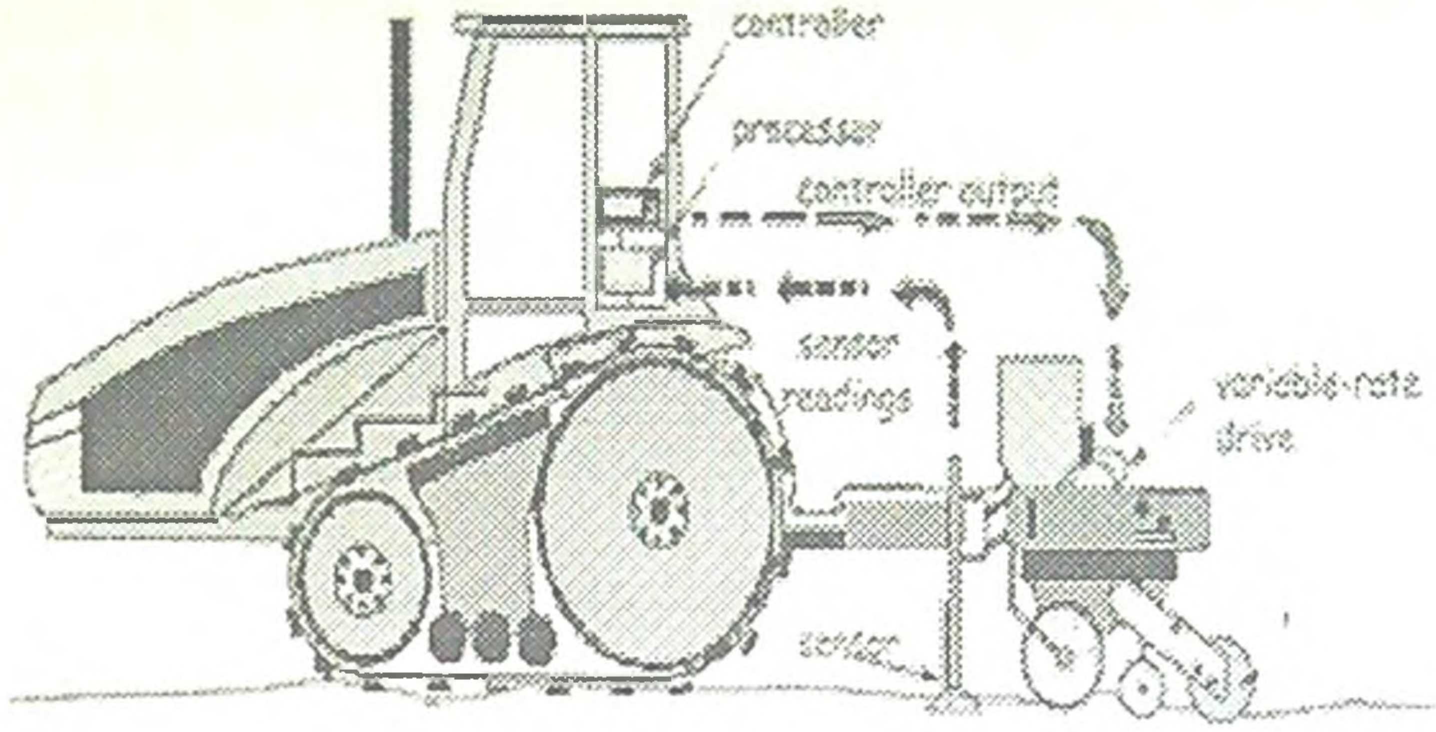


Figure 6. Sensor based VRT

Variable Rate Applicator

The variable rate applicator has three components

- Control computer
- Locator and
- Actuator

The control computer coordinates the field operation. It has a map of desired activity as a function of geographic location. It receives the equipment's current location from the locator, which has a GPS in it, and decides what to do based upon the map in its memory or data storage. It then issues the command to the actuator, which does the input application.

Variety of substance including granular and liquid fertilizer, pesticides, seed and irrigation water can be applied by VRT systems. The most widely used VRT machines are large scale chemical applicators that control up to 11 different materials at once. The VRT systems adjust the actual material flow rate and regulate the desired application rate of chemicals in the fields.

5. Yield Monitoring (YM) and Yield Mapping

The vast majority of the agricultural fields have inherent spatial variability in parameters such as soil type, nutrient availability, drainage status, slope and aspect. Crop grown today respond to this variability to different extents but the end result at harvest, is yield that varies in quality and quantity across the field.

Knowledge of the variability of yield at harvest can be used in two important ways:

1. It enables the farmer to make more improvement management decision regarding the succeeding crop.
2. It can provide a basis for varying fertilizer application according to a defined strategy.

Accurately knowing the yield variability within a field can be become the corner stone of crop management plan. But first, its important to know if the yield variability within the field is stable from year to year. We should find out if some areas consistently yield higher from year to year which other areas consistently yield lower. Else we should find the yield variability pattern changes within the field each year. If the yield pattern is not consistent its important to determine the cause of this yield variability. Perhaps weather is the cause. Its wise to have several yield data before putting too much stock in the yield maps (or) before making worthy management changes.

Yield Monitors

Instantaneous yield monitors measure and record yield data continuously as the combine travels across the field. Some system records each data point separately (when connected to DGPS receiver) and other system collects a number of points that are then processed to provide load summary data. Some system measure crop volume which other system weigh the crop. All the system has the capability to measure the area harvested for each recorded weight or volume. Most system measure grain moisture continuously.

Basic Yield Monitor Component

To measure instantaneously crop yields, their items must be known

1. Flow rate through the harvesters separating system the flow rate is measured in units of volume or mass per unit time.

2. The harvester travel speed (measured in unit of distance or unit time)

3. The width harvested (Cutting width is measured in feet inches or number of rows)

Yield Mapping

In order for the farmer to be able to manage within – field variability, it is necessary to determine the source of variation and to quantify the variability in yield. The main sources of within – field variability are summarized as (Steven and Millar, 1997)

- ✓ Soil related factors such as structure and type, nutrient availability and compaction
- ✓ Agronomic variables, e.g. crop disease, plant emergence, seed rates and leaf area index,
- ✓ Others, e.g. field amalgamation and drainage.

Yield map generation

For precision farming, there is a need of a yield map showing the variability. Such yield maps from high resolution remote sensing data have been generated by Taylor *et al.* (1997). Ray *et al.* (2001) used the NDVI derived from merged of IRS LISS III and Pan to generate yield map of potato farm which showed a variability of 0.83 to 3.7 kg/m^2 within a field variation of 4.7 ha. Wheat yield variability map also generated using NDVI, derived from high resolution ground based spectro – radiometer data.

Geostatistics plays a great role in generating yield maps with the help of remote sensing data. Bhatti *et al.* (1991) and Mulla (1997) have shown the usefulness of geostatistical techniques such as kringing and cokriging to generate maps from a combination of remote sensing images of soil sampling.

Applications of precision farming (Ramanathan, 2004)

i) Yield monitoring. They provide a crop yield by time or distance (e.g. every second or every few metres).

ii) Yield mapping. GPS receivers coupled with yield monitors provide spatial coordinates for the yield monitor data. This can be made into yield maps of each field.

iii) Variable rate fertilizer. Variable rate controllers are available for granular, liquid and gaseous fertilizer materials. Variable rates can either be manually controlled by the driver or automatically controlled by an on board computer with an electronic prescription map.

iv) Weed mapping. A farmer can map weeds while combining, seeding, spraying or field scouting by using a keypad or buttons hooked up to a GPS receiver and data logger. These occurrences can then be mapped out on a computer and compared to yield maps, fertilizer maps and spray maps.

v) Variable spraying. By knowing weed locations from weed mapping spot control can be implemented. Controllers are available to electronically turn booms on and off, and alter the amount (and blend) of herbicide applied.

vi) Topography and boundaries. Using high precision DGPS a very accurate topographic map can be made of any field. Field boundaries, roads, yards, tree stands and wetlands can all be accurately mapped to aid in farm planning.

vii) Salinity mapping. GPS can be coupled to a salinity meter sled that is towed behind an ATV (or pickup) across fields affected by salinity. Salinity mapping is valuable in interpreting yield maps and weed maps as well as tracking the change in salinity over time.

viii) Guidance systems. Guidance systems using high precision DGPS that can accurately points out the position of a moving vehicle within a foot or less.

ix) Records and analyses. Precision farming may produce an explosion in the amount of records available for farm management. Electronic sensors can collect a lot of data in a short period of time electronic controllers can also be designed to provide signals that are recorded electronically. A lot of new data is generated every year (yields, weeds, etc). This means a large database is needed with the capability to archive, and retrieve, data for future analyses.

Managing Variability (Chetty, 2004)

Once variation is adequately assessed, farmers must match agronomic inputs to known conditions employing management recommendations that are site specific and use accurate application control equipment.

a. Precision soil fertility managements

Nutrient input to crop production is important because soils naturally do not supply nutrient in sufficient quantities to meet nutrient demands of commercial crops. Soils vary in their ability to supply nutrients to plants and crops vary in their demand for nutrients.

The fact that soil supply and plant demand varying space and time and nutrient losses through leaching, erosion and runoff also vary temporally and spatially indicating that significant opportunities may exist for precision management of soil fertility. For successful implementation, the concept of precision soil fertility management requires data on in field variability with accurate identification and interpretation, then only the variability that influences crop yield, crop quality due to environments can be managed with inputs of accurate amount applied to that specific point.

Nitrogen management strategies are approached in two ways

i. Prevention strategies

Wherein prescriptive application of N inputs are made prior to or early in the N uptake phase of plant growth to avoid nutrient deficiencies. Preservation is the most common N management strategy and is usually based on some combination of yield goal, N requirements of the crops, residual soil N in the soil profile and N mineralized from soil or plant residues. It appears that precision N management will be feasible using prevention strategies based on N balance approaches that rely on soil testing for residual soil profile nitrates where temporal variation in soil profile nitrates is low.

ii. Intervention strategies

Research on precision N management has taken three basic approaches. First approach is based on application of current N recommendations to site-specific within field scales where some form of grid soil sampling is employed. This approach is based on the prediction of N required of crops using a balance sheet approach that is the basin of current N recommendation for crop production. The second approach is to develop site specific optimal N rate recommendations based on condition specific N response curves. The third approach is to develop site-specific intervention N management based on crop monitoring of N status.

Since the key to precision N management is that the factors that regulate these processes vary in space and we expect precision N management to be profitable and beneficial to the environment to varying degrees under the following conditions.

- Where N inputs are high.

- Where residual N is temporally stable and high residual N is predictable from the yield of the previous crops
- Where crop quality is affected by excess N in the soil.
- Where crop yield spatial variability is high and predictable.
- Where net mineralization is high and consistently related to soil and landscape properties.
- Where N application is not restricted in time.
- Where leaching potential is high and spatially variable prior to or during the crop N uptake period of plant growth.
- Where variation in topographic position regulates N availability or yield.

Chandrasekaran *et al.* (2004) explained some new approaches for nutrient management in irrigated rice. By this practice the gap between crop needs and supply of nutrients from the soil are critically assessed as the existing blanket fertilizer recommendation with fixed rate and timing is not suitable for a larger area, since there is an existence of larger variation in fertility gradients and it is an approach for feeding rice with nutrients as and when needed and dynamically adjusted to locations and seasons.

The components of site-specific nutrient management

- Selection an attainable yield goal
- Estimation of the plant NPK requirement
- Determination of indigenous NPK supply
- Computation of NPK fertilizer rates
- Usage of real-time N management

i. Nitrogen Management

Leaf Colour Chart (LCC)

It is a method by which the actual time of nitrogen requirement is known by matching with the greenness of the leaf at different intervals with different shades of greenness provisioned in the leaf colour chart. The principle is the leaf colour intensity is directly related to the leaf chlorophyll content and leaf nitrogen status. The LCC can be used to monitor plant nitrogen status insitu in the field and to determine the right time of N top dressing to rice. In such a way N fertilizer is to be applied when leaf colour is below the critical value. It is fixed 4 as critical value for transplanted rice. During *kuruvai*, if the critical value falls below 4, nitrogen @ 35 kg /ha has to be applied and 30 kg/ha for thaladi/samba seasons respectively and it also suits for direct wet seeded rice crop.

ii. P and K Management

Rice crop requires balanced application of N, P and K to produce high and stable yields. Soil nutrient supply varies enormously from field to field and/or farm to farm. Thus rice crop requires variable N, P and K rates for different fields. As already indicated farmers can use simple technique such as LCC for determining N rate, for estimating P & K requirement omission plot techniques of the respective nutrients (P & K) can be adopted during high yielding season for deciding on P & K rates for different rice fields. The omission plots 25 m^2 (5m x 5m) is to be laid out in the field to determine the level of soil P and K status or supply. Optimum rates of N and K are applied in P omission plot and N and P in K omission plot. Best crop management practices are followed for the omission plot. At the end of the season, farmers can measure the crop yield in the omission plot and the P and K requirement for using the calculation indicated.

Site-specific nutrient management approach (Phosphorus)

1. Select a yield goal (8.0 t/ha example)
2. Use the computed value P requirement for 1 t/ha rice yield viz., 2.6 kg P /ha for calculation
3. Estimate the plant P requirement (8 x 2.6 kg P/ha = 20.8 kg P/ha)
4. Determine indigenous P supply from P omission plot (+ NK plot) with normal yield (6 t/ha) 6 x 2.6 kg P/ha = 15.6 kg P/ha
5. Amount of P to be added for 8 tonnes yield target (P requirement for 8 tonnes viz., 20.8 kg/ha – P supplied form soil with 6 tonnes viz., 15.6) 20.8 – 15.6 = 5.2 kg P/ha
6. Calculate P fertilizer rate = 5.2 x 100/25* = 20.8 kg P/ha

(as P_2O_5 20.8 x 2.29 = 47.6 kg P_2O_5 kg/ha)

(* Recovery efficiency = 25 %)

Site-specific nutrient management approach (Potassium)

1. Select a yield goal : 8.0 t/ha
2. Use the computed value of K requirement for 1 t kg/ha rice yield viz., 15 kg/ha for calculation
3. Estimate the plant K requirement: 8 x 15 kg K/ha = 120 kg K/ha
4. Determine indigenous K supply from K omission plot (+ NP plot) yield : 6.5 t/ha; 6.5 x 15 kg /ha = 97.5 kg K/ha
5. Amount of K to be added for 8 tonnes yield target (K requirement for 8 tonnes viz., 120 kg/ha – K supplied form soil with 6.5 tonnes viz., 97.5) 120-97.5 = 22.5 kg K/ha.
6. Calculate K fertilizer rate = 22.5 x 100/50* = 40 kg K /ha

(* Recovery efficiency = 50 %)

The two approaches described above were recently integrated in a flexible framework of simple SSNM in Asia, including nationwide initiatives in several countries. Distribution of LCC has increased from 25000 in 2001 to 280000 in 2003.

What is System of Rice Intensification (SRI)?

System of Rice Intensification involves the use of certain management practices, which together provides better growing conditions for rice plants, particularly in the root zone, than those plants grown under traditional practices. SRI was developed in Madagascar in the early 1980s by Father Henri de Lauhanie, a Jesuit priest. In 1990, Association Tefy Saina (ATS) was formed as a Malagasy NGO to promote SRI. It has since been tested in China, India, Indonesia, Phillippines, Sri Lanka and Bangaladesh with positive results.

Most rice farmers plant fairly mature seedlings (20-30 days old), in clumps, fairly close together with standing water maintained in the field for as much of the season as possible. These practices seem to reduce the risk of crop failure. It seems logical that more mature plants should survive better, that planting in clumps will ensure that some seedlings should result in more yield; and that planting in standing water means the plants will never lack water and weeds will have little opportunity to grow.

Six key novel practices in SRI

1. Young seedlings

Seedlings are transplanted early. Rice seedlings are transplanted when only the first two leaves have emerged from the initial tiller or stalk, usually when they are between 8 and 15 days old. Seedlings should be grown in a nursery in which the soil is kept moist but not flooded. The seed sac should be kept attached to the infant root, because it is an important energy source for the young seedlings. The young seedlings should be planted so carefully that the root tip is not inadvertently left pointing upward. The effect of young seedling (14 days old) over normal seedling (21 days old) was studied on growth and yield of rice and the yield of rice in various treatments were furnished in Table 1.

Table – 1. The effect of age and number of seedlings on yield of rice

Treatments	Young seedling (kg/ha)		Normal seedling (kg/ha)	
	Kuruvai 2003	Late Thaladi 2003	Kuruvai 2003	Late Thaladi 2003
One seedling spacing (20.0 x 20.0 cm)	6951	5377	6329	4859
Two seedling spacing (20.0 x 20.0 cm)	6553	4868	5142	4572
Three seedling spacing (20.0 x 20.0 cm)	6355	4402	5802	3905
One seedling spacing (22.5 x 22.5 cm)	7444	6138	7714	5160
Two seedling spacing (22.5 x 22.5 cm)	7745	5019	7384	4710
Three seedling spacing (22.5 x 22.5 cm)	7641	4538	7120	4230
One seedling spacing (25.0 x 25.0 cm)	7149	4978	6725	4142
Two seedling spacing (25.0 x 25.0 cm)	6951	4286	6329	4450
Three seedling spacing (25.0 x 25.0 cm)	6752	4093	6329	3567

2. Single seedling

Seedlings are planted singly rather than clumps of two or three or more. This means than individual plants have room to spread and to send down roots. They do not compete as much with other rice plants for space, light and nutrients in the soil.

3. Wider spacing

Seedlings are planted in a square pattern with plenty of space between them in all directions. Usually they are spaced at least 22.5 cm x 22.5 cm. It helps for vigorous root growth and more tillering. The square pattern facilitates in situ incorporation of weeds by cono weeder.

4. Less seed rate

This method requires much lower seed rate (5-8 kg/ha) than traditional methods (75-100 kg/ha).

5. Moist but unflooded soil conditions

Rice has traditionally been grown submerged in water. In SRI method, soil is kept moist but not flooded during the vegetative period, ensuring that more oxygen is available in the soil for the roots, occasionally the soil should be allowed to dry to a point of cracking except in saline soils. This will allow oxygen to enter the soil and also induce the roots to grow and search for water. In SRI method, unflooded condition is only maintained during vegetative period and from flowering to harvest, 1-3 cm of water is kept in the field as is done in the traditional method.

6. Cono weeding

This can be done by cono weeder. First weeding should be done fourteen days after transplanting and this should be continued upto 40 days @ 7-10 days interval. At least two or three weedings are recommended. This practice of churning of soil seems to improve soil structure and increases the aeration of the soil. Thus the incorporation of weed biomass into the soil results in enrichment of CO_2 near to root zone increases the biological activities, increases soil microbes population and activities results in better nutrient availability in soil and uptake by plants.

Ramaswamy, (2004) explained some important micro irrigation techniques. Micro irrigation refers to application of water in small quantity as drops to the zone of plant roots through a network of plastic pipes fitted with emitters or micro sprinklers. The planning and design of drip irrigation system is essential to supply the required amount of irrigation water to all the plants in the irrigation regime at any depends on the water taken by plant and the amount of water that evaporate from the soil in the immediate vicinity of root zone in a day. The water requirement and irrigation schedule can be estimated by pan evaporimetre. The design of micro irrigation commonly called as drip or trickle system broadly involves selection of proper emitters or micro sprinklers, laterals, submains, mains and head equipment.

Depending upon the water source, sand filter or mesh filters are provided to remove the impurities like trash algae, fungi, minute sand particles etc. electric motor pumpsets or Diesel sets or over head tanks are the normal pumping units to imparts pressure for micro irrigation system. Normally, main pipeline and submains are made up of PVC or HDPE with outside diameters ranging from 40mm to 75 mm. The laterals are made up of LLDPE with 12mm or 16 mm diameter pipes.

Micro sprinklers

Depending upon the use either for lawn or for short vegetable crops/ nurseries, the following types of micro sprinklers could be adopted with varying degrees of specification.

Table – 2. Adoption of micro sprinklers with varying degrees of specification

S.No.	Specification	Micro sprinkler	Jets/ sprays	Pop-up sprinkler	Rain gun
1.	Discharge	15-50 lph	25-75 l/hp	1500-2000lph	72,000- 1,00,000 lph
2.	Diameter range	1.5-4.5m	1 – 2.5m	10-15m	30-100m Trajectory (24to 27°)
3.	Pressure rating	0.3-1m	10-30m	20-40m	20-60 m

Economics of Micro irrigation

Micro irrigation saves 40-50% of irrigation water with the increased water use efficiency. It controls the weeds and labour saving is the main focus for the present day agricultural labour scarcity. The micro irrigation has covered most of the perennial crops like Coconut, Mango, Sapota, Amla to a larger extend in many states in India due to wider spacing and low unit cost per ha. However, the micro irrigation is being attempted in almost all the close growing field crops particularly vegetables and flowers during recent times. Though the initial cost seems to be higher for many field crops, the pay back period is 1-1 ½ years and B/C ratio ranges from 1.09 to 5.16. The cost economic of some crops are given in the following table 3.

Table - 3. Cost economics of various crops

Crop	Crop spacing (m)	Drip irrigation cost (Rs.)	Pay back period (year)	Benefit - Cost Ratio
Banana	1.8 x 1.8	47,500	1	3.00
Grapes	3.03 x 1.8	44,000	<1	3.28
Pomegranate	4.3 x 4.3	30,000	<1	5.16
Ber	4.5 x 4.5	30,000	1	4.56
Tomato	0.9 / 0.6 x0.6 Paired row	30,000	1 season	1.09
Papaya	1.81 x 1.81	40,000	1	4.09
Cotton	1.5/0.9 x 0.6 Paired row	47,500	1 ½	1.83
Sugarcane	1.0/0.6x0.1 Paired row	47,500	1	3.45

Jagannathan, (2004) reported the modification of microclimate for precision farming. In general "the climate experienced in a valley of small area when compared to that experienced over the entire mountain" is referred to as microclimate in meteorological parlance. However, the microclimate of the crop is defined as "the climate near the ground in which the plants live". It is customary to divide atmospheric phenomena in various scales. The terms macro, meso and micro-scale are arbitrarily used depending upon the user. The summary of scales in time and space listed below gives us a comprehensive idea of the different scales to be adopted by agricultural meteorological personnel.

Table – 4. Different types of micro climate

Sl	Scale name	Time scale	Horizontal scale	Vertical scale
1.	Microscale	0.1 second to 1 minute	<1mm to 100m	<1mm to 3m
2.	Toposcale	3 seconds to 30 minutes	10m to 3km	1m to 100m
3.	Mesoscale	1 minute to 3 hours	300m to 30km	10m to 1km
4.	Synoptic scale	1 hour to 1 day	3km to 1000km	1km to 10km
5.	Macroscale	½ day to 1 week	30km to 10^4km	1km to 20km
6.	Global scale	3 days to longer	300km to globe	1km to 100km

(Rao, 2003)

Modification of Solar Radiation

The modification of solar radiation which is the beginning of all can be approached in two ways; 1. Manipulating the incoming soar radiation (insolation) during daytime and 2. Manipulating the outgoing radiation at night.

Manipulation of incoming radiation during day

a. Increasing the surface absorptive power (Heat trapping)

b. The reduction in albedo of the soil surface will make the soil more prone for absorption of solar radiation. Differently coloured soil surfaces have different coefficients of reflection of shortwave solar radiation and hence different proportions of solar energy are absorbed by the surface. So net radiation of the soil surface can be changed by altering the surface colour. In temperate countries with a cold season, dark materials can be applied to the soil to increase the soil temperature in spring time for earlier germination. Increasing the surface reflective power (Heat evasion)

The temperature reduction measured over grass vegetation is greater than that from (white chalk) powder for two reasons. The vegetation is actually shading the soil surface besides the grass transpiration requires more energy than bare soil radiation.

The surface reflective power of the surrounding objects will help in manipulation of the radiation received by the crops. The reflection by white washed walls, aluminium reflectors, etc., contributes a large amount of energy to the air, soil and vegetation. Liming lower portion of stem for coconut and rubber during summer is being practiced by farmers in Kerala

Table – 5. The temperature of the upper layer of the soil by 10 °C for a period of three weeks and the energy balance in MJ m^{-2} day^{-1}

Particulars	Bare soil (albedo 0.3)	Whitened soil (albedo 0.6)
Incoming short -wave radiation	+27.2	+27.2
Net short-wave radiation	+19.0	+10.9
Net long-wave radiation	+12.8	+9.8
Net radiation at soil surface	+6.2	+1.1
Evaporation(latent heat exchange)	-4.1	-3.4
Sensible heat exchange	-1.9	+2.5
Soil heat flux	-0.2	-0.2

b. Increasing the exposure through site selection

In northern hemisphere the southwest slope will receive more solar radiation than other sides and this could be favourably used by planting the crops in these slopes.

c. Decreasing the exposure through shading

During summer or in the absence of rains, the heat load on some of the plants is above tolerance limits in the tropics and sub-tropics. Shading is common method of evading solar radiation. Shading can be done by either through artificial means or by natural means. Crops like tomato and soybean can made to flower if the day length is reduced by using cloth tents as shading material. Many orchid plants are grown successfully under shade nets. Incase of natural shading a taller and robust companion will provide sufficient shade to enable it to grow better as could be observed in the case of black pepper grown under the shade of silver oak plants. Recently the cultivation of Vanilla in coconut grooves gained momentum because of the microclimate provided by coconut to Vanilla.

2. Manipulation of outgoing radiation during night

A black cloth or shade tents made of cotton reduces the effective outgoing radiation thereby increases temperature. Off-season vegetables can successfully grown by this technique.

Different methods of microclimatic modification

Mulching

Mulching is the application, or creation of some soil cover, which reduces vertical transfer of heat and water vapour. Mulches vary in surface albedo, in thermal conductivity and capacity and in porosity to vapour and all of these are important. Mulches may consist of:

i. A loose layer of top soil (harrowing produces a mulch, apart from other effects);

ii. Cut or gathered vegetable material, such as grass, weeds, straw, tree leaves;

iii. Redeployed surface material, such as stubble, litter and stones;

iv. Manufactured materials, such as paper, plastics and reinforced aluminium foil.

Surface geometry

The influence of micro-topography i.e. the effects of small irregularities such as mounds, ridges, furrows and trenches with vertical dimensions of at most a few meters mainly aims at altering the amount of solar radiation. It has effects on soil temperature and soil moisture. The germination and emergence of considerable range of crops can thereby be altered. Daytime geometrical relationships between direct sunshine and slope and aspect of small ridges and furrows are very much dependent on their orientation with respect to slopes and the position of the sun. In the early morning the tops of ridges are colder than at ground level, both because of excessive sky view and because of the relatively large distance to deep soil heat. Thereafter sunny slopes heat up appreciably, depending on orientation, also because reflected radiation may still be absorbed at the other side (radiation trapping). It was observed on dry North-South oriented ridges, where plants placed on west facing slopes survived because in the early shade they were able to make use of occasional morning dew.

Slope and aspect (direction) affect the soil temperature and soil heat flux since capture of radiation is determined in part by these factors. Slope and aspect are more important in summer than winter because the low sun angles in winter season increase the proportion of diffuse radiation. Whatever the season, the slope and aspect are of lesser importance in cloudy than in clear conditions for the same reason. It is possible to design methods that beneficially alter the temperature regimes and ridging and shaping is on such method. The figure below indicates that in a north-south running furrow the temperature were lowest in the furrow. Generally the west facing slope was warmer than the opposite slope. This is because the east facing slope is illuminated at a time of a day when the soil is most cool. Evaporation of dew at this time also tends to keep temperatures low.

Crop geometry

When the crop covers the ground completely, the absolute value of temperature, humidity and winds at the surface, and the vertical gradients of these elements are decisively altered by the crop itself. On horizontal ground the spacing of row crops, and the seasonal changes in the ratio of crop height to distance between the rows, drastically affects amount of sunshine reaching the actual soil surface. The general form of the relationship between the possible hours of direct sunshine reaching the ground and the ratio E where E = (height of crop) / (distance between rows) is indicated in the diagram below for different orientations for the different times of the year in the mid latitudes.

Wind breaks and shelter belts

Wind influences plants physiologically and mechanically. As high winds increase evapotranspiration loss, erection of windbreaks and shelterbelts can reduce evapotranspiration also. The beneficial effects of windbreaks are as follows

- Checking air movements and thus affording protection to fields and orchards
- Checking top-soil erosion and more effective in sand soils
- Evapotranspiration is reduced over the crop field by reducing wind speed.
- Providing shade to the farm-shed

Irrigation and drainage

Sprinkler irrigation or spray-irrigation, also called above canopy irrigation, has high application costs. On fast draining soil it may the only effective technique. As side effect it temporarily increases the humidity of the air. Another important side-effect is that water applied to the leaves with two consequences; first the direct evaporation from the leaves produces cooling and second induced leaf wetness gives a risk of fungus infection. The figure below indicates the effect of above canopy and below canopy irrigation. In subtropical climates dry leaf temperature may reach 40 °C and therefore cooling by 10 °C is beneficial. But care should be taken to sprinkle for few hours only and not much later than noon.

On well drained soils which are suited for irrigation decreases the diurnal variation of soil temperatures. Depending upon the temperature of the applied water, irrigation may temporarily decrease average day time temperature of the soil to some extent and may increase soil temperature at night. A most important effect of draining a soil is improved aeration of the subsoil, leading to an increase of the oxygen content and a decrease of carbon-dioxide content. A bare, well-drained soil will exhibit a larger diurnal variation of temperature to a greater depth than in the same soil without good drainage and its average temperature will be higher. Moreover, the drained soil will have a larger capacity for storing rain or irrigation water and consequently suffer less from erosion caused by surface runoff.

Protection against frost damage

Of the two types of frost, radiation frosts and advective frosts, the former has drawn almost exclusively all attention in frost research. The idea that the advection of cool arctic air cannot be helped is widely believed. At the time of site selection care can be taken so that sufficient shelter can be provided to minimize the damage.

Passive methods against frost protection

a. Soil must be compact and must not be isolated from the air above it.

b. Ploughing in autumn instead of spring gives the opportunity to settle down in the winter

c. Winter mulch should be cleared before flowering time

d. Mechanical weeding can loosen soil appreciably, and if it needed in spring time chemical weed killers should be considered as an alternative.

e. If the soil is too loose for any reason, then it is advisable to use equipments such as rollers to compact it.

f. An interesting way of increasing the thermal conductivity and capacity of soil is irrigating prior to a threatened frost.

Active methods of protection against frost

a. Thermal insulation – any covering roof of a crop like a straw mat

b. Interception of outgoing radiation – artificial clouds of water mists or smoke screens.

c. Air mixing – avoiding temperature inversion in night by wind machines

d. Sprinkling – overhead irrigation water while freezing release latent heat sufficient enough to keep the temperature crop below 0 °C. Minimum sprinkling rates to give basic protection are 1.5 to 2.0 mm h^{-1} for low-growing plants; 2.0 mm h^{-1} for fruit trees and 2.0 to 2.5 mm h^{-1} for vines.

e. Direct air and plant heating – heaters of small fires used in high value orchards

Steps to be taken for implementing precision farming in India

In the present existent situation, the potential of precision agriculture in India is limited by the lack of appropriate measurements and analysis techniques for agronomically important factors. High accuracy sensing and data management tools must be developed and validated to support both research and production. The limitation in data quality/availability has become a major obstacle in demonstration and adoption of precision technologies. The adoption of precision agriculture needs combined efforts on behalf of scientist, farmers and the government. The following methodology could be adopted in order to operationalise precision farming in the country.

1. Creation of multidisciplinary teams involving agricultural scientist in various fields, engineers, manufacturers and economist to study the overall slope of precision agriculture.

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

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

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

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

As a first step towards operationalization of precision farming it is necessary to establish a DGPS infrastructure for the country. It would enable the farmer to get an accuracy of few centimeters in various unit processes (sowing, fertilizer application, herbicide-pesticide application etc.) involved in PF. A DGPS networks would cater to the needs of multitude of application (Meterology, transportation, geodetic survey, crustal deformation studies, disaster management and mitigation etc.,) of which of PF is one. Each DGPS master reference is capable of providing the services within a radius of 100 km radius. Hence the network of master station required establishing the DGPS infrastructure, which would cover the entire country, is calculated.

Area of India	= 329 million hac
Area of GPSs (Circular area, PI=3.14)	= PI * (100) ^2 Sq.km
	= 31400 Sq.km
	= 3.14 million hac
Total No. of GPSs reference Stations required for country	= 329/3.14
	= 105
Cost of single DGPS set	= Rs.3lakhs
Total cost of the entire Structure	= 105*3
	= 3.15 cores

The real value for the farmer is that he can adjust seeding rates, plan more accurate crop protection programmes, perform more timely tillage and know the yield variation within the field. There benefits will enhance the overall cost effectiveness of this crop production. Since the country is going to spend the amount, the GDP is considered rather than the farmer's personal income. Hence the cost benefit analysis of the present project is

GDP of India (1993)	= Rs.12, 924.855 billion
Amount spent for R&D	= 0.3% of GDP
	= 38.775 billion
Cost benefit analysis	= 38.775 billion/315million
	= 12,309

Thus it is proved that there is an enormous benefit in implementing this DGPS network, which would further pave the way for precision farming.

Conclusion

In this time of increasing input cost, decreasing commodity prices and environmental concerns, farmers and government authority are looking for new ways to increase efficiency and costs and subscribe to sustainable agriculture. While precision farming technology as a future farming tool.

Precision farming or precision agriculture requires the collection, coordination, and analysis of massive quantities of data. A large position of that data will be collected by electronic instrumentation operating within each field. GPS receivers can provide location determination for sample collection points and to the georeference continuous data. Information on soil properly variation often obtained today by laboratory analysis of manually collected samples, will be streamlined by the use of sensing technologies currently under development. Grain yield variations will be measured using combine yield-monitored sensors, several of which are currently commercially available.

The profitability of precision farming is available as field conditions. In highly uniform fields better knowledge of soil and plant parameters is not as likely to results in greater economic returns as it is in field with variable conditions. Producers who use precision farming management must recoginize that information becomes another input to the system, and it has a cost with soil, weed, fertility and yield maps for a particular field, the producer can know more about the field potential and determine which areas of a field are creating the largest profit as well as, which areas are not capable of producing. Precision farming technology brings increased efficiency to crop production. By closely matching application rates with crop weeds, profit potential can be increased and possible environmental impacts can be minimized.

Future thrust:

- Identification of crops and estimation of area and production of short duration crops grown in fragmented land holdings.
- Detection of crop stress due to nutrients imbalance and quantification of their effects on crop yield.
- Automation of land evaluation procedures for a variety of application using GIS techniques.
- Information on soil nutrient status.
- Extending precision farming database to smaller farm size and diverse crops/cropping system.
- Developing Decision Support System for management of biotic and abiotic stress at the farm level.
- More accurate yield model.

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Discussion

How can we apply precision farming in plantation crops?

We can apply it plantation crops by applying pesticides using aircraft, using fertigation and grading of fruits.

Is it necessary to conduct soil analysis in the lab?

Yes, we have to conduct the preliminary nutrient analysis in the lab, then we have to tabulate it under different soil fertility classes and this data is to be fed to GIS.

If precision farming affect the biodiversity?

Yes, In precision farming we are not following mixed cropping systems, we are following mainly monocropping only. In such situations precision farming will affect the biodiversity.

Rate of Phosphorus in soil?

1. Low - < 9 kg ha^{-1}
2. Medium – 9 – 22 kg ha^{-1}
3. High - > 22 kg ha^{-1}

Role of precision farming in pest management?

Using light traps, specific bio control agents, microbial pesticides, trap crops, transgenic crops and applying pesticides using air craft. But using aircrafts for pesticide application is expensive and can cause many environmental hazards.

KERALA AGRICULTURAL UNIVERSITY

COLLEGE OF HORTICULTURE, VELLANIKKARA

Agron. 751.Seminar

Topic: Precision Farming

Name: S.T. Rathish
Admission No: 2005-21-103

Venue: Seminar Hall
Date: 21-04-2006
Time: 9.30 – 10.15 am.

ABSTRACT

Precision farming is one of the most scientific and modern approaches to sustainable agriculture that has gained momentum towards the 21st century. Precision farming is the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production (Pierce and Nowak, 1999). In other words, it is the matching of resource application and agronomic practices with soil attributes and crop requirements as they vary across a field.

Emerging precision agriculture technologies rely heavily on global positioning system (GPS), geographical information system (GIS), remote sensing, yield monitoring devices, variable rate technologies for application of inputs.

The global positioning system makes possible to record the field variability as geographically encoded data. It is possible to determine and record the correct position continuously. This technology considers the agricultural areas, more detailed than previously, however a larger database is available for the user (Nemenyi *et al.*, 2003). Pecze, (2001) cited by Nemenyi *et al.*, (2003) for storing and handling these data, the application of a geographical information system is essential. The geographical information system makes possible to generate complex view about our fields and to make valid agro technological decisions. Remote sensing data from the soil and crops is processed and then added to GIS database (Moran *et al.*, 1997). Yield monitors are crop yield measuring devices installed on harvesting equipment. The yield data from the monitor is recorded and stored at regular intervals along with positional data received from the GPS unit. GIS software takes the yield data and produce yield maps.

Variable rate technology consists of farm field equipment with the ability to precisely control the rate of application of crop inputs and tillage operations (Buick, 1997).

These interlinked technologies in precision farming pave way for better crop production and environmental safety.

In India more than 57.8 per cent of operational holdings has size less than 1 ha. With this field size and the farming is mostly subsistent type. Hence it is difficult task to adopt the techniques of precision farming at individual field level. However, for the adoption of precision farming, one can consider, instead of individual fields, contiguous field, with same crop under similar management practices.

Carbon Sequestration for Sustainable Agriculture

By

Rathish, S.T.
(2005-21-103)

Seminar Report

Submitted in partial fulfillment for the requirement of the Course No. Agron 752, Seminar (0+1)

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2006

Declaration

I, Rathish, S.T. (2005-21-103) hereby declare that the seminar entitled "**Carbon Sequestration for Sustainable Agriculture**" has been prepared by me, after going through the various references cited here and has not been copied from my fellow students.

Vellanikkara

Rathish, S.T.
(2005-21-103)

Certificate

Certified that this seminar report entitled "**Carbon Sequestration for Sustainable Agriculture**" is a record of work done independently by **Rathish. S.T.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Place : Vellanikkara

Date :

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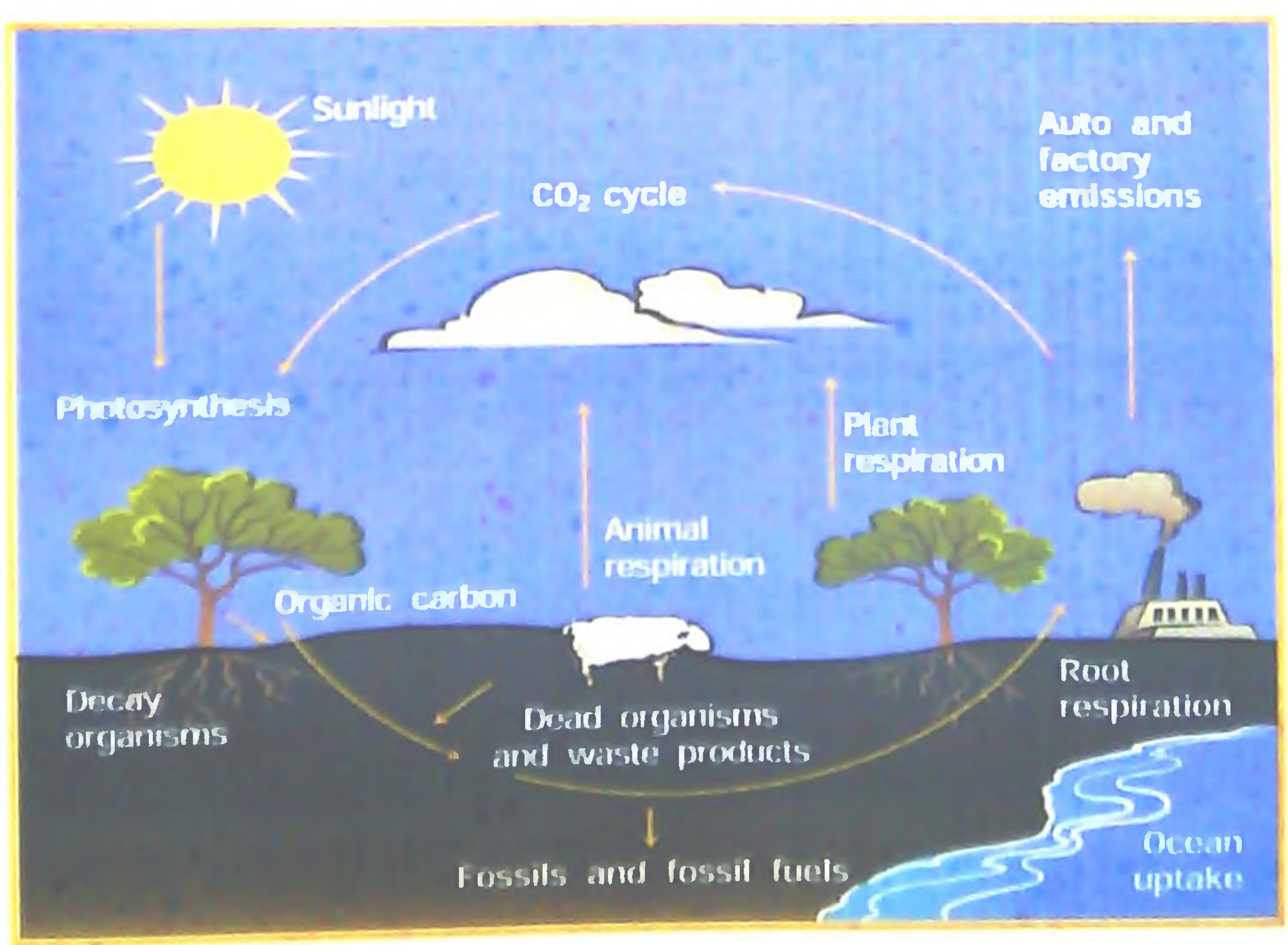
Carbon sequestration

1. Introduction

Increasing awareness on greenhouse gases has opened eyes worldwide. Agriculture emits and stores atmosphere gases that absorb radiation. The carbon cycle, through which CO_2 from the atmosphere is converted to organic forms by plant photosynthesis and then returned to the atmosphere through respiration, is the basis for life on earth. Soil organic matter contains more carbon as found in vegetation, on a worldwide scale. Therefore soil organic matter plays a critical role in the global carbon balance and the greenhouse effect. The sequestering of carbon in soil organic matter involves the production of complex organic structures. Besides carbon, these structures contain hydrogen, oxygen, nitrogen, phosphorus and sulfur. It is a process to increase the soil carbon, which could not only reduce the effects of global atmospheric pollution by carbon dioxide, but also to improve the prospects for a long-term solution to the world (country) food problem (Lal, 2004). Before going to carbon sequestration we should know about the carbon cycle.

Fig. 1. Carbon cycle



CO_2 through photosynthesis is converted to plant material. When the crop is harvested and removed from the farm, carbon is lost. If livestock consume the crop, the carbon may be returned to the soil in the form of manure. Crop residue, roots and manure are carbon (energy) source for microorganisms. Converting organic carbon to CO_2 is mineralization of carbon. When microorganisms respire, CO_2 is released to the atmosphere. Short-term SOM (Soil Organic Matter) is residue that is readily decomposed. Short-term SOM is a source of nitrogen, phosphorus, and sulfur for plants. Short-term SOM lasts 1 to 3 years. Long-term SOM (humus) is the carbon form that resists decomposition and may last for greater than 1000 years. Soil carbon losses are exacerbated through erosion and to a lesser extent, may be lost through leaching of dissolved organic carbon (DOC).

The basic processes of the carbon cycle are: CO_2 - in through photosynthesis, and CO_2 - out through decomposition.

2. Food Grain production

Table - 1. Population Trends and food grain yields (World and India)

Year	World population (billions)	Food grain production (mt)	India population (billions)	Food grain production (mt)
2002	6.2	1819	1.1	205.9
1992	5.43	1788	0.88	176.4
1982	4.6	1533	0.72	129.6
1972	3.8	1141	0.58	108.4
1962	3.1	851	0.46	82.0

(FAO, 2002)

The global population of 6 billions is increasing at the rate of 1.3% (or) it will be 73 billion by 2020 or 9.4 billions by 2050 (FAO, 2002)

Therefore, as agricultural scientists the principal global concerns of 21st century before us are:

1. Food security due to rapid increase in world population.
2. Soil degradation by land misuse and soil mismanagement.
3. Anthropogenic increases in atmospheric greenhouse gases.

All these issues are linked to the sustainability of soil quality especially in relation to the soil organic carbon (SOC) and its dynamics.

3. Greenhouse effect

The atmosphere is a classical example of a "common pool resource", which is being overexploited. With rapid industrialization and expansion of intensive agriculture through deforestation and ploughing contributes to the emission of gases to a greater extent into the atmosphere. Carbon dioxide, CH_4, and N_2O in the atmosphere are the gases emitted by agricultural soils and are responsible for global warming as a consequence termed as "greenhouse effect".

3.1. Global warming

During the past 50 years there has been a growing concern about climatic changes resulting from the increasing concentrations of CO_2 and other gases in atmosphere. According to the data of World Resources Institute, 1987, carbon deposition in atmosphere is equivalent to about 3.2 billion tones. The contribution of different countries to atmosphere carbon deposition varies very widely. With an increase in CO_2 concentration the amount of solar radiation absorbed by the atmosphere would increase, making the earth warmer. This can alter the global hydrological cycle and alter the distribution and productivity of terrestrial biota, which is termed as Global Warming. Countries having highest carbon emissions are given in Table 2.

3.1.1. Effect of greenhouse gases on atmospheric environment, climate and pollution

Active gases in the atmosphere which trap outgoing solar radiation causing warming are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), troposphere ozone (O_3), carbon monoxide (CO) and chlorofluorocarbon (CFC).

3.1.1.1. Carbon dioxide

CO_2 is fundamental to sustain life on earth for two reasons

1. It is a source of C for photosynthesis
2. Its acts like blanket in atmosphere that keeps the earth warmer.

Table – 2. Countries with the highest carbon dioxide emissions

Sl No.	Country	CO_2 emissions from fuel combustions (mt)	Per capita CO_2 emissions (tonnes)
1.	USA	5652	19.66
2.	China	3271	2.55
3.	Russia	1503	10.43
4.	Japan	1207	9.47
5.	India	1016	0.97
6.	Germany	838	10.15
7.	Canada	532	16.93
8.	UK	529	8.94
9.	South Korea	452	9.48
10.	Italy	433	7.47

(Singh *et al.*, 2001)

Table 3. Composition and changes to concentration of greenhouse gasses in the atmosphere

Global gases (%)	Current concentration	Annual increase (%)	Contribution of warming (%)
CO_2	375 ppm	0.5	40-50
CH_4	1.78 ppm	0.8	20.25
N_2O	310 ppb	1.0	5-10
CFC_s	0.24 ppb	3.0	15-20

(IPCC, 2001)

3.1.1.2. Methane

One molecule of CH_4 traps about 32 times more heat than a molecule of CO_2. Although the troposphere methane concentration is only 1.78 ppm as compared to 57 ppm of CO_2, methane is responsible for approximately 25% of the anticipated warming (IPCC, 1996)

The global CH_4 cycle is closely linked to the CO_2 cycle, 10-35% of the global annual production of CO_2 is believed to result from the CH_4 oxidation.

3.1.1.3. Nitrous oxide

An increase of 0.2% to 0.3% in N_2O concentration in the atmosphere contributes about 5% to the supposed greenhouse warming. One molecule of N_2O is approximately 150 times more effective than CO_2 Nitrous oxide is considered to contribute to the destruction of the protective ozone layer in the stratosphere. The estimates of the effects of ozone depletion suggest a 4% to 6% increase in case of skin cancer with each 1% drop in ozone concentration (IPCC, 2001)

The increase in global temperature because of radiative forcing of Greenhouse Gases (GHG's) in the atmosphere has been estimated to be 0.6°C during 20th century and is projected to be 1.4 to 5.8°C by 2100 relative to 1990 (IPCC, 2001).

The contribution of fossil fuel may increase to 8.0 Pg C yr^{-1} by the year 2005 if present trends of its utilization continue.

A total of 5.7 Pg C yr^{-1} is reabsorbed in terrestrial ecosystem, oceans and in some other unknown sinks leaving a net enrichment of 3.4 Pg C in atmosphere. A large part of this enrichment comes directly or indirectly from soils. Various sinks and sources of carbon is given in Table 4.

Table - 4. Carbon flow various sources to sink

Carbon flow	Pg C yr^{-1}
Source	
Fossil fuel	6.4
Land use change	1.1
Tropical deforestation	1.6
Total sources	9.1
Sinks	
Atmospheric increase in CO_2	3.4
Terrestrial	2.0
Oceans	2.0
Unknown sink	1.7
Total sink	9.1

(IPCC, 1996)

4. Carbon sequestration

The provision of long term storage of carbon in the terrestrial biosphere, underground, or oceans, so that the buildup of CO_2 concentration in the atmosphere will be reduced (Chinnamuthu and Basha, 2003)

5. Types of carbon sequestration

5.1. Terrestrial sequestration

CO_2 from the atmosphere is absorbed by trees and plants through photosynthesis. Carbon is stored in biomass (tree trunks, foliage and roots) and in soils.

5.2. Oceanic sequestration

It is the direct injection of CO_2 into the mid water or deep ocean and enhancement of natural ocean carbon sequestration by fertilization of phytoplankton. There are two types as follows.

5.2.1. Shallow ocean sequestration: It is the injection of CO_2 into shallow ocean to increase the growth of phytoplankton and other marine organisms which extract CO_2 from the ocean water to build their skeleton and shells.

5.2.2. Deep ocean sequestration: This is having enormous sequestration potential because of their vast size of the favourable physical conditions (high temperature, low temperature and low life content) that operates at depth of greater than around 800 m.

5.3. Microbial sequestration

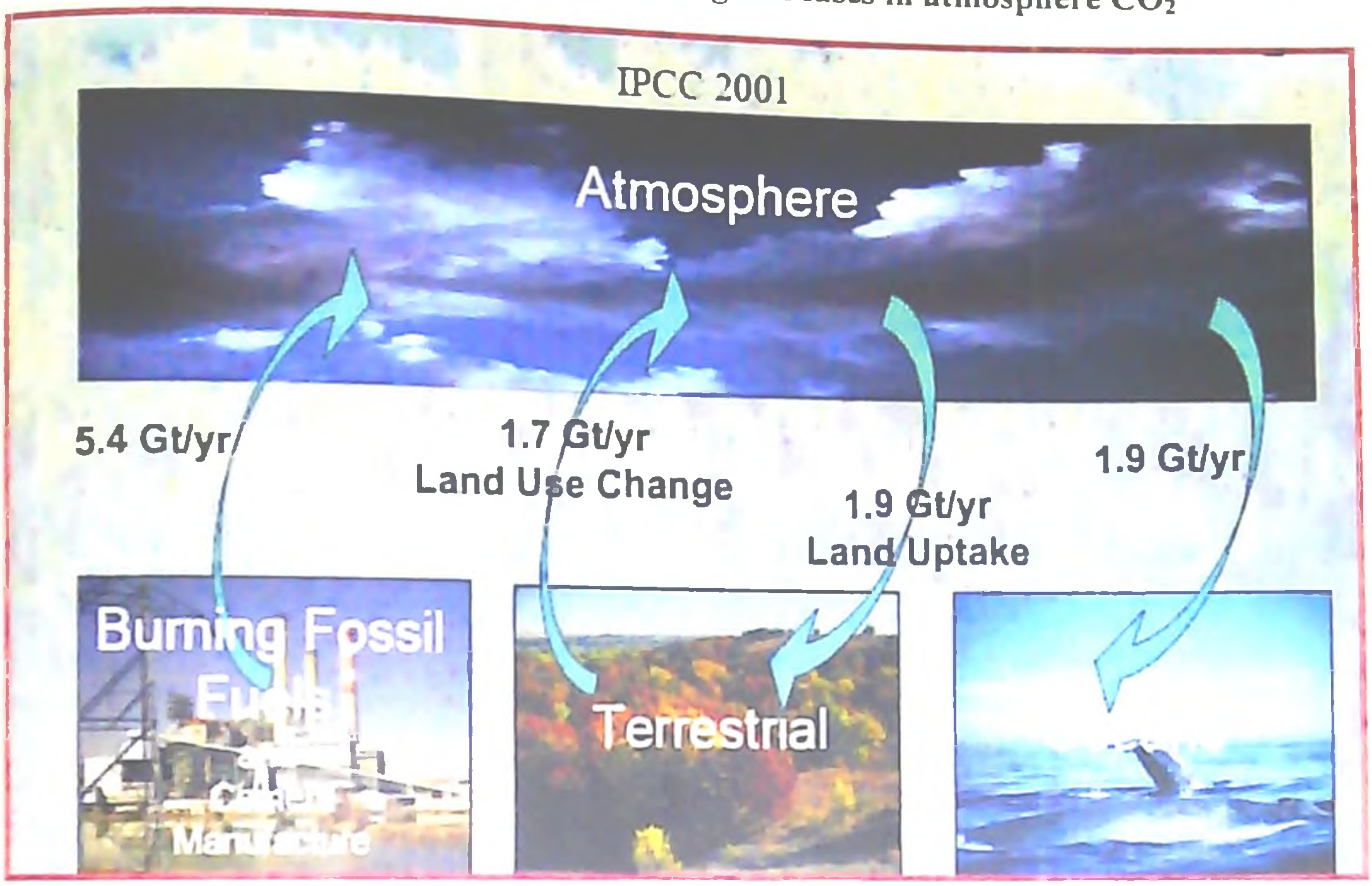
Microbes are responsible for much natural CO_2 absorption on land and sea and are also important causes for producing fuels such as methane and hydrogen.

5.4. Geologic sequestration

It is also known as geo sequestration. This involves injecting CO_2 directly into underground geological formations. Such formations may be natural porous rock structures. They may be man made, such as unused mines and expanded petroleum fields.

(Among the above methods of carbon sequestration, the terrestrial sequestration is getting importance, because of its less cost and easily adoptable these technologies)

Fig. 2. Net annual fluxes are causing increases in atmosphere CO_2



Because of burning fossil fuel and mismanagement of land there is about 7.1 Gt C $year^{-1}$ releasing to atmosphere. But we can store the carbon by terrestrial and ocean only to the extent of about 3.8 Gt C $year^{-1}$.

6. Terrestrial sequestration

Terrestrial sequestration is achieved by four components. These are as follows

6.1. Soil sequestration

6.2. Agriculture sequestration

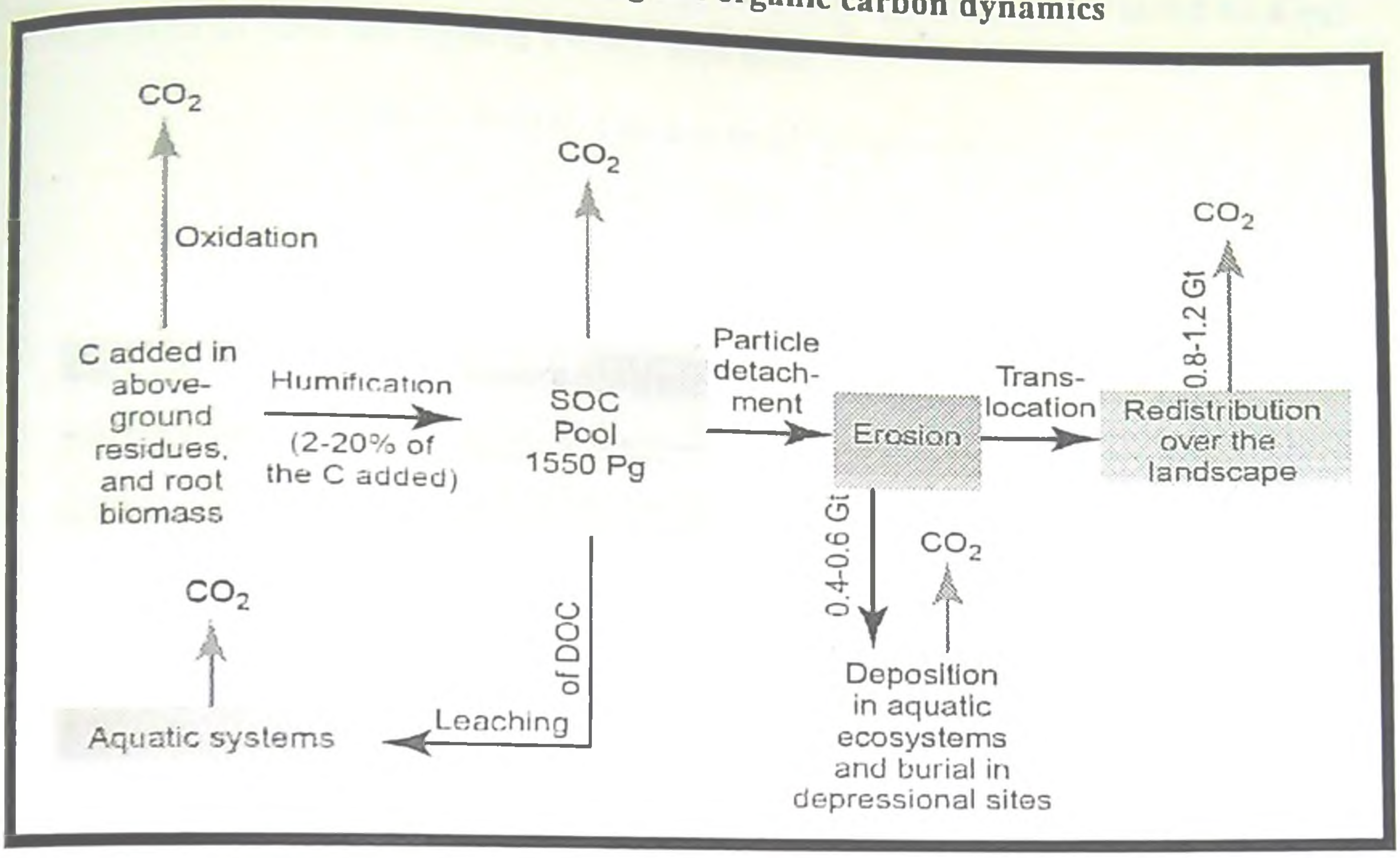
6.3. Agroforestry sequestration

6.4. Forestry sequestration

6.1. Soil sequestration

Carbon sequestration is transferring atmospheric CO_2 into soil carbon and storing it securely so it is not immediately reemitted (Lal, 2004).

Fig. 3. Process affecting soil organic carbon dynamics



The soil organic carbon pool represents a dynamic gains and losses. Conversion of natural to agricultural ecosystems causes depletion of the soil organic carbon pool by as much as 60% in soils of temperate regions and 75% or more in cultivated soils of the tropics (Robertson *et al.*, 2000)

The increased soil organic carbon contributes positively to soil tilth, fertility, and water holding capacity, and thereby increases crop production, promotes sustainability and enhances land value for producers (Russell *et al.*, 2003). At the global level, increased sequestration of C in agricultural soils has the potential to mitigate the increase in atmospheric gases (Young, 2003)

Table – 5. Potential of carbon sequestration in world soils (0.4 – 1.2 Gt C/yr)

Sl No	Soil types	Carbon sequestration (Gt C/ yr)
1	Irrigated soils	0.01 to 0.03
2	Cropland soils	0.4 – 0.8
3	Range lands and grass lands	0.01 – 0.3
4	Restoration of degraded and desertified soils	0.2 to 0.4

(Lal, 2004)

In cropland soils the sequestration of carbon is very high (0.01 to 0.8 Gt C/yr) compared to all other soil types in a world wide basis.

Table - 6. SOC loss due to different erosions

Severity of erosion	SOC loss (Pg C)		
	Water erosion	Wind erosion	Total
Light	1.4 – 2.1	0.5 – 0.8	1.9 – 2.9
Moderate	6.7 – 11.2	0.4 – 0.7	7.1 – 11.9
Strong and extreme	7.9 – 13.2	2.0 – 3.0	9.9 – 16.2
Total	16 – 27	3 – 5	19 – 32

(Lal, 2000)

Water erosion causes severe degradation of land, and high amount of water causes rapid- decomposition of organic matter, which put together to severe loss of carbon compared to wind erosion

6.1.1. Mechanisms of soil carbon stabilization

Other than unfavorable environmental factors, which retard C decomposition in soils (e.g. unfavorable soil pH, temperature, desiccation, anaerobiosis, absence of decomposers and presence of toxic factors), there is increased possibility for stabilization of C in soils. The mechanisms of soil C stabilization could be grouped into physical, chemical and biological protection measures or their combinations.

6.1.1.1. Physical protection and stabilization mechanisms

These mechanisms are better understood than other mechanisms. They largely arose from the interactions of SOC with soil mineral matrix forming strong chemical bonds or causing inaccessibility of the soil C to decomposer organisms or their enzymes. According to Larson *et al.* (1991) as much as half of the total SOM is maintained and protected in soils by these mechanisms. The two major groups of mechanisms being responsible for the retention of organic substances (e.g. pesticides) and soil C by clay minerals. These are (1) physico-chemical stabilization by sorption of organic matter to clay surfaces (e.g. Cation and anion exchange, polyvalent Cation bridging, H-bonding) forming complexes and (2) physical stabilization by the penetration of organic matter into interlayer spaces of expanding clay minerals thereby encapsulate and shield the organic matter, inhibiting its accessibility to degrading soil micro-organisms or their enzymes.

The adsorption of soil C to clay and silt particles (< 20µm) is an important determinant of the stability of SOC in both tropical and temperate soils.

Another proposed form of physical protection of SOC by encapsulation is during aggregate formation. This has received more recent attention and has been incorporated in many soil C turnover models as a function of soil texture. More persistent agents (e.g. clay-polyvalent metal-humified organic matter complexes) bind micro-aggregates while more temporary and transient agents (e.g. roots, fungal hyphae, polysaccharides) bind microaggregates to macroaggregates. Root exudates, soil microbes and fauna promote aggregation by excreting agents which bind soil particles together. It was found that macroaggregates in no-tillage (NT) soils provided higher protection of SOC, which may otherwise be mineralized under conventional tillage (CT) soils. Stable macro-aggregates in cultivated soils have been shown to contain more C and relatively younger C than the C in micro-aggregates. Various studies have showed that tillage caused a loss of SOC due to detrimental direct and indirect effects, attributed to the mechanical (ploughing) and chemical (wetting-drying cycles) disruptions of soil structure, and increased water availability and soil aeration

Soil aggregation is a transient property and aggregates are continually being formed and destroyed. Aggregation is not necessarily a sequential process of binding smaller particles into larger particles but could result from the formation of micro-aggregates form macroaggregates when macroaggregates fragment depending on soil type. Thus aggregate protection of SOC is high when aggregate stability is high and aggregate turnover is low.

The role of aluminium (Al) and allophone and probably iron in protecting SOC against microbial decomposition has also been proposed by different workers, especially for Andosols. Houghton *et al.* (1999) found higher soil C being stabilized in allophonic (Andosols) than non-allophanic soils and attributed this to the presence of Al and allophone with its high specific surface area. Lal *et al.* (2000) proposed that a ligand exchange between the surface hydroxyl groups of allophone and the carboxyl groups of humic acids (HA) provides the mechanism for C sequestration in Andosols, in the presence of $CaCl_2$ as a background electrolyte.

6.1.1.2. Chemical protection and stabilization mechanisms

These mechanisms are attributed to the production of charcoal (or black C) by fires and biologically inert or recalcitrant and refractory compounds and very slowly decomposable humic substacnes (HS) and organic compounds such as lipids (eg. Waxes, cutins, suberins), and chitin by plants, soil fauna, and soil micro-organisms.

These compounds may be present initially in the plant and animal residues added to the soil or synthesize in situ. They possess biochemical recalcitrance due to their inherent structural stability, especially rigid alkyl structures.

The role of black C has been implicated recently as a potential source of stabilized C in soils in Australia, Europe and Brazil. This has also been reported in Japanese Andosols, where a long history of anthropogenic and natural grassland fires are responsible for the production of the black humus layers or A-type humic acid which showed strong aromatic C-H stretching infrared bands. Black C is composed of stacked layers of polyaromatic units with varying levels of organization. Due to its high aromaticity and the highly condensed structure, black C is generally considered as the most recalcitrant of SOC. Estimated turnover time for charcoal is 5,000 to 10,000 years.

Early studies of SOM have attributed the stability of HS to their molecular structural recacalcitrance such as large size, non-diffusable, disorderly structure and being co-polymered thus inhibiting their rapid decomposition by micro-organisms or their enzymes in soils. Recently, Lal *et al.* (1999) attributed the biochemical recalcitrance of HS to their intra- and inter-structural bond strengths, the degree of aromaticity and the degree of regularity of occurrence of structural units in the recalcitrant biomolecules. This chemical recalcitrance can originate as the primary molecular structure such as aromatic ring structures or changes induced by decomposition processes in the soil environment (eg. condensation reactions).

In contrast to the theories of HS as being high molecular weight polymers, recent theories proposed that HS are supramolecules consisting of associations of small heterogeneous molecules held together not by covalent bonds but by weak forces such as dispersive hydrophobic interactions (van der Waals, π- π, CH- π bonding) and hydrogen bonding in contiguous hydrophilic and hydrophobic domains of apparently high molecular size.

This unstable conformation is stabilized by increasing intermolecular covalent bonds by oxidation enzymes such as phenol oxidases. A copper – containing phenol oxidase enzyme, laccase, has been produced by soil fungi and mycorrhizas.

It has been proposed that hydrophilic components released from microbial degradation of plant tissues or formed by microbial synthesis become progressively sequestered in the hydrophobic domains of humus and protected against further degradation.

The most recalcitrant humic fractions contains mainly aliphatic or alkyl compounds. The hydrophobic protection was most effective in silt- and clay-size soil particles and may also occur with larger soil particles. Lal (1999) showed that soil aggregate stability was enhanced and maintained with time by hydrophobic than by hydrophilic components of organic matter. This implies that the aggregate staility of soils or C stabilization can be improved by promoting the hydrophobicity of native humus or by adding materials such as organic waste or lignite with high hydrophobic components. Water repellency of soils caused by hydrophobic interfaces in aggregates and soil particles has also been proposed as another mechanism of hydrophobic protection of SOC.

6.1.1.3. Biological protection and stabilization mechanisms

Several biological mechanisms and processes have been proposed but the extent and relative significance of these mechanisms are still unclear. These include the classical model of aggregate formation and organization in which micro-aggregates are bound together by roots and fungal hyphae and transient (polysaccharides) agents, the role of plant root debris and plant-derived rhizodeposits, laccase enzyme production by white rot fungi and mycorrhizas, microbial community diversity in micro-habitats and the formation of refractory organic compounds by micro biota in the guts of soil arthropods. Most of these proposals are in the experimental stage and insufficient data are available at present to verify and validate the proposed mechanisms.

6.1.1.4. VAM

VAM in one of the beneficial microbes, which can reduce the CO_2 level in the atmosphere without any side effect. It is a heterotrophic endomycorrhiza fungus, which infect the root of the host plant and survive in it by consuming the CHO from the host plant and in exchange, this beneficial fungi feed the essential nutrients to the host plants from the soil through the hypae. By this beneficial function, the mycorrizal plant increase the rate of photosynthesis when compare to non-mycorrizal plants. Hence the survival of the mycorrizal plants captured the 30 % atmospheric CO_2 and stored in the soil in the form of glomolin. It will act as a binding agent to form aggregates.

6.2. Carbon sequestration through agricultural systems

Agricultural practices can reduce these emissions by increasing the density and depth of carbon in the soil profile and decreasing the decomposition of carbon and losses due to erosion. Tillage and planting practices that reduce soil erosion and the land application of manure and other organic materials can increase carbon sequestration. There are also hidden carbon costs associated with fertilizer, pesticides and irrigation due to emissions of CO_2 during manufacturing and from energy consumption.

Changes in agricultural practices have the potential to reduce carbon emissions by 288 million tons/year in the U.S. and 1 billion tonnes/yr worldwide. The carbon sink capacity of the world's agricultural and degraded soils is 50 to 66% of the historic carbon loss of 42 to 78 gigatons of carbon. The rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system, and soil management. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands.

An increase of 1 ton of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kilograms per hectare (kg/ha) for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas. As well as enhancing food security, carbon sequestration has the potential to offset fossilfuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions.

Results indicate, on average, that a change from conventional tillage (CT) to no-till (NT) can sequester 57 ± 14 g C m^{-2} yr^{-1}, excluding wheat (*Triticum aestivum* L.) fallow systems which may not result in SOC accumulation with a change from CT to NT. Enhancing rotation complexity can sequester an average 14 ± 11 g C m^{-2} yr^{-1}, excluding a change from continuous corn (*Zea mays* L.) to corn-soybean (*Glycine max* L.) which may not result in a significant accumulation of SOC. Carbon sequestration rates, with a change from CT to NT, can be expected to peak in 5-10 yr with SOC reaching a new equilibrium in 15-20 yr. Following initiation of an enhancement in rotation complexity, SOC may reach a new equilibrium in approximately 40-60 yr. Carbon sequestration rates, estimated for a number of individual crops and crop rotations in this kind of study can be used in spatial modeling analyses to more accurately predict regional, national, and global C sequestration potentials.

Increasing soil C through changes in land use and management is a low cost and environmentally beneficial method of sequestering substantial amounts of atmospheric CO_2. However, it is generally viewed that soils, like other biological sinks (e.g. vegetation stocks), have an inherent upper limit above which no additional C can be stored. The magnitude of this upper or 'saturation' limit is crucial to know as it will govern the ultimate significance of the soil sink and the time period over which it can be exploited for CO_2 sequestration. However, at present, we have little knowledge of the 'C carrying capacity' of soils and moreover we do not know how rates of C sequestration may differ for soils that are far from, versus close to, some saturation level. there is a level at which soil C becomes saturated and this level is determined by the behavior of four different C pools: 1) a chemically protected C pool, 2) a silt- and clay-protected C pool, 3) a microaggregate-protected C pool, and 4) an unprotected C pool. Losses of soil organic matter are accelerated in the hotter and dryer climates.

6.2.1. The important strategies of enriching C in soil are

6.2.1.1. Tillage practices

Types of Tillage Systems (Reddy and Reddy, 1992)

No-till: From planting to harvest, the soil is left undisturbed with the exception of nutrient injection. In most systems, planter-mounted coulters till a narrow seedbed assisting in the placement of fertilizer and seed. Herbicides are the primary agent for weed control.

Ridge tillage: Similar to no-till, the soil is not tilled between the harvest of one crop and planting of the next. The ridge till system involves planting crops on raised ridges with sweeps, disk openers, coulters, or row cleaners. Residue remains on the soil surface between the ridges.

Mulch tillage: Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used prior to planting, but at least 30 percent of the soil surface is covered with residues after planting.

Reduced-till: Tillage systems that leave 15-30% of crop residue on the soil surface after planting are considered reduced-till systems.

Conventional-till: Tillage systems that leave less than 15% of crop residue on the soil surface after planting are considered conventional-till systems. These systems generally involve plowing or intensive tillage.

However, ploughing is unlike any natural disturbance because nothing in nature repeatedly and regularly turns over the soil to the specified plough depth of 15-20 cm. Conversion of plough-based farmland to conservation tillage reduces risk of soil erosion and can sequester some of the C that would have been otherwise lost.

In some cases, soil organic carbon can be augmented upto 50 per cent through no-till or reduced tillage practices.

Table – 7. SOC accumulation due to conservation tillage

Treatment	0-15 cm		15-30 cm	
	No-tillage	Tillage	No-tillage	Tillage
Soil organic C (%)	0.24	0.22	0.15	0.15
Hydrolysable-N (mg kg^{-1})	179.2	168.0	175.0	156.8

Sehgal and Abrol (1994)

Ploughing increases mineralization of SOC by mixing crop residues in soil, bringing it closer to microbes, increasing O_2 concentration in soil, disrupting aggregates and exposing physically protected organic matter to microbial and enzyme activity, so that there is a decline is SOC content with in 15 cm depth of surface layer.

6.2.2. Cover Crops and Crop Rotation

Frequent use of sod-type legumes and grasses in rotation with food crops is an important strategy to enhance SOC and improve soil quality. The practice of summer fallowing observed in semi-arid countries can decrease SOC pool at the rate of 320 to 530 kg C ha^{-1}. Sehgal and Abrol (1994) have shown that three-year cultivation of mungbean and clusterbean increased SOC from 0.22 to 0.26 and 0.28 per cent, respectively.

6.2.3. Crop residues, manure and fertilizers, green manuring

World over 3.4 Pg residues are produced with almost a tenth of it in India. On global basis nearly 1.53 Pg C yr^{-1} is accumulated in residues (Lal, 1999). Returning crop residues to soil increases SOC that shows linear increases with the quantity of residue returned (Duiker and Lal, 1999).

Returning crop residues to soil has converted many soils from "source" to "sink" to atmospheric CO_2 (Rasmussen *et al.* 1998) by enhancing soil productivity.

Table – 8. SOC gain due to crop residue incorporation

Parameter	No residue	CB residue	MB residue	Manure
SOC (%)	0.19	0.21	0.20	0.21
Total N (mg kg^{-1})	270	300	290	320
Available –N (kg ha^{-1})	135	143	137	149
Available-P (mg ha^{-1})	7.1	8.7	7.3	9.2

CB-Cluster Bean MB- Mung bean (Sehgal and Abrol, 1994)

6.2.4. Pastures

Cadisch *et al.* (1998) reported that the introduction of improved pastures increased SOC at the rate of 230 to 3300 kg C ha^{-1} yr^{-1} in tropics. Long term experiments in Australia showed that soil under long-term pasture (1918-1986) contained 11.5 x 10^9 g ha^{-1} more organic C than unfertilized cropped plots (Rosenzweig and Hillel, 2000).

Table – 10. SOC (%) gain due to pastures

Treatment	Soil depth (cm)	
	0-15	15-30
Cultivated field	0.29	0.20
4 years with stubble	0.44	0.33
4 years without stubble	0.40	0.28
6 years with stubble	0.53	0.38
6 years without stubble	0.45	0.31
8 years with stubble	0.49	0.39
8 years without stubble	0.43	0.31

(Rosenzweig and Hillel, 2000)

After harvesting the leftover portion of stubbles with roots having the capacity to store the carbon to some extent even in the subsurface soil also. Calculations suggest that 3.6×10^{11} g C can be sequestered in only 832448 ha of permanent pastures of Rajasthan if proper management practices are followed.

6.2.5. Mulching

Table – 9. SOC gain due to mulching

Treatment	Runoff (t ha^{-1})	Soil loss (kg ha^{-1})	SOC (%)	N (mg kg^{-1})	K_2O (mg kg^{-1})
Clean cultivation	54.50	5.08	0.28	218.04	136.34
Natural grass	35.08	2.17	0.36	222.21	172.78
Zea mays cultivation	39.65	4.41	0.34	234.72	125.44
Zea mays straw mulch @ 5 t ha^{-1}	40.25	2.10	0.33	217.33	127.93
Zea mays straw mulch @ 10 t ha^{-1}	32.24	2.20	0.34	234.72	116.87
L *leucocephela* mulch @ 5 t ha^{-1}	27.36	1.29	0.30	218.03	157.25
L *leucocephela* mulch @ t ha^{-1}	26.17	1.34	0.34	234.72	125.44

(Yadav *et al.*, 2000)

This table expresses that there is a definite increase in SOC with increase in the quantity of mulch added to the soil

Santhy *et al* (2000) have reported continuous cultivation (even intensive) with optimum fertilization and organic manuring, would buildup soil organic carbon status.

6.2.6. Other methods

6.2.6.1. Increase carbon sinks in soil organic matter and above ground biomass

- Adopt mixed rotations with cover crops and green manures to increaser biomass additions to soil
- Adopt agroforestry in cropping systems to increase above – ground standing biomass.
- Minimize summer fallows and periods with no ground cover to maintain soil organic matter stocks.

- Use soil conservation measures to avoid soil erosion and loss of organic matter.
- Apply composts and manures to increase soil organic matter stocks.

6.2.6.2. Reduce direct and indirect energy use to avoid GHGs emissions

- Conserve fuel and reduce energy use in buildings and stores
- Use composting to reduce manure methane emissions
- Substitute biofuel for fossil fuel consumption
- Reduce the use of inorganic fertilizers and adopt targeted and slow release fertilizers, as fertilizer manufacture is highly energy intensive
- Reduce use of pesticides to avoid indirect energy consumption

6.2.6.3. Increase renewable energy production to avoid carbon emissions

- Cultivate annual and perennial crops, such as grasses and coppiced trees for combustion and electricity generation with crops replanted each cycle for continued energy production
- Use biogas digesters to produce methane, so substituting for fossil fuel sources.

6.3. Carbon sequestration through agroforestry systems

Carbon sequestration potential is one of the promising but little – studied characteristics of agroforestry systems. By deliberately integrating trees with crop and animal production systems, agroforestry systems offer a promising avenue for carbon storage and greenhouse gas emissions in several of the managed terrestrial ecosystems around the world. Exploitation of mechanisms such as nutrient cycling, nitrogen fixation by tree legumes, and deep capture of nutrients by deep rotted components offers a distinct possibility for reducing agrochemical inputs to these systems, yet maintaining the system productivity at reasonable levels on a sustained basis. Furthermore, with the emphasis on fruit trees and other multipurpose trees that provide multiple products and services, the proportion of total photosynthates that is removed from the system is minimized, thereby facilitating storage of more carbon in the system than in conventional, clear cut silvicultural systems (Nair and Nair, 2002). Examples of management opportunities in agroforestry for C sequestration include adoption of "green" technologies such as return of biomass and plant residues to fields, providing vegetative barriers and canopy cover on soil surface to reduce soil erosion and reclaiming degraded lands such as salt affected and eroded soils through tree planting.

The extent of and possibility for agroforestry vary in different parts of the world. Alley cropping and improved fallow systems are good examples of intensive biomass management systems in the tropics, whereas shaded perennial and silvipastoral systems represent situations with permanent tree cover. The five recognized agroforestry systems in the temperate region alley cropping, forest farming, riparian buffer, silvipasture and windbreaks vary greatly in their carbon storage potential (Zinkhan and Mercer, 1997). Average carbon storage by agroforestry practices has been estimated as 9, 21, 50 and 63 Mg C ha^{-1} in semiarid, subhumid, humid and temperate regions (Montagnini and Nair, 2004)

Currently agroforestry worldwide as 400 million hectares with an estimated C gain of 0 72 Mg C ha yr^{-1} with a potential for sequestering 26 Tg C ha yr^{-1} by 2010 and 45 tg C ha yr^{-1} by 2040 The estimate also says that 630 million hectares of unproductive crop land and grasslands could be converted to agroforestry worldwide, with the potential to sequester 391 Tg C ha yr^{-1} by 2010 and 586 Tg C ha yr^{-1} by 2040 (IPCC, 2001). The estimate are that 1 ha of agroforestry could save 5 ha from deforestation and agroforestry systems could be established in up to 2 million ha in the low altitude regions annually (Dixon, 1995)

Basically there are three categories of activities through which forest management can help reduce atmospheric carbon *Carbon sequestration* (Through afforestration, reforestation and restoration of degraded lands, improved silvicultural techniques to increase growth rates and implementation of agroforestry practices on agricultural lands), *Carbon conservation* (through conservation of biomass and soil carbon in existing forests, improved harvesting practices such as reduced impact logging, improved efficiency of wood processing, fire protection and more effective use of burning in both forest and agricultural systems); and *Carbon substitution* (increased conversion of forest biomass into durable wood products for use of biofuels such as introduction of bioenergy plantations and enhanced utilization of harvesting waste as feedstock such as sawdust for biofuel).

6.3.1. Carbon sequestration by tree based systems

The basic premise of carbon sequestration potential of land use systems including agroforestry systems is relatively simple. It revolves around the fundamental biological/ecological processes of photosynthesis, respiration and decomposition (Nair and Nair, 2003). Essentially carbon sequestered is the difference between carbon 'gained' by photosynthesis and carbon 'lost' or released by respiration of all components of the ecosystems and this overall gain or loss of carbon is usually represented by net ecosystem productivity. Most carbon enters the ecosystem via photosynthesis in the leaves and carbon accumulation is most obvious when it occurs in aboveground biomass. More than half of the assimilated carbon is eventually transported below ground via root growth and turnover, root exudates and litter deposition and therefore soils contain the major stock of C in the ecosystem

6.3.2. Carbon sequestration by tree components

Conceptually trees are considered to be a terrestrial carbon sink (Harmon, 2001). Therefore, managed forests can theoretically sequester carbon in both *in situ* (biomass and soil) and *ex situ* (products). According to FAO (2000) estimates, forest plantations cover 187 million ha worldwide, a significant increase from the 1995 estimate of 125 million ha. Carbon sequestration in above ground biomass for ten native tree species were comparable to exotic species growing under similar conditions (Table 11).

6.3.3. Carbon sequestration by alley cropping

Some results from alley cropping experiments report on increases in soil organic carbon when prunings are returned to the soil. These increases are thought to be due to higher density of roots in alley cropping systems in comparison with adjacent plots with conventional agriculture (Schroeder, 1994). Carbon sequestration potential of different agroforestry systems are given in Table 12.

Table – 11. Carbon content in above ground biomass of 10 plantation tree species at 10 years of age at la Selve Costa Rica

Plantation species	Carbon content (Mg ha-1)			
	Foliage	Branch	Stem	Total
Balizia elegans	0.6	2.5	17.3	20.5
Calophyllum brasiliense	5.8	10.6	29.7	46.3
Dipteryx panamensis	5.3	15.4	82	102.6
Genipa americana	1.1	4.8	17.5	23.3
Jacarnda copaia	0.8	1.6	42.5	44.9
Virola koschnyi	2	4.1	31	37

(Montagnini and Nair, 2004)

Table – 12. Estimated C sequestration through agroforestry systems practices in the USA by 2025

Agroforestry practice	Potential C sequestration Tg C yr –1, sum of the above and below ground storage
Alleycropping	73.8
Silvipasture	9.0
Winbreaks	4.0
Riparian buffer	1.5
Short rotation woody crops, forest farming	2.0
Total	90.3

(Montagnini and Nair, 2004)

6.4. Carbon sequestration through forestry systems

Globally, forest vegetation and soils contain about 1146 Pg C, with approximately 37 per cent of this C in low-latitude forests, 14 per cent in mid-latitudes, and 49 per cent at high latitudes.

Application of optimum forest and agroforestry management practices like selected cutting of application of fertilizers on 500-800 ha in 12-15 key nations could sequester 1-2 Pg C yr^{-1} using current infrastructure (Dewar, 1990).

An analysis of changes that could be achieved in the carbon cycle with a global, large scale afforestation programme that is economically, politically, and technically feasible. They estimated that only about 345 Mha would actually be available for plantation and agro-forestry for the sole purpose of sequestering carbon.

Table - 13. SOC gain with raising different tree species

Species	Original		After 20 years	
	pH	SOC (%)	pH	SOC (%)
Eucalyptus tereticornis	10.3	0.12	9.18	0.33
Acacia nilotica	10.3	0.12	9.03	0.55
Albizzia lebbek	10.3	0.12	8.67	0.47
Terminalia arjuna	10.3	0.12	8.15	0.47
Prosopis juliflora	10.3	0.12	8.03	0.58

(Lugo and Brown, 1992)

Though there are variations in the quantity of C sequestered there is a definite gain by growing various sp. of trees over a period of time.

7. Kyoto Protocol

The Kyoto Protocol is an international treaty on global warming. It is actually an amendment to the United Nations Framework Convention on Climate Change (UNFCCC). Countries which ratify this protoaol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emission treading if they maintain or increase emissions of these gases. Some current estimates indicate that if successfully and completely implemented, the Kyoto Protocol is predicted to reduce the average global rise in temperature by somewhere between 0.02°C and 0.28°C by the year 2050 (Korhonen *et al.*, 2002).

7.1.Status of the agreement

The treaty was negotiated in Kyoto, Japan in December 1997, opened for signature on March 16, 1998, and closed on March 15, 1999. The agreement came into force on February 16, 2005 following ratification by Russia on November 18, 2004. As of August 2005, a total of 153 countries have ratified the agreement (representing over 61% of global emissions). Notable exceptions include the United States and Australia. According to the terms of the protocol, it enters into force "on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession". Of the two conditions, the "55 parties" clause was reached on May 23, 2002 when Iceland ratified. The ratification by Russia on 18 November 2004 satisfied the "55 percent" clause and brought the treaty into force, effective February 16, 2005.

7.2. Details of the agreement

According to a press release from the "United Nations Environment Programme": *The Kyoto Protocol is a legally binding agreement under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990 (but note that, compared to the emissions levels that would be expected by 2010 without the Protocol, this target represents a 29% cut). The goal is to lower overall emissions from six greenhouse gases carbon dioxide, methane, nitrus oxide, sulphur hexafluride, HFC's and PFC's- calculated as an average over the five-year period of 2008-12. National targets range from 8% reductions for the European Union and some others to 7% for the US, 6% for Japan, 0% for Russia, and permitted increases of 8% for Australia and 10% for Iceland."*

This agreement was adopted at the Earth Summit in Rio de Janeiro in 1992. All parties to the UNFCCC can sign or ratify the Kyoto Protocol, while non-parties to the

UNFCCC cannot. Most provisions of the Kyoto Protocol apply to developed countries, listed in Annex I to the UNFCCC.

8. Emissions trading/Carbon trading

Each Annex I country has agreed to limit emissions to the levels described in the protocol, but many countries have limits that are set above their current production. These "extra amounts" can be purchased by other countries on the open market. So, for instance, Russia currently easily meets its targets, and can sell off its *credits* for millions of dollars to countries that don't yet meet their targets, to Canada for instance. This rewards countries that meet their targets, and provides financial incentives to others to do so as soon as possible.

8.1. Establish a plantation for carbon credits

Landholder can create a planted forest on his own land.

Carbon credits generated - calculated and verified

Credits sold into an emissions trading market.

8.2. Establish a plantation for other reasons

Establish a forest to address environmental issues

Salinity

Land and repair

Biodiversity enhancement

Forest would never be harvested.

No revenue from the sale of forest products

The only revenue - from sale of the carbon credits.

8.3. Trading In Carbon Credits Today

Toyota - $800,000 - model forest.

Nebraskan energy company Tenaska - $500,000 - Costa Rican rainforest.

BP initiated an internal carbon trading system, involving 10 business units around the world.

Pacific Power carbon credits - 1,000-hectare forest plantation (NSW) from the NSW State Forests organization.

8.4. Benefits of Carbon Trading

The reduction in overall cost of meeting emission reduction targets. Proactively manage greenhouse risk. Land owners get income for their land. Helps additional planting of trees - salinity amelioration, biodiversity enhancement. Conversion to greenhouse gas friendly fuels and energy. Employment and wealth creation in rural areas. Technology transfer- developed countries - developing countries. Trading is transparent – prices international – bids and offers from around the globe.

8.5. Limitations in carbon trading

The difficulty of annual accounting of sequestration from forests, given the costs of measurement. Costs of compliance with the MEU regime. The difficulties created by "buyer liability", particularly the risk implications for potential buyers and the inability to build a market under such a system. The transition system to a Kyoto Protocol regime. Restriction to Article 3.3 sequestration.

9. Precision farming / farming by soil

Precision farming, farming by soil or soil-specific management, is another important strategy of decreasing losses and enhancing biomass production through alleviation of soil-related constraints.

The application of nutrients and water as required for the specific soil conditions enhances use efficiency of inputs and improves crop yield. A judicious combination of integrated nutrient management and precision farming can enhance SOC concentration and improve soil quality (Leiva *et al.*, 1997).

10. Ongoing research is focusing carbon sequestration efforts on

- Sequestering carbon in underground geologic repositories
- Enhancing the natural terrestrial cycle

- Carbon sequestration in oceans
- Sequencing genomes of micro-organism for carbon management

11. Conclusion

If we can go for conservation tillage, a considerable amount of soil organic carbon buildup can take place. Cover crops, green manuring, crop rotation, cropping system and proper fertilization found to increase the biomass production which in turn increase carbon sequestration in soil. Increasing area under forest to capture carbon is one of the viable options to increase the carbon sequestration. Raising of trees and pastures on degraded soils also contribute remarkable enhancement in soil organic carbon. Finally the appropriate agronomical and soil management practices enhance the carbon sequestration.

12. Future thrust

- Improving the area under forest
- Crop management techniques
- Appropriate land use planning and management
- Emission of GHG can be reduced in many sectors – energy sectors

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14. Discussion

Why agro forestry system is considered as having more carbon sequestration?

Agroforestry has importance as a carbon sequestration strategy because of carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. The potential seems to be substantial; but it has not been even adequately recognized, let alone exploited. Proper design and management of agroforestry practices can make them effective carbon sinks. As in other land-use systems, the extent of C sequestered will depend on the amounts of C in standing biomass, recalcitrant C remaining in the soil, and C sequestered in wood products. Average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, subhumid, humid, and temperate regions. For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C ha^{-1} yr^{-1}.

What happens when CO_2 increase in atmosphere to carbon cycle?

Because of high CO_2 increase in atmosphere it leads to the imbalance in carbon cycle. So that high concentration of CO_2 is accumulated in the atmosphere compare to biosphere. I t leads to global warming.

Biofuel importance in carbon sequestration?

Biofuel production contributes to reduction in net GHG emissions because, as plant grows photosynthesis absorbs CO2 from atmosphere concentrating it in the feedstock, when burned this is released. Thus Biofuel use involves recycled carbon. Offsets net GHG emissions relative to fossil fuels by about 75-95 percent for power use about 35% for liquid fuel

What are the initiatives government has taken in India? (In carbon sequestration)

Increasing the present area under forest. Converting the wastelands into agroforestry systems. In Kerala Central Plantation Crops Research Institute – Kassargod and Kerala Forest Research Institute - Peechi are involved in carbon sequestration activities.

15. Abstract

Carbon dioxide is a very important atmospheric constituent in the heat budget of the earth and atmosphere. There is a sharp increase in CO_2 in recent times due to human – made interventions in terms of burning fossil fuels such as coal, oil and natural gases. The projected concentration of CO_2 in the atmosphere by 2030 is more than 370 ppm. The rate of increase in CO_2 concentration will lead to an increase in the earth's temperature between 1.0 °C and 3.5 °C by the turn of this century (Rao, 2005).

Carbon sequestration refers to the provision of long term storage of carbon in the terrestrial biosphere, underground or the oceans so that the buildup of CO_2 concentration in the atmosphere will be reduced. Carbon sequestration implies transferring atmospheric CO_2 into soil and storing it securely, so it is not immediately reemitted. Thus soil carbon sequestration means increasing soil organic and inorganic carbon through judicious land use and recommended management practices (Lal, 2004). Strategies to increase soil organic carbon pool include soil restoration and woodland regeneration, no – till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands.

An increase of 1 tonne of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kg ha^{-1} for wheat, 10 to 20 kg ha^{-1} for maize, and 0.5 to 1 kg ha^{-1} for cowpea (Lal, 2004). Conceptually trees are considered to be a terrestrial carbon sink. Therefore, managed forests can, theoretically, sequester carbon both *in situ* (biomass and soil) and *ex situ* (products) (Harmon, 2001).

In 1997, December 1 through 11, the climate convection held a conference in Kyoto, Japan. The aim of the conference was to achieve agreement on a treaty that would require the industrialized part of the world to limit its emissions of green house gases.

One of the best flex may given by Kyoto protocol to developed countries to meet its level is carbon trading. In this the developed countries issues credits to absorb its emitted carbon from air to the developing countries. It may be done by enhanced natural regeneration, reduced impact logging, and joint implementation methods (Chinnamuthu and Basha, 2004)