REVIEW OF LITERATURE
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2.1. Greenhouse gases and atmospheric change

CH$_4$ is the major component of natural gas and is second important greenhouse gas after carbon dioxide (Etheridge et al., 1998) with a current ambient concentration of 1.7 ppmv. The average lifetime of each CH$_4$ molecule that reaches the atmosphere is about 8-10 years (Dlugokencky et al., 1996) and its global warming potential in relation to CO$_2$ is about 26.9 for a ten-year integration period (Lelieveld et al., 1993). N$_2$O is another important greenhouse gas, which is emitted into the atmosphere with the average lifetime of about 150 years and a net greenhouse effect of about 300 times greater than that of molecule of CO$_2$. These gases are having effects on the radiative balance due to their relatively long atmospheric residence times (Table 1). The global sources and sinks of the greenhouse gases are given in Table-2.

Table 1: Characteristics of Greenhouse Gases in the atmosphere (Bouwman and Sombroek, 1990)

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Trace Gas</th>
<th>Residence Time (Years)</th>
<th>Radiative absorption potential</th>
<th>Annual Rise (%)</th>
<th>Contribution to Global warming Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CO$_2$</td>
<td>100</td>
<td>1</td>
<td>0.50</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>CH$_4$</td>
<td>10-12</td>
<td>32</td>
<td>1.00</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>CFCs</td>
<td>50-150</td>
<td>&gt;10,000</td>
<td>3.00</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>O$_3$</td>
<td>0.1-0.13</td>
<td>2,000</td>
<td>2.00</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>N$_2$O</td>
<td>170</td>
<td>150</td>
<td>0.25</td>
<td>4</td>
</tr>
</tbody>
</table>
Table-2: Global emissions and sources of major Greenhouse gases (IPCC, 1997)

<table>
<thead>
<tr>
<th>Source Type</th>
<th>CARBON DIOXIDE (Gt) C</th>
<th>METHANE (Tg)</th>
<th>NITROUS OXIDE (Tg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Annual Emission</td>
<td>6.5 – 7.5</td>
<td>400-600</td>
<td>11-17</td>
</tr>
<tr>
<td>Biotic emission(%)</td>
<td>20-30</td>
<td>70-90</td>
<td>90-100</td>
</tr>
<tr>
<td><strong>Sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil fuel use</td>
<td>5.7</td>
<td>Paddy fields 60</td>
<td>Oceans 1.4-2.6</td>
</tr>
<tr>
<td>Shifting Cultivation</td>
<td>1-2</td>
<td>Wet Lands 115</td>
<td>Natural soils 2.7-5.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ruminants 80</td>
<td>Cultivated Soils 0.3-3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Termites 20</td>
<td>Forests 0.5-2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land fills 30</td>
<td>Grass lands 0.5-1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oceans/lakes 10</td>
<td>Automobiles 0.2-0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biomass burning 40</td>
<td>Biomass Burning 0.2-1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fossil, coal &amp; gas exploration 100</td>
<td>Adipic Acid production 0.4-0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Animal wastes 25</td>
<td>Nitric acid production 0.1-0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CH₄ Hydrate 5</td>
<td>Stationary Combustion 0.1-0.3</td>
</tr>
<tr>
<td><strong>Sinks</strong></td>
<td>Oceans 1</td>
<td>Atmospheric Removal 470</td>
<td>Removal by soils 0.5-1.0</td>
</tr>
<tr>
<td></td>
<td>Atmospheric accumulation 3.5</td>
<td>Soil Oxidation 32</td>
<td>Photolysis in Stratosphere 7-13</td>
</tr>
<tr>
<td></td>
<td>Biosphere</td>
<td>Atmospheric Increase 30</td>
<td>Atmospheric Increase 3-4.5</td>
</tr>
<tr>
<td></td>
<td>Charcoal Formation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2.2. Atmospheric Methane: Sources & Sinks

The build-up of CH₄ in the atmosphere is attributed to various activities, mainly the bacteria mediated methanogenesis (biogenic CH₄) occurring in anoxic ecosystems and the thermo catalytic reactions (thermogenic CH₄). Sources of CH₄ can be both abiological and biological (Table. 3). The abiological sources such as mining, transport, fossil fuels and biomass burning contribute about 20-30% to the total atmospheric CH₄. Based on the measurements of the natural abundance of carbon isotopes (^13C and ^14C) in
the atmospheric CH₄ about 70% of total emission is biogenic in origin (Bergamaschi et al., 1998). Based on the estimates of CH₄ trapped in polar ice cores, the tropospheric CH₄ concentration in the atmosphere has increased over the past 300 years by 115% (Houghton et al., 1990). Some of the sources and sinks are explained below.

Table 3. Estimated sources and sinks of atmospheric CH₄ (Watson et al., 1992)

<table>
<thead>
<tr>
<th>Sources and Sinks</th>
<th>Best Estimate (Tg. Yr⁻¹)</th>
<th>Likely Range (Tg. Yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sources</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural wetlands</td>
<td>115</td>
<td>100-200</td>
</tr>
<tr>
<td>Termites</td>
<td>20</td>
<td>10-50</td>
</tr>
<tr>
<td>Oceans</td>
<td>10</td>
<td>5-20</td>
</tr>
<tr>
<td>Freshwater</td>
<td>5</td>
<td>1-25</td>
</tr>
<tr>
<td>Methane hydrate</td>
<td>5</td>
<td>0-5</td>
</tr>
<tr>
<td><strong>Anthropogenic</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal mining, natural gas &amp; petroleum industry</td>
<td>100</td>
<td>70-120</td>
</tr>
<tr>
<td>Rice paddies</td>
<td>60</td>
<td>20-150</td>
</tr>
<tr>
<td>Enteric fermentation</td>
<td>80</td>
<td>65-100</td>
</tr>
<tr>
<td>Animal wastes</td>
<td>25</td>
<td>20-30</td>
</tr>
<tr>
<td>Domestic sewage treatment</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Land fills</td>
<td>30</td>
<td>20-70</td>
</tr>
<tr>
<td>Biomass burning</td>
<td>40</td>
<td>20-80</td>
</tr>
<tr>
<td><strong>Sinks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric removal</td>
<td>470</td>
<td>420-450</td>
</tr>
<tr>
<td>Soil</td>
<td>30</td>
<td>15-45</td>
</tr>
<tr>
<td>Atmospheric increase</td>
<td>32</td>
<td>28-37</td>
</tr>
</tbody>
</table>

2.3. Paddy cultivation

Paddy fields constitute approximately 12 percent of the total CH₄ budget. The area under paddy is about 10% of the world’s total cultivated area with an increase of more than 1% y⁻¹ during the last three decades and the global paddy production may have to be increased by a factor 1.6 to meet the growing demand by the year 2020 (Bouwman., 1990). Extrapolation of available flux measurement data to the global harvested area of
paddy (of dry land, rainfed and irrigated types), estimates a global CH$_4$ emission of 60-140 Tg y$^{-1}$ (Aselmann and Crutzen, 1989).

### 2.3.1. Wetlands

The global wetland area is 530-570 mha and most of these wetlands occur between 50$^\circ$N and 70$^\circ$N and between 10$^\circ$N and 10$^\circ$S. The global CH$_4$ emission from wetlands ranges between 40 and 160 Tg y$^{-1}$ (Aselmann and Crutzen, 1989). The geographic information coupled with more flux measurements are therefore required to narrow the range of estimates. Methanogenesis is a temperature dependent process with a five fold increase for every 10$^\circ$C temperature increase. Based on past temperature anomalies and estimates of future warming by the year 2080, the CH$_4$ emissions from wetlands will amount to 3 times more than the values of year 1880 emissions (Burke et al., 1990). In addition to the stimulation of methanogenesis in hydrates, this composed of strong bonds of water molecules surrounding CH$_4$ molecules. Methane hydrates are most prevalent at depth in permafrost and in sea sediments. A tentative estimate of the CH$_4$ release from hydrates is 5 Tg CH$_4$ y$^{-1}$ (Cicerone and Oremland, 1988). The total area of artificially drained wetlands in temperate regions is 23 mha (being 6 percent of the temperate wetlands), of which 60 percent in Finland-USSR, 25 percent is Western and Central Europe and 7 percent in North America. Drainage of tropical wetlands during that period was only 4 percent and large areas of natural wetlands will be affected by land reclamation. Large parts of Amazonian wetlands may vanish, while in other places new wetlands will be created in the realization of hydroelectric power schemes. Extension of cattle farming in seasonally flooded or submerged savannas and reclamation of wetlands
is proceeding in many parts of South America, while in other tropical regions wet paddy cultivation often occurs in reclaimed wetlands.

2.3.2. Submerged soils

The chemistry of submerged soils is a subject of scientific and ecological interest. Its scientific interest springs from its applications in geochemistry, pedology, agriculture, limnology, oceanography and pollution control. The chemical changes are that when soils are saturated with water for a sufficiently long time to give the soil, distinctive gleyey horizons, resulting from oxidation–reduction processes. The characteristics of these soils are 1) partially oxidized ‘A’ horizon high in organic matter 2) mottled zone in which oxidation and reduction occurs alternatively and 3) permanently reduced zone which is bluish green in colour.

The largest portion of the gases usually found in higher amounts in submerged soils consists of CO₂, CH₄, and N₂ (Table-4). Within a few hours of soil submersion, microorganisms consume all the O₂ present in the water or trapped in the soil. Oxygen and other atmospheric gases can enter the soil only by molecular diffusion in the interstitial water. This process is found to be 10,000 times slower than diffusion in gas-filled pores (Ponnampertuma, 1972). N₂ is the major gas component in soil immediately after flooding. Its rapid evolvement soon after flooding possibly results from relative accumulation due to aerobic and anaerobic respiration of nitrate, if it is present in soil. N₂ seems also to be transported to the rhizosphere by the air-transporting system of the paddy plant (Yoshida, and Broadbent, 1975).

Paddy is the only crop plant, which can be grown under various degrees of submergence. Submerged conditions exhibit the characteristics of greater amount of soil
solution, reduced oxygen level, and reduced aerobic microbial activity and an altered chemical status of the soil.

Table-4 Range of gases in submerged soils

<table>
<thead>
<tr>
<th>Gas</th>
<th>Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>35-90</td>
</tr>
<tr>
<td>Methane</td>
<td>4-55</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>2-10</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0-9</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1-6</td>
</tr>
</tbody>
</table>

There are various changes that occur in submerged soils such as physical (depletion of \( \text{O}_2 \), accumulation of \( \text{CO}_2 \), compaction, bulk density, puddling, gaseous exchange and movement of water etc.), chemical (soil reduction and transformation of different nutrient elements etc.), physicochemical pH, electrical conductivite (Ec) and redox potential (Eh) etc and biological properties (decomposition of organic matter, mineralization and immobilization processes etc.) which are influenced by submergence (Das, 1996). The depletion of \( \text{O}_2 \) from the soil profile occurs and the microbes depend on the metallic elements for the energy and utilize the \( \text{O}_2 \) present in the metallic complex ion and reduce them. The physicochemical properties that are at the instance of submergence are 1) decrease in redox potential (Eh), 2) increase in pH of acid soils and decrease in pH of alkaline soils, 3) Increase in specific conductance and 4) Cation-exchange reaction involving \( \text{Fe}^{2+} \). Redox potential (Eh) is oxidation-reduction chemical reaction in which electrons are transferred from a donor to an acceptor. The electron donor looses electrons and increases its oxidation number or accepts electrons and gets reduced. The source of electrons for biological reduction is organic matter. The submerged soils may exhibit Eh potentials as low as \(-300\) to \(-400\) mv depending upon the type of soil, organic matter, iron and manganese content, pH and temperature. The understanding of the redox potential
will be helpful in studying the paddy-water-soil environment, which influences crop growth, nutrition and yield, thus in turn influence the methanogenesis processes. The critical redox potential for reduction of CO₂ into CH₄ is in the range of -200 to -280 mv.

2.3.3. Landfills

Anaerobic decay of collected municipal and industrial organic matter, which is dumped in landfills, add 30-70 Tg CH₄ y⁻¹ to the atmosphere globally. The largest emission currently comes from landfills in the industrialized world and this source has been increasing in recent decades but at present its rise is stagnating. Projections for the year 2000 suggest a doubling of waste generation in developing countries. Reduction of emissions from landfills may be achieved by gas harvesting or by recycling of solid wastes (Bingemer and Crutzen, 1987).

2.3.4. Ruminants and Termites

The global CH₄ emission by ruminant animals is 65-100 Tg y⁻¹ and cattle and buffaloes produce about 80 percent of this amount, the rest is from sheep (7 Tg y⁻¹) and wild ruminants (2-6 Tg y⁻¹). About 40 percent of the CH₄ produced by domestic animals are emitted in the developing countries, mainly in Asia, followed by South America and Africa. The major regions for CH₄ from cattle are North America (11 Tg y⁻¹), Europe (8 Tg y⁻¹) and the former USSR (7 Tg y⁻¹) (Crutzen and Graedel, 1986). Changing from animal protein to more plant proteins in human nutrition is a possible way of reducing these CH₄ emissions. Modifying feeding strategies and rumen processes and development of CH₄ inhibitors also merits attention (EPA, 1989). The CH₄ production by termites ranges from 10 to 100 Tg y⁻¹ (Cicerone and Shetter, 1981). Field measurements are
required here, since living conditions and type of nutrition of the numerous families of termites are completely different.

2.3.5. Biomass burning

The major sources of CH₄, which are closely related with land use are the burning of biomass, slash and burn agriculture (shifting cultivation) and burning of fuel wood. Seiler et al (1984) estimated that the CH₄ production from biomass burning increased from 41-74 Tg y⁻¹ in 1950 to 47-84 Tg y⁻¹ in 1960 and 53-97 Tg y⁻¹ in 1975 depending on the basis of the increasing population of shifting cultivators, increasing production of industrial and fuel wood and of food production. These estimates have recognized the large uncertainties and sources of variability, such as amounts of biomass burnt, types and conditions of burning. Growing populations will increase the demand for agricultural land and fuel wood and therefore, this source will probably continue to increase in the future. Possible ways to reduce this source are replacement of slash and burn agriculture by agro-forestry and alternative non-carbonaceous sources of energy (such as solar energy) to substitute fuel wood.

2.4. Factors affecting CH₄ production and emission from paddy soil

The production and emission of CH₄ in flooded paddy soils are controlled by many edaphic and agroclimatic factors such as redox potential, pH, temperature, organic matter content, (native or added), sulphate content, moisture regime, soil type and paddy cultivars. Besides, many cultural practices including application of fertilizer influence the rate of production and emission of CH₄ from flooded paddies. The influence of various factors on production and emission of CH₄ from paddy soils is reviewed in the following pages.
2.4.1. Climatic parameters

Various meteorological elements related to the heat balance within the paddy plant canopy affect CH₄ emission rates in paddy fields. In a study on effect of several micrometeorological parameters within the paddy canopy including hourly solar radiation, net radiation, soil heat flux, relative humidity, air temperature, water temperature, soil temperature, latent heat flux and sensible heat flux (Lee et al., 1996). This indicates that incoming energy flux and evapotranspiration from the plant canopy influenced CH₄ emission rates at the canopy level. CH₄ emission rates per unit leaf area showed the highest correlation with soil heat flux compared with the other elements (Lee et al., 1996). This observation suggested that solar energy plays an important role as a thermal energy source for CH₄ emission and that the amount of energy reaching the ground may be more important than previously thought in determining CH₄ emission.

2.4.1.1. Temperature

The tropical and subtropical regions are subjected to higher ambient temperature than that in temperate region. The ambient temperature would eventually influence the floodwater and the soil temperature in flooded paddy fields. It is well known that temperature strongly affects methanogenesis (Dunfield et al., 1993; Lindau et al., 1993) and that increasing temperature leads to higher CH₄ emission. The increase in temperature accelerates the decomposition of organic matter (Kirschbaum, 1995) which eventually increases the rate of emission of CH₄ and CO₂. CH₄ production rate at soil temperature of 30°C was higher by a factor of 2.5 to 3.5 than that at 17°C in flooded soil samples (Conrad 1996). Parashar et al. (1991) reported 10-30% increase in CH₄ fluxes with 1°C increase in soil temperature. At low temperature the growth of non-
methanogenic H₂-producing bacteria is suppressed restricting the supply of H₂ for methanogens. Most of the methanogenic isolates exhibit optimum growth at a temperature range of 30°C to 40°C (Vogels et al., 1988). Diurnal variations in CH₄ efflux from paddies have been positively correlated with soil temperature (Denier van der Gon and Neue, 1995; Neue et al., 1995; Shin et al., 1995, Wang et al., 1994). The relationship between the diurnal variation in CH₄ emission and soil temperature could be expressed by Arrhenius equation (Sass et al., 1991; Wang et al., 1997). The effect of temperature on CH₄ emission from paddy fields is probably due to its influence on the solubility of CH₄ in the soil solution and in flood water (Neue et al., 1995). Hosono and Nouchi (1997) suggested that temperature around the root greatly affects CH₄ transport process in paddy plants, and that the processes of the root greatly affects CH₄ transport through paddy plant.

2.4.1.2. Light

The role of light on CH₄ emission in paddies has not been clearly understood. King (1990) reported that CH₄ production and emission in natural wetlands were more pronounced in the dark than under light. Turner et al. (1992) observed a positive relationship between CH₄ emission, paddy yield and solar radiation. Seasonal emission rates of CH₄ and amount of paddy grain yield from individual fields were positively correlated with accumulated solar radiation for both straw-incorporated and control plots (Sass et al., 1992). A 1% increase in cumulative solar radiation is accompanied by a 1.1% increase in CH₄ emission and a 15% increase in paddy yield. Solar radiation and hence photosynthetic activity of the paddy plant correlate with CH₄ production and grain yield through partitioning of non-structural carbohydrates to the root system and grain
panicle. If photosynthates are proportionately partitioned to the root system, then the amount of plant derived substrates available for methanogenesis is directly associated with solar radiation (Sass and Fisher, 1998). CH₄ flux from paddy fields of Philippines was more pronounced in dry season compared to wet season (Neue et al., 1994). The elevated CH₄ production and emission in the dry season was related to higher solar radiation and biomass.

2.4.2. Edaphic factors

CH₄ efflux varies from field to field as well as at different sites of the globe suggesting the role of soil as an important determinant in CH₄ emission. Redox potential, pH, soil type, salinity /acidity, clay mineralogy, organic matter content and soil amendments are the important soil factors affecting CH₄ efflux from paddy soils. CH₄ production potential of soil is largely influenced by its physico-chemical and biological characteristics. Neue et al. (1990) outlined a number of soil characteristics not favourable for CH₄ production that includes: (i) electrical conductivity of >4 dS cm⁻¹, (ii) acidic soil reaction, (iii) ferritic, gibberitic, ferruginous or hydroxide mineralogy, (iv) >40% of kaolinitic or halloysitic clay and (v) <18% clay content in the fine earth fraction if the water regime is epigamic. These characters are generally found in paddy soils like Oxisols, most of the Ultisols and some of the Aridisols, Entisols and Inceptisols. However, relationship of CH₄ production and emission to dynamic soil properties are well established (Neue et al., 1997).

2.4.2.1. Soil redox potential

Redox potential of soils is one of the major factors controlling CH₄ production and emission in paddy soils. CH₄ is produced in the soil following submergence in a
thermodynamic sequence after reduction of NO³⁻, Mn⁴⁺, Fe³⁺ and SO₄²⁻ (Visser et al., 2002). In a laboratory study with paddy plants grown in soil suspension at controlled redox values, CH₄ production increased 10 fold as redox potential decreased from -200 mV to -300 mV (Kludze et al., 1993). CH₄ production was enhanced by the intensity of soil reduction, and methanogenesis in the presence of available organic matter, was stimulated only at redox levels of -200 mV or below (Kludze and DeLaune, 1994). Methanogens produce CH₄ generally at redox potential of -200 mV to -250 mV (Bouwman, 1991).

2.4.2.2. Soil pH

pH is an important parameter influencing CH₄ production in flooded soil. Methanogens are mostly neutrophilic and can grow over a narrow pH range 6.0 to 8.0 (Neue and Roger, 1993) but, they may also exist in extreme alkaline conditions (Oremland et al., 1982). Production of CH₄ in paddy soil takes place at near neutral pH (Bouwman, 1991; Neue, 1993). Parashar et al. (1991) found that CH₄ emission from some Indian paddy fields reached the peak at soil pH of around 7.5 to 8.5. According to Ponnamperuma (1972), pH of most acid and alkaline soils stabilizes at near neutrality few days after submergence. Acharya (1935) reported that the decomposition of added organic matter in a flooded soil was highest at pH of 7.5 to 8.0 with peak production of gases such as CH₄ with accumulation of higher amount of organic acid. There is evidence that the H₂ utilizing methanogenic bacteria cease to function at pH below 6.0 (Boopathy and Mariappan, 1984). According to Wang et al. (1993), 0.2 unit increase in pH over that of neutral soil suspension pH increased CH₄ production by 11 to 20% at-250
mV and 24 to 25%-200mV. A significant correlation existed between CH₄ and soil pH with optimum CH₄ production at pH 6.9 to 7.2 (Wang et al., 1993).

2.4.2.3. Soil Salinity

A soil is called saline if the electrical conductivity of its saturation extract exceeds 4 dS.m⁻¹. Salinity is one of the key soil factors influencing CH₄ production and its emission from paddy (Bachelet and Neue, 1993; Denier van der Gon and Neue, 1995; Neue and Sass, 1994) and soils having higher electrical conductivity are not suitable for CH₄ formation (Neue et al., 1990). Saline soils represent about 15% of the arid and semiarid lands of the world irrigated areas. Out of 7 m ha of salt affected soils in India, coastal saline soils occupy about 2.1 m ha. Paddy, a moderately salt tolerant crop, is widely grown in these coastal saline soils with moderate success (Neue et al., 1998; Siddiq and Shiva Kumar 1998). According to Garrity et al. (1986), about 2 m ha of inland saline soils are used for paddy cultivation in India and Pakistan. While non-sulphate salts like chloride, carbonate and bicarbonate are predominant in soils of non-coastal salt affected regions, salts notably sulphates and chlorides are dominant in the coastal saline soils.

2.4.2.4. Carbon sources

Studies using C-isotope techniques demonstrate two distinct metabolic path-ways of biological CH₄ formation: CO₂ reduction that uses hydrogen gas, fatty acids or alcohols as a hydrogen donor and transmethylation of acetic acid or methyl alcohol or amines and sulphides, which does not involve CO₂ as an intermediate (Vogels et al., 1988) and the equations are
Reduction of CO₂

\[ 4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \] ...

Acetic acid

\[ CH_3COOH \rightarrow CH_4 + CO_2 \] ...

Methanol

\[ 4CH_3OH \rightarrow 3CH_4 + CO_2 + 2H_2O \] ...

Amines

\[ 4(CH_3)_2NH + 3H_2O \rightarrow 3CH_4 + CO_2 + 4NH_4 \] ...

Sulphide

\[ 2(CH_3)_2S + 2H_2O \rightarrow 3CH_4 + CO_2 + 2H_2S \] ...

Submerged soils provide appropriate conditions for generating CH₄ under anaerobic conditions. The different carbon containing compounds transformed in to methane under submergence especially in the paddy soils. A limited number of simple compounds provide energy and carbon for the growth of methanogenic bacteria. Three main sources supplies the carbon for methanogenic bacteria in flooded Paddy soil: the original soil, the root litter and exudates from growing paddy plants (Oremland, 1988). The mechanism of CH₄ fermentation was investigated using C¹⁴ tracer technique and found two metabolic pathways as shown in eq.1 and eq.2. In case of Paddy fields, the mid-season drainage increases the soil Eh and reduces the CH₄ formation. The importance of CH₄ transport gained momentum that the transport through plant serenchemys was maximum as compared to diffusion and bubble transport (Minami and Yagi, 1988).

The exogenous supply of organic material to the soil, whether it is the crop residues or as a manure, appears to be the single most important contributor to CH₄ production. Yagi and Minami (1991) found that application of paddy straw at rates of 6-9 t/ha increased CH₄ emission rates to about 1.8-3.5 fold. However, application of compost prepared from paddy straw did not appreciably enhance CH₄ fluxes, indicating the importance of labile carbon in CH₄ formation. Methane reduction rates have been
shown to be linearly correlated with water soluble carbon in the soil or with readily mineralizable carbon and the method of application also affects methanogenesis (Sass et al. 1991). More CH4 is released and the emission is more sporadic when organic matter is placed at a greater depth. A linear relationship between CH4 production and rates of application of paddy straw was observed in crowley paddy soil (Wang et al., 1992).

Root exudates and plant litter may provide substrates for both methanogenic and methanotrophic bacteria. Root exudates consist mainly of carbohydrates, organic acids, amino acids and phenolic compounds (Martin and Heilman 1986). Root exudation enhances CH4 emissions from three week old paddy plants in laboratory experiments (Raimbalt et al. 1977). In addition to root exudation, dead plants contribute to the organic carbon pool from above-ground plant and root litter and these additional sources of substrates are the main causes of temporal and spatial variation in CH4 production and emission (Schutz et al. 1989).

2.4.3. Agronomic practices

Farmers adopt different agronomic practices in diverse paddy growing areas. The agronomic practices which are associated with paddy growing are land preparation, water management, sowing and transplantation, plant protection measures and harvest affect CH4 emission (Bouwman, 1990). Agronomic practices such as ploughing, puddling, leveling, tillage, transplanting, harrowing, weeding, harvesting and pre-flooding and post-harvest drying can release soil-entrapped CH4 by ebullition through soil disturbances (Denier van der Gon et al., 1992; Minami and Neue, 1994, Neue, 1993). CH4 is released in considerable amounts immediately following drainage after harvest, but its emission decreases subsequently concomitant with an increase in CH4.
oxidation (Denier van der Gon et al., 1992; Neue et al., 1994). The practice of direct sowing (wet and dry seeding), instead of transplanting may lead to decrease in the CH₄ emission (Neue, 1993). Deep water cultivation is being practiced in pokkali and kuttanad soils of Kerala, where in the influence of tidal waves determines the water level and thus in turn determines the CH₄ emission from these soils. Although the initial pH of the soils in low, the saline water even if salinity is low, increase the pH to near neutral or towards neutral thus increase in the CH₄ emission.

Fig 1. Fate of Methane in Rice Fields
2.4.3.1. Water management

The flood water regime is the single most important determinant for CH₄ production and emission from paddy fields (Neue, 1993; Yagi et al., 1996). Soil flooding is by irrigation or by rain water which restricts the oxygen supply to the soil in the paddy fields thereby creating conditions favorable for anaerobic decomposition of organic matter and subsequent formation of CH₄ (Conrad, 1996). According to Neue (1993), the deep water paddy emits less CH₄, in spite of high rate of production, attributed to the decreased transport and release of CH₄ due to submergence of aerial parts of the paddy plants. CH₄ production and emission can be negligible in upland paddy fields, due to lack of permanent flooding of the soil (Bouwman, 1991; Hogan and Bratz, 1990; Minami and Neue, 1994). On the contrary, the irrigated paddy fields can be a major source of CH₄ emission due to continuous flooding (Adhya et al., 1994; Minami and Neue, 1994; Neue and Roger, 1993; Yagi, 1997). Midseason drainage, a popular practice in Japan to alleviate anaerobic toxicity to paddy plants, can reduce total emission rates of CH₄ during paddy season by 42-45% (Yagi, 1997). However, while reducing CH₄ emission, emission of N₂O is increased by midseason drainage (Yagi et al., 1996). Mishra et al. (1997) also reported that continuous flooding emitted more CH₄ than that in alternate flooding and drying. Similarly CH₄ emission rates were considerably low in intermittently irrigated field plots as compared to that in continuously flooded plots (Yagi et al., 1994).
2.4.3.2. Organic manure

Application of organic substrates, including green manures, often increases the CH$_4$ flux from flooded paddy (Denier van der Gon and Neue, 1995; Wassmann et al. 1996; Yagi and Minami, 1990). It is also reported that CH$_4$ emission from green manure applied field plots was higher than in urea applied plots (Denier van der Gon and Neue 1995). Soil C:N ratio is an important parameter affecting CH$_4$ production in flooded soils (Wang et al., 1992). The higher CH$_4$ emission due to fertilizer application has often been attributed to the enhanced plant biomass (Minami, 1994). The addition of fresh organic sources to the paddy fields increases the availability of methanogenic substrates and thereby enhances CH$_4$ production and emission (Neue, 1993; Neue et al., 1994). However, the relationship between CH$_4$ emission and organic input in the paddy field is not clear (Sass and Fisher, 1998). Tsutsuki and Ponnamperuma (1987) reported a distinct stimulation of CH$_4$ production in flooded soils amended with fresh leguminous green manure (Gliricidia sepium stems and leaves), but not when amended with composted paddy straw. But according to Wang et al., 1992 application of paddy straw (0.5, 1.0, 1.5 and 2.0% w/w) to the flooded soil samples increased CH$_4$ production significantly almost in proportion to the rate of paddy straw application. In greenhouse and laboratory studies, CH$_4$ emission increased by 3-12 times from soils amended with organic sources (paddy straw and cellulose) over that of the control (Delwiche and Cicerone, 1993; Satpathy, et al., 1997). The effects of different mineral fertilizers on CH$_4$ efflux from flooded paddies are not consistent and even contradictory in some cases (Minami, 1995; Wassmann et al., 1993). In Asia, urea and ammonium sulphate application account for 80% and 6% of the N fertilizers respectively, used in paddy fields. Urea retarded CH$_4$
efflux by 18% from paddies in an Italian soil over that of unfertilized fields, while, CH₄ emission increased with increased urea application in Lousiana paddy fields (Lindau et al., 1991). Addition of ammonium to the flooded water increases CH₄ efflux from paddy field by inhibiting CH₄ oxidation in the soil-flood water interface (Conrad and Rothfuss, 1991). Ammonium sulphate and potassium nitrate at 120 kg.N.ha⁻¹ reduced CH₄ emissions by 55% and 59%, respectively, over that of urea-N application (Lindau, 1994). Unlike nitrogenous fertilizers, not much information is available on other mineral fertilizers containing sulphur and phosphorus. In a greenhouse experiment, CH₄ emission from flooded soil was suppressed when amended with gypsum (Delwiche and Cicerone, 1993). In a recent field study, application of single superphosphate (SSP) distinctly inhibited CH₄ emission from a flooded field planted to paddy (Adhya et al., 1998), but the effect was more related to the sulphate content of SSP. In subsequent laboratory incubation studies, CH₄ production depended on the source of P applied and the sulphate content of the P sources. CH₄ emission from paddy field was considerably retarded by the application of phosphogypsum when compared to that of urea amended plots (Metra-Corton et al., 1996).

2.4.3.3. Cropping system

Continuous submergence of paddy fields is practiced in some tropical areas where irrigation water and the climate allow the cultivation of two or even three crops of paddy in a year. Under these conditions, the soils remain constantly under reduced condition leading to higher CH₄ emissions (Trolldenier, 1995). On the other hand, growing a dryland crop which can cause for sufficient aeration of the soil and increase the redox potential (Neue, 1993), that, in turn, may reduce CH₄ emission. In wetland paddy-based
cropping systems, the wet season paddy crop may be followed by an upland crop (Neue, 1993). Permanent submergence of paddy fields causes high CH₄ emissions as redox potential decreases up to -300 mv, whereas growing an upland paddy crop alternating with lowland paddy crop may increase the redox potential to more than -100 mv, and thus reduce CH₄ emission (Neue, 1993). In case of lowland paddy fields of Kerala, the redox potential varies from -220 to -40 mv emitted high CH₄ emissions and these soils are rich in organic carbon content.

2.4.3.4. Paddy cultivars

More than 90% of CH₄ fluxes from paddy soils are mediated by the paddy plant via a passive transport mechanism (Denier van der Gon and van Breemen 1993). There is a considerable literature on cultivar variation in CH₄ emission from flooded paddies (Satpathy et al., 1998). Although paddy varieties differ in emitting CH₄ to the atmosphere, CH₄ emission was not correlated to plant characters such as tiller number, shoot length, shoot weight and root biomass (Husin et al., 1995). Apart from the direct role of the paddy plant in gas transport, certain inherent physiological characteristics including oxidizing power of paddy roots can also affect the fate of CH₄ in the root region before they are transported to the atmosphere. Increasing oxidation of the rhizosphere can lead to decreased CH₄ emission due to increased inhibition of methanogenesis and enhanced CH₄ oxidation in the rhizosphere (Denier van der Gon and Neue 1996). However, higher gas transport capacity may leads to not only more CH₄ transported (increasing emission), but also increased O₂ transport to the root zone (decreasing emission). Paddy varieties also differ with regard to the root exudates pattern and the amount of carbohydrate contents in the root exudates (Ladha et al., 1986). Root
exudates and the decaying root during senescence are used as substrates for methanogenic bacteria (Holzapfel-Pschorr et al., 1985, 1986; Nouchi et al., 1990). One of the mitigation strategies for reducing CH₄ emission is to opt for paddy cultivars with low CH₄ emission potential, but with higher grain yield (Neue, 1993; Sass et al., 1994; Swaminathan, 1994; Wassmann et al., 1993).

2.4.3.5. Chemical inhibitors including pesticides

Metabolic inhibitors can also inhibit CH₄ production and thereby reduce CH₄ emission from paddy fields. Nitrification inhibitors such as nitrapyrin and acetylene are reported to inhibit CH₄ production in soils (Bronson and Mosier, 1991; Lindau et al., 1993). Application of calcium carbide, also a nitrification inhibitor, is an effective means of mitigating CH₄ emission from paddy field without any adverse effect on paddy grain yield (Banerjee et al., 1990). Lindau et al. (1993) found that CH₄ emission from paddy fields decreased by 35% and 14% following application of encapsulated calcium carbide and dicyandiamide, respectively. Wax coated calcium carbide and nitrapyrin effected a significant reduction in CH₄ emission in paddies (Keerthisinghe et al., 1993). Swaminathan (1994), recommended the use of neem cake, a nitrification inhibitor, to reduce CH₄ emission from paddy fields. The inhibitory effect of various chemical compounds on methanogenesis. 2-Bromoethane-sulphonic acids (BES), an analogue of coenzyme-M of methanogens, is a specific inhibitor of methanogens (Oremland and Capone, 1988). Many chlorinated CH₄ analogues like methylene chlorine and carbon tetrachloride can also inhibit methanogenesis. Several benzene ring compounds (Patel et al., 1991) and nitrogen containing compounds are known to suppress methanogenesis in pure cultures and in soil. Chlorinated hydrocarbons like methylene chloride, chloroform
and carbon tetrachloride inhibit methaneogenesis. Chloroform effect a total inhibition in
CH₄ production in paddy soil without affecting the glucose turnover (Krumback and
Conrad, 1991). Heavy metals (cadmium) suppress CH₄ production and emission from
paddy fields (Mishra et al., 1999). Tin chloride and certain other tin compounds inhibit
certain methanogens in pure cultures (Boopathy and Daniels, 1991). Addition of Fe³⁺ to
iron deficient paddy soil, in low concentration, reduces CH₄ emission (Wassmann et al.,
1993). Although several studies have been conducted to investigate the role of pesticides
on soil biochemical processes of importance to soil fertility (Domsch and Paul, 1974),
very little information is available on the effect of pesticides on CH₄ production and its
fate in paddy ecosystem.

Most of the agricultural chemicals, applied directly to the soil or eventually
reaching the soil upon foliar application, may affect microbial transformations of
importance to soil fertility (Rao et al., 1993) and environment. Organochlorine
insecticides DDT (2,2-dichlorodiphenyl trichloro ethane) is known to inhibit CH₄
production as well as oxidation in culture medium (McBride and Wolfe, 1971). In a
recent study, application of commercial formulation (an isomeric mixture) of
hexachlorocyclo-hexane (HCH) to flooded fields planted to paddy significantly inhibited
CH₄ production (Satpathy et al., 1997). Similarly commercial formulation of carbofuran,
a carbamate insecticide, when applied at a rates of 2 kg and 12 kg. ha⁻¹ to a flooded field
planted to paddy, resulted in significant inhibition of CH₄ emission. Interestingly, in
laboratory incubation studies, carbofuran inhibited net CH₄ production when applied at
low rates (5 and 10 µg.g⁻¹ soil) but stimulation was there when applied at a rate of 100
µg.g⁻¹ soil (Kumaraswamy et al., 1998). Pesticides can also affect the process of CH₄
oxidation in soils. Application of 2,4-D, a commonly used herbicide at 5 µg.g⁻¹ soil increased the time for CH₄ removal while at concentration of about 25 µg.g⁻¹ soil CH₄ oxidising activity was completely inhibited (Arif et al., 1996). HCH inhibited CH₄ oxidation significantly at 5 µg.g⁻¹ soil and almost completely at 10 µg.g⁻¹ soil. Oxidation of CH₄ was, however, stimulated by carbofuran when applied at low rates and inhibited when applied at a rate of 100 µg.g⁻¹ soil (Kumaraswamy et al., 1998).

2.5. Spectral reflectances of vegetation

All the objects on the earth reflect, absorb, transmit or radiate energy in the form of electromagnetic waves (Fig. 2). The physico chemical properties of the object, determine the characteristics of the spectrum and have distinct spectral pattern or signature of its own. Measurements of the radiance of each resolution element of the ground in appropriate narrow wavelength bands can be used to produce multi-spectral images (Fig. 3). Electronic remote sensing systems consist of three basic modules (White, 1977). The main module is sensor system (video camera, scanner, radar) and the other two are tape recorder and computerized image processor. The sensor system covers the electromagnetic spectrum from 0.32µm to 1m (Rudd and Taylor, 1980) depending on the sensing objectives. Most vegetation and soils can be identified by reflectance or emittance in 0.25 to 15µm wavelength (Park, 1970). The spectral reflectance to crop and other vegetation canopies is determined by different physical properties (Bauer, 1985) as mentioned in Table. 5.
Table 5

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Spectral range</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visible (0.4-0.7µm)</td>
<td>Biochemical &gt; Biophysical &gt; Physical</td>
</tr>
<tr>
<td>2</td>
<td>Near infrared (0.7-1.3µm)</td>
<td>Physical &gt; Biophysical &gt; Biochemical</td>
</tr>
<tr>
<td>3</td>
<td>Middle infrared (1.3-3µm)</td>
<td>Biophysical &gt; Physical &gt; Biochemical</td>
</tr>
<tr>
<td>4</td>
<td>Thermal infrared (3-14µm)</td>
<td>Biophysical &gt; Physical &gt; Biochemical</td>
</tr>
<tr>
<td>5</td>
<td>Microwave (1mm-1cm)</td>
<td>Physical &gt; Biophysical &gt; Biochemical</td>
</tr>
</tbody>
</table>

Fig. 2-4

Fig. 2: The electromagnetic spectrum (after Lifshitz and Klein, 1960)

Fig. 3: Observed absorption spectrum of earth's atmosphere (after Blaha, 1987)

Fig. 4: Significant spectral response characteristics of grass vegetation (Horne, Grove and Davis, 1975)
Vegetation absorbs electromagnetic energy in the visible spectrum (0.4-0.7μm) and uses it for photosynthesis, where as in the near infrared spectral wavelengths (0.7-1.35μm), the reflectance is very high due to internal reflections between the walls of the hydrated cells and the intercellular spaces of air in the mesophyll of the leaves (Myers, 1983). The green light (0.52-0.57μm) is reflected with a slightly higher intensity than the blue and red light (0.6-0.7μm) and the human eye is particularly sensitive to the radiation coming from the green band of the spectrum. The major absorption bands at 1.45, 1.95, 2.60μm are due to water in the leaf. With decrease in water content, middle infrared reflectance at these wavelengths increases. Healthy vegetation canopies are characterized by lower reflectance in the red band and a higher reflectance in the near infrared band (Fig.4).

Field spectrometry was used to establish fundamental relationship between the spectral reflectance characteristics of an in-situ plant canopy and the biomass of the green portion of the canopy (Tucker et al., 1975). Shibayama and Akiyama (1989) measured the spectral reflectance of rice canopies in the visible reflective, near infrared and middle infrared wavelength regions. The relation between radiometric data and leaf area index and middle infrared wavelength regions. The relation between radiometric data and leaf area index and above ground dry phytomass was investigated during eleven development periods and suggested that, inclusion of middle infrared band data improved the production of total biomass.

These wavelengths in green at 550μm, once in the red at 670μm, one in the near infrared at 870μm and two in the middle infrared, at 1650μm and 2200μm. Were
Kondratyev and Pokrovsky (1979) proved that bands in the green, red and near infrared regions are optimal if information above vegetation is to obtained. Applications of different spectral regions to remote sensing are shown in Fig. 4.

2.6. IRS WIFS (Wide Field Sensor) data

Studies to determine the feasibility of identifying crop species and varieties using single data remote sensing imagery have been carried out in Kansas by Morain and Coiner (1970) and in Switzerland by Steiner (1970). WIFS data have been used for a number of studies such as crop discrimination and inventory (Oza et al., 1996). Single data WIFS analysis has been used for crop production estimates. The crops covered are Kharif rice and wheat and this aims at State level forecasts (Anonymous, 1998).

Townshend and Justice (1990) in their study proved that, coarse resolution data need not be a severe limitation. The daily coverage of IRS-WIFS data is suitable for studying vegetation dynamics, though the spatial resolution of 188.3km at nadir makes it virtually impossible to distinguish individual fields and the measured radiance is accounted by the entire land cover mix in the area. The study by Azzali (1991) has shown that, instead of covering the entire geographic area of administrative unit such as a district, taking average VI over predominantly agricultural lands, provide improved crop monitoring capabilities. The complementary role is because, the WIFS has two spectral channels which are similar to the bands 2 and 4 of Landsat MSS, 3 and 4 of TM, 3 and 4 of LISS and 2 and 3 of HRV covering important spectral regions for vegetation analysis. The 1st band in both the sensors cover the chlorophyll absorption while the second band is located in the high infrared reflectance spectral region. In case of WIFS data, a combination of large pixel size and relatively broad spectral bands increases the chance
of data averaging (Jensen, 1996). Kasturirangan et al (1996) stated that high frequency of
the availability of the WiFS data due to the short re-visit period facilitated the monitoring
of crops. Studies by Navalgund et al (1996) revealed that WiFS data was found to be
suitable for deriving regional information on the spatial distribution of rabi rice crops
grown in the Godavari delta and pulse crops cultivated in the Kharif rice fallow fields of
Krishna delta of Andhra Pradesh and Palakkad and kottayam districts of Kerala state,
India. The temporal WiFS data has been found to be useful in monitoring cropping
patterns and systems (Brig and Ahuja, 1998). Roy and Agarwal (2000) opined that wide
field sensors for regional scale mapping of IRS 1DC/1D provides the advantage of
covering a very large area in a single instantaneous field of view avoiding any
illumination difference. Suitability of such moderate resolution data for regional
vegetation as compared to AVHRR data marks better choice for monitoring and research.
The pixel size of 188 meters suits regional scale mapping. It has high temporal resolution
i.e., five days and large area coverage 810 x810 sq.kms., and is helpful in assessing crop
condition and developing improved yields models for large areas.

Table -6

2.7. Remote Sensing of agricultural crops

The first remote sensing (RS) based study specifically aimed at crop area estimation
was undertaken in 1974-75 under ISRO-ICAR Viz., Agricultural Resources Inventory
Survey Experiment (ARISE) project, in Anantapur district of Andhra Pradesh and in
Patiala district of Punjab to estimate acreages under various crops using aerial colour
infrared (CIR) photography. Remote sensing techniques were successfully used in Crop
Acreage and Production Estimation project for crops like rice, sorghum, soyabean, wheat,
Table 6. SENSOR CHARACTERISTICS OF IRS SATELLITES

<table>
<thead>
<tr>
<th>IRS-1A</th>
<th>IRS-1B</th>
<th>IRS-1C</th>
<th>IRS-1D</th>
<th>IRS-P2</th>
<th>IRS-P3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Altitude (km)</strong></td>
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<td>904</td>
<td>817</td>
<td>737</td>
<td>817</td>
</tr>
<tr>
<td><strong>Launch date</strong></td>
<td>17.05.1988</td>
<td>29.08.91</td>
<td>28.12.1995</td>
<td>29.09.1997</td>
<td>15.10.1994</td>
</tr>
<tr>
<td><strong>Sensors &amp; Resolution (m)</strong></td>
<td>LISS-I (72.5), LISS-II (36.25)</td>
<td>LISS-I (72.5), LISS-II (36.25)</td>
<td>PAN (5.8), LISS-III (23.5)</td>
<td>PAN (5.8), LISS-III (23.5, 70.5(MIR))</td>
<td>LISS-II 32.74 (across track)</td>
</tr>
<tr>
<td><strong>Number of bands</strong></td>
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<td>4</td>
<td>4 (LISS-III)</td>
<td>4 (LISS-III)</td>
<td>4</td>
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<tr>
<td><strong>Repetition (days)</strong></td>
<td>22</td>
<td>22</td>
<td>24</td>
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</tr>
<tr>
<td><strong>Swath (km)</strong></td>
<td>148 (LISS-III), 74 (LISS-II)</td>
<td>148 (LISS-III), 74 (LISS-II)</td>
<td>141 (LISS-III), 70 (PAN)</td>
<td>148 (LISS-III), 70 (PAN)</td>
<td>130 (WIFS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>810 (WIFS)</td>
<td>810 (WIFS)</td>
<td>810 (WIFS)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200 (MOS)</td>
</tr>
</tbody>
</table>
groundnut, rapeseed mustard, cotton and jute/mesta and showed successful results (SAC 1990, Venkataratnam et al., 1993). Quarmby et al. (1993) derived the NDVI data related to crops and used to estimate yields of cotton, rice and maize successfully closer to 90% of the official figure. The estimate of crop yield is possible from NDVI, 50-100 days before harvest. Frolking et al. (1999) conducted a study on agricultural land use in China for comparison of area estimates from ground-based census and satellite-borne remote sensing. Estimates of total crop land area, rice acreage and irrigated crop land area in China from land cover maps derived from optical remote sensing in 1992-93 and country level agricultural census data for 1990 were compared at national, regional, provincial and county scales. For topographically flat north and central China there was high correlation between remote sensing and census-based estimates of paddy rice area and total irrigated cropland area. Realizing the need to have more comprehensive, multiple forecasts for major crops of the country at national, state and district levels, recognizing the importance of agro-meteorology and conventional forecasting system, a programme viz., Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL) has been conceptualized and being institutionalized (Navalgund, 2002). Acquisition of ground truth forms an indispensable part in the interpretation of remotely sensed data. Knowledge and information regarding the topography, climate, land cover, soils, cropping patterns, land use patterns etc., of the area to be visited is needed for proper planning of ground truth visits (Venkataratnam, 1984). Lilliesand and Keifer (1994) stressed on the use of ground truth reference data in remote sensing applications. Huang Jing Feng et al. (2000) stated the importance and necessity of
selecting an accurate geometric correction method, which is easier for non-professional users for rice growth monitoring and yield estimation.

2.8. Rice identification and acreage estimation—Indian Scenario

Based on the crop calendar and proper selection of single data imagery, district level acreage estimation of summer rice in Cachar district of Assam was estimated by visual interpretation of Landsat MSS data by Singh (1983). One of the first studies using digital techniques was, carried out in India by Kalubarme (1986) in Cuttack and Puri districts of Orissa using Landsat MSS digital data. He identified training sites representing paddy cultivation based on ground truth data and aerial photographs, and showed that remote sensing estimates were close to conventional survey reports. Nageswara Rao and Rao (1987) attempted the use of the remotely sensed data for different rice canopy patterns in India using Landsat MSS False Colour Composites and rice crop was identified with an accuracy of 90% in areas having >50% of cropped area under rice and where rice occupied less than 50% it was identified with an accuracy of 75%. Parihar et al. (1987) demonstrated the procedure of rice acreage estimation in Orissa using single data satellite data during peak weak period of rice in Kharif season using supervised classification method and two stage stratified random sampling approach. Availability of high quality data from IRS-1A since March/April 1988 has proved another dimension and greater impetus to crop production forecasting studies in India. Kalubarme and Vyas (1998) carried out a study for rice acreage estimation in Midnapur district of West Bengal. Parihar et al (1990) estimated rice acreage for three Kharif seasons in Orissa and for on Kharif season in Tamil Nadu and estimates was satisfactory at state levels, but at district/group of districts showed high deviations. Venkataratnam and Ravi Sankar
(1992) identified and estimated acreage of rice and sugarcane and irrigated dry crops in both rabi and kharif seasons in Nizamsagar command area, using IRS-1A digital data.

Creation of forest mask

Studies to determine the feasibility of identifying crop species and varieties using single data remote sensing imagery have been carried out in Kansas by Morain and Coiner (1970) and in Switzerland by Steiner (1970). WiFS data have been used for a number of studies such as crop discrimination and inventory (Oza et al., 1996). Townshend and Justice (1990) in their study proved that, coarse resolution data need not be a severe limitation. The daily coverage of IRS-WiFS data is suitable for studying vegetation dynamics, though the spatial resolution of 188.3 km at nadir makes it virtually impossible to distinguish individual fields and the measured radiance is accounted by the entire land cover mix in the area. The study by Azzali (1991) has shown that, instead of covering the entire geographic area of administrative unit such as a district, taking average VI over predominantly agricultural lands, provide improved crop monitoring capabilities. The complementary role is because, the WiFS has two spectral channels which are similar to the bands 2 and 4 of Landsat MSS, 3 and 4 of TM, 3 and 4 of LISS and 2 and 3 of HRV covering important spectral regions for vegetation analysis. The 1st band in both the sensors cover the chlorophyll absorption while the second band is located in the infrared region. In case of WiFS data, a combination of large pixel size and relatively broad spectral bands increases the chance of data averaging (Jensen 1996, Everett et al., 1993). Kasturirangan et al (1996) stated that high frequency of the availability of the WiFS data due to the short re-visit period facilitates the monitoring of crops. Studies by Navalgund et al (1996) revealed that WiFS data was found to be
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a single instantaneous field of view avoiding any illumination difference. Suitability of
such moderate resolution data for regional vegetation as compared to AVHRR data marks
better choice for monitoring and research. The pixel size of 188 meters of WiFS data
with fairly high temporal resolution i.e., five days and large area coverage $810 \times 810$ sq.
Kms., is helpful in assessing crop condition and developing improved yield models for
large areas.

2.9. Identification of Agricultural crops and Acreage Estimation

Remote sensing techniques were successfully used in Crop Acreage and
Production Estimation project for crops like rice, sorghum, Soyabean, wheat, groundnut,
rapeseed mustard, cotton and jute/mesta and showed successful results (SAC 1990,
Venkataratnam et al., 1993)(Fig. 16). Quarmby et al (1993) derived the NDVI data
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area, rice acreage and irrigated crop land area in china from land cover maps derived
from optical remote sensing in 1992-93 and country level agricultural census data for 1990 were compared at national, regional, provincial and country scales. For topographically flat north and central China there was high correlation between the two approaches, whereas in some other areas was only moderate to weak correlation between remote sensing and census based estimates of paddy rice area and total irrigated cropland area. Realizing the need to have more comprehensive, multiple forecasts for major crops of the country at national, state and district levels, recognizing the importance of agro-meteorology and conventional forecasting system, a programme viz., Forecasting, Agricultural Output using Space, Agro-meteorology and Land based observations (FASAL) has been conceptualized and being institutionalized (Navalgund, 2002).