



ICAR Sponsored Winter School on

Advanced Techniques for Assessment of Soil Health, GHG emissions and Carbon Sequestration in Rice under Changing Climatic Scenario and Mitigation Strategies



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Training Manual
ICAR Sponsored Winter School
on

**“Advanced Techniques for Assessment of Soil Health, GHG
emissions and Carbon Sequestration in Rice under Changing Climatic
Scenario and Mitigation Strategies”**

11th Nov. to 1st Dec., 2014

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Foreword

Increasing human population, decreasing resource base, environmental degradation and climate change pose serious threats to agriculture ecosystem. Agriculture and society in general, is challenged to develop strategies for sustainable management of soil resources that sustain life on earth. The thin layer of soil covering the surface of the earth represents the difference between survival and extinction for most land-based life. Like water, soil is a vital natural resource essential to civilization but, unlike water, soil is nonrenewable on a human time scale. This is a conclusion supported by archeological evidence suggesting that soil degradation was responsible for extinction or collapse of the many earlier civilizations. The soil health is more so important in the context of climate change; the general public and scientific communities are increasingly focusing on the impact of climate change on the terrestrial ecosystem with particular attention being paid to GHGs emission. Mitigation of these GHGs is an important goal for the humanity. Soil organic carbon pool is the largest among the terrestrial carbon pools. The restoration of SOC pool in the arable land represents a potential sink for carbon dioxide. Management and enhancement of SOC with reduction in GHG emissions is important for sustainable agriculture. To monitor carbon changes in soil and biotic pool and estimate GHG emissions from different production systems require improved accuracy in sampling and measurement methodologies. As the emissions of GHG and carbon sequestrations are of international significance, measurement processes need to be unbiased and more accurate measurement will be more broadly accepted. Soil performs both production and environmental functions. The challenge ahead in sustaining life on planet earth will require new vision, holistic approaches for managing soil resources in the context of climate change, and a renewed partnership between science and society. It requires all the ingenuity of science to work for both humanity and the natural ecosystems. The welfare of present and future population depends on the soil quality and resilience under agriculture. In order to insure that the processes performed by soils are sustained, tools for assessing soil processes, GHG emissions and carbon sequestration for evaluating the effect of management practices on soil processes are needed.

The Winter School on ‘Advanced Techniques for Assessment of Soil Health, in Rice under Changing Climatic Scenario and Mitigation Strategies’ being organized at this Institute for 21 days starting from 11th November, 2014 will update the knowledge of the natural resource management scientists about the recent developments and strategies for soil health assessment, GHG emissions and carbon sequestration in rice under changing climatic scenario for sustainable rice production in the country. Hope this training manual that contains the relevant information will serve many purposes for the scientific community for whom it is intended.



(T. Mohapatra)

Director

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1. Soil Organic Carbon Sequestration Potential in Indian Agriculture

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Abstract

The importance of soil organic carbon (SOC) to the physical, chemical, and biological aspects of soil quality is well recognized. SOC is a part of the global C cycle and, world SOC pool estimated up to 1.0 m depth is twice as large as that in the atmosphere and nearly three times that of biotic pool. There is increasing recognition that the rate of emissions of CO₂ can be mitigated by capturing it from the atmosphere, storing and maintaining in soil through a process called soil organic carbon sequestration. Soils of India have lower SOC and hence there is a large sink capacity for atmospheric CO₂ sequestration. Many of the management practices that are effective in increasing SOC in agricultural soils also improve productivity and profitability, conserve the resource base and protect the environment. In order to support a role for soil organic carbon in emissions trading, there is an urgent need to resolve several key research issues and quantifying interactions of SOC sequestration with soil emissions of other GHG, namely N₂O and CH₄ and developing soil carbon models that can account for locally relevant agricultural management practices.

Introduction

Following the unprecedented expansion and intensification of agriculture in India, there is clear evidence of a decline in the organic carbon (OC) contents in many soils as a consequence; while on the other hand it has been reported that good farming practices such as balanced fertilization and addition of crop residues either maintains or results in build up or depletion of Soil Organic Carbon (SOC) stock (Swarup *et al.* 2000; Kong *et al.* 2005). The process of decline of organic matter is accelerated by the process of nutrient depletion, soil erosion and other forces of land degradation. In India, addition of organic matter was considered so important that numerous studies with organic manures were conducted. The primary purpose was to determine their nutrient equivalence in comparison to chemical fertilizers. Despite the fact that organic manures contain almost all the essential plant nutrients and produce other non-nutrient benefits also, their value was principally assessed in terms of N only (Katyal 1993; Tandon 1997). The benefits of soil organic carbon are linked closely to the fact that it acts as a storehouse for nutrients, is a source of soil fertility, and contributes to soil aeration, thereby reducing soil compaction. Other benefits are related to the improvement of infiltration rates and the increase in storage capacity for water. Furthermore, it acts as energy source for soil microorganisms. On the other hand intensive rice-based systems as reported from long-term experiments are showing symptoms of 'fatigue', witnessed by stagnating or declining yields (Dawe *et al.* 2000; Narang & Virmani 2001; Ladha *et al.* 2003). The depletion of soil fertility, associated with a reduction in quantity and/or quality of soil organic matter are some of the reasons attributed to this decline in yield (Ram 1998; Dawe *et al.* 2003).

Irrespective of its potential benefits to productivity and profitability, organic carbon might be sequestered by vegetation and soils, as a possible way of mitigating some detrimental effects of global climate change. Soils, and managed agricultural soils in particular, represent a potentially significant low to no cost sink for greenhouse gases (GHGs) (Lal 2004a; Pacala & Socolow 2004). The great majority of agronomists and soil scientists agree that most agricultural soils can store more carbon and

even a modest increase in carbon stocks across the large land areas used for agriculture would represent a significant GHG mitigation. Nevertheless there are much uncertainty and debate on the total potential of soils to store additional carbon, the rate at which soils can store carbon, the permanence of this carbon sink, and how best to monitor changes in soil carbon stocks (Sanderman *et al.* 2010).

This paper primarily discusses global organic carbon stocks with special reference to India, functions of organic carbon *vis-a-vis* agriculture, SOC sequestration and mitigation potential, commoditization of soil organic carbon, stability and turnover of SOC, management options to make agricultural land to store additional SOC along with a summary of field evidence for stocks changes in India. This is followed by a discussion of some of the difficulties in accurately measuring change in SOC stocks.

Soil organic carbon

Soils contain large amounts of carbon in both organic and inorganic forms. Organic C is found in soils in the form of various organic compounds, collectively called soil organic matter (SOM). SOM includes all living and non-living organic material in all stages of decomposition. The turnover rate of SOM varies due to complex physical, chemical and biological interactions in soil. World soil estimated up to 1 meter depth comprises about 1550 Pg (Pg = Petagram = 1×10^{15} g = billion ton) as organic C is about 2 times the atmospheric pool of 780 Pg, and about 2.5 times the biotic pool of 620 Pg (Lal 2009). The sheer size of the soil carbon pool and the annual flux of carbon passing through the soil are two of the reasons that SOC can play a significant role in mitigating GHG emissions. Historically, approximately 78 Pg C has been lost from the global soil pool due to land-use conversion for agriculture with approximately 26 Pg attributed to erosion and 52 Pg attributed to mineralization (Lal 2004b). These large historic losses and the concomitant potential to return to pre-clearing SOC conditions are precisely the reason many researchers believe there is great potential for agricultural soils to sequester large amounts of atmospheric CO₂ relative to current SOC levels.

The Indian situation

Total SOC pool in soils of India is estimated at 21 Pg to 30 cm depth and 63 Pg to 150 cm depth. The SOC pool in soils of India is 2.2% of the world pool for 1 m depth and 2.6% to 2 m depth (Lal 2004c). It is home to 1.1 billion or 16% of the world population and also supports 500 million domestic animals. The land resources comprises 329 m ha of geographical area with only 161.8 m ha of arable land (11.8% of the world) of which 57.0 m ha (21.3% of the world) is irrigated, 68.5 m ha of forest and woodland (1.6% of the world), 11.05 m ha of permanent pasture (0.3% of the world) and 7.95 m ha of permanent crops (6.0% of the world). Approximately 12 m ha of land is under one or more than one form of degradation arising due to water erosion, wind erosion, salinity, alkalinity, etc. The large land base has a potential to sequester C and enhance productivity while improving environment quality.

Soil organic matter in agriculture

Soil organic matter plays an important role in many physical, chemical and biological processes in soil; its depletion has numerous adverse ecological and economic consequences. Whereas increase in SOC is accompanied by increase in crop yield and productivity both under fertilized and unfertilized field through increase in plant nutrients in soil; increased microbial biomass, decreased soil bulk density; improved aggregate structure; increased water-holding capacity and hydraulic conductivity; increased cation-exchange capacity; reducing the magnitude of degradation processes

such as erodibility, crusting, compaction and runoff leading to resource use efficiency (Lal 2004a; Amezketa 1999; Blair *et al.* 2006; Verrel and Obrien 1996; Whitbred *et al.* 1998). Proper management of SOC is important to food security and the protection of marginal lands (Scherr 1999). The mean residence times of soil organic matter vary from less than one year to a few hundred years, if properly managed, the soil and plant have a significant potential to act as temporary carbon sinks. The human-induced carbon sinks, however, require a continuous effort, not only in order to be established, but also to be maintained.

Soil organic carbon sequestration and GHG mitigation potential

Agriculture contributes 29 % of CO₂ equivalent GHGs (1415 mt) in India. A substantial portion of emitted CO₂ is sequestered in agricultural biomass and soil. The contribution of Indian agriculture towards GHGs budget is not as large as anticipated earlier. Another potent GHG is methane which is emitted in copious amounts through inundated paddy cultivation. Emission of methane from rice paddies in India is estimated at 2.4 to 6 Tg (Tg = Teragram = 1 x 10¹²g) out of the world total emission of 25.4 to 54 Tg from all sources and 16 to 34 Tg from rice cultivation. The average methane flux from rice paddies ranges from 9 to 46 g m⁻² over a 120- to 150-day growing season.

The potential of agriculture (excluding bioenergy) to absorb large quantities of atmospheric CO₂ through soil carbon sequestration which has strong synergy with sustainable agriculture is widely being put forward as one of the mitigating options for climate change (Lal 2002; Post *et al.* 2004). Thus, one of the more promising ways to reduce the rate of rise in atmospheric CO₂ is to encourage management policies that promote C sequestration in vegetation and ultimately in soils (Idso & Idso 2002). Soils of India have lower SOC and hence there is a large sink capacity for atmospheric CO₂ sequestration. The IPCC 2nd Assessment report estimated that the global potential CO₂ mitigation by agriculture could be in the range of 0.9–2.5 Gt C yr⁻¹ (Gt = Giga tone = 1 x 10⁹ t) including 0.5–1.6 Gt C yr⁻¹ from biofuel production, 0.1 Gt C yr⁻¹ from fuel savings and a limited restoration of previously cultivated wetland soils, the remaining 0.4–0.9 Gt C yr⁻¹ mitigation potential from increased soil carbon sequestration. This does not mean that a sequestration potential of several hundreds of Tg C yr⁻¹ would not be worth the trouble to realize, since such an improved soil humus management provides lots of other agricultural and environmental benefits.

It is estimated that globally, over the next century, agricultural soils could sequester 40 to 80 billion metric tons of carbon (Cole *et al.* 1997). Total potential of SOC sequestration in India is 17 to 23 Tg C year⁻¹ including 7 to 10 Tg C year⁻¹ for restoration of degraded soils and ecosystems, 5 to 7 Tg C year⁻¹ for erosion control and 6 to 7 Tg C year⁻¹ for adoption of recommended management practices (RMP) on agricultural soils (Table 1). The RMP related estimations are based on eco-region wise extrapolation and the rates of SOC sequestration from data of long-term experiments reported in the literature (Swarup 1998). There could always be a possibility to have forward revision of these figures through adoption of varied innovative management practices and precision in estimation. The recent works on rate of carbon sequestration under different eco-regions in different cropping system with varied soil management options (Purukayastha *et al.* 2008; Kundu *et al.* 2007; Banger *et al.* 2009; Majumdar *et al.* 2008; Padre-Tirol *et al.* 2007; Nayak *et al.* 2009) are some examples of technical potential of SOC sequestration. Similarly, different land degradation figure has been reported by different agencies due to use of different scale and methodologies, the first approximation of harmonized statistics shows that about 120.72 M ha as waste land and degraded land (Yadav &

Sarkar 2009), there is a need for its rehabilitation by different land use and soil management practices which could be an important sinks for carbon.

Table 1. Total potential of carbon sequestration in soils of India (Lal, 2004c)

Process	Potential (Tg C year ⁻¹)
A. Soil organic carbon (SOC)	
Restoration of degraded soils	7.2–9.8
Agricultural intensification	5.5–6.7
B. Secondary carbonates	21.8–25.6
C. Erosion control	4.8–7.2
Total	39.3–49.3

Soil organic matter is therefore one of our most important national resources; it's unwise exploitation has been devastating; and it must be given its proper rank in any conservation policy. There is a need for determining a just value of soil organic carbon as commodity which can be traded like any other farm product. Under valuing a resource can lead to its abuse. It is important to identify criteria for determining the societal value of soil C for soil quality enhancement and ecosystem service, and using it for trading purposes. Carbon credits and its marketing are one such international attempt to mitigate the growth in concentrations of GHGs by commoditizing the carbon. Soil and biotic carbon is treated as a tradable commodity under Clean Development Mechanism (CDM) of the Kyoto Protocol. Article 3.3 of the Protocol explicitly mentions emissions from sources and removals by sinks as a direct consequence of human intervention affecting land-use changes, deforestation, reforestation and afforestation undertaken since 1990. Article 3.4 identifies agricultural land as a possible C source which should be included in the emission inventories that are prepared regularly by the UNFCCC Parties. However, the Protocol does not include provisions for national crediting for C sequestration in agricultural soils. During the first five-year commitment period (2008-2012) of the Kyoto Protocol, afforestation and reforestation projects will be eligible for crediting under the CDM. Other sink activities, such as forest conservation and soil C sequestration, will not be eligible. Still, soil C sequestration could become eligible for crediting under the CDM during subsequent commitment periods (Ringius 2001).

One carbon credit is equal to one ton of carbon dioxide, or in some markets, carbon dioxide equivalent gases. Certified Emission Reductions (CERs) are a type of emissions unit (or carbon credits) issued by the CDM Executive Board for emission reductions. Greenhouse gas accounting for soil carbon in agriculture under the Kyoto Protocol is based on the rate of change in carbon stock. Therefore, if conventional practice causes a decline and the new practice reduces the rate of loss, credit can be earned. This is a real reduction in emissions that could be counted under an emissions trading scheme. It is estimated that conversion of all crop lands to conservation tillage in United States could sequester 25 Gt C over next 50 years. Some farmers have started receiving payments from coal burning utilities in emission trading arrangements brokered through Chicago Climate exchange (Baker *et al.* 2007) and payment are based on the premises that conservation tillage sequester the equivalent of 0.5 t CO₂ ha⁻¹ year⁻¹. Small and marginal farmers constitute major chunk of land holders in India. Aggregating small land holders (1-5 acre farm size) to make a meaningful transaction is a challenge for paying the benefit of carbon credits. However reputed organization can

verify the activity undertaken for C sequestration or reducing C emission and award the VERs (verified emission reduction) - As ICRISAT does in India, which in turn can be traded.

Stability and turnover of SOC

Three main mechanisms of SOC stabilization have been proposed: (1) chemical stabilization, (2) physical protection and (3) biochemical stabilization (Christensen 1996; Stevenson 1994). Largely chemical stabilization is the result of physico-chemical interaction of SOC with soil minerals through the process of cation bridging, ligand exchange and hydrogen bonding. It depends on various factors, including the characteristics of the organic matter, reactivity and specific surface of soil minerals, base-cation status, presence of Fe and Al oxides, pH, and redox conditions (Sollins *et al.* 1996; Baldock & Skjemstad 2000; von Lutzow *et al.* 2006). Physical protection of C is intimately tied to processes responsible for creation, turnover, and stabilization of soil aggregates at multiple, often hierarchical, scales (Tisdall & Oades 1982; Jastrow & Miller 1998; Six *et al.* 2004) which make the substrate spatially inaccessible to microbes and enzymes. However, its relevance is mainly limited to topsoil horizons. Biochemical stabilization is understood as the stabilization of SOC due to its own chemical composition (e.g. recalcitrant compounds such as lignin and polyphenols) and through chemical complexing processes (e.g. condensation reactions) in soil. There is an important class of biochemically recalcitrant compounds, generically termed black carbon, formed as result of fire (Lehmann *et al.* 2008) that can constitute a significant fraction of SOC in most soils.

SOM cannot increase forever; it can only reach a certain balanced level (Hassink 1996). The equilibrium point of SOC over a long time can be affected by many factors including climate, vegetation type, nutrient availability, disturbance, land use, and management practices (Six & Jastrow 2002). Although tropical conditions favor SOC decline, its level seldom reaches a stage of complete exhaustion. Rather, SOC-levels in cultivated soils tend to attain a steady state, described as a lower equilibrium limit (Buyanovsky & Wagner 1998). There is also an upper limit for SOC that is the equilibrium content typical for a virgin ecosystem. If SOC loss by erosion is negligible, then SOC level in a properly managed soil fluctuates between these two extremes. Cultivation alone tends to stabilize the SOM at the lower equilibrium level. But SOC additions and fertilizer applications tend to shift the equilibrium towards the upper limit.

Hence similar management practices may result in positive sequestration in one soil that is far from its maximum C stabilization level, while no change in another soil that is much closer to its upper equilibrium point. With the same input of organic material in terms of quantity and quality, clay soils contain more organic matter than sandy soils (Jenkinson 1988). The annual change of SOC is equal to the annual mineralization amount minus the annual accumulation. Thus, a zero annual change of SOC can be interpreted as having reached a balance because total mineralization must be equal to total accumulation. Therefore, if the actual annual mineralization rate can be determined, it is possible to calculate the requirement of organic materials to reimburse the SOC lost by mineralization in the field, thereby maintaining SOC equilibrium (Chun-Yan *et al.* 2006).

Management practices and soil carbon sequestration

Many promising practices for soil carbon sequestration have been identified (Kimble *et al.* 2002). Long term studies have shown that improved fertilizer management, manuring and compost application, residue incorporation, crop rotation, green manuring, reduced tillage, adjusting irrigation method, restoration of waste land and Agro-forestry enhance C storage. These practices not only promote sustainable agriculture but also mitigate the impact of climate change through both carbon

sequestration and minimized emissions of GHGs. A single land use or management practice will not be effective at sequestering C in all regions (Lal *et al.* 1998). The cropping systems and the management practices that could provide C input higher than the above critical level are likely to sustain the SOC level and maintain good soil health in the subtropical regions of the Indian subcontinent (Mandal *et al.* 2007). For example, a legume-based cropping system accumulates carbon at a lower rate than a cereal-based system, as its residues decompose more rapidly, and a soil under continuous flooded rice (rice-rice) accumulates carbon at a higher rate than under a rice-wheat rotation that is aerobic for part of the time. Long term experiments on rice based system has shown that balanced fertilization with NPK, however, caused an enrichment (9.3-51.8% over the control) of SOC, its extent being influenced by the cropping systems (Mandal *et al.* 2007). Similarly in long term rice-wheat experiment conducted in different agro-climatic zones of India, we estimated that application of 50% NPK + 50% N through FYM in rice, 100% NPK in wheat (NPK + FYM), sequestered 0.39, 0.50, 0.51 and 0.62 Mg C ha⁻¹ year⁻¹ over control (no NPK fertilizers or organics), respectively (Figure 1) at Ludhiana (Trans Gangetic Plains), Kanpur (Upper Gangetic Plains), Sabour (Middle Gangetic Plains) and Kalyani (Lower Gangetic Plains).

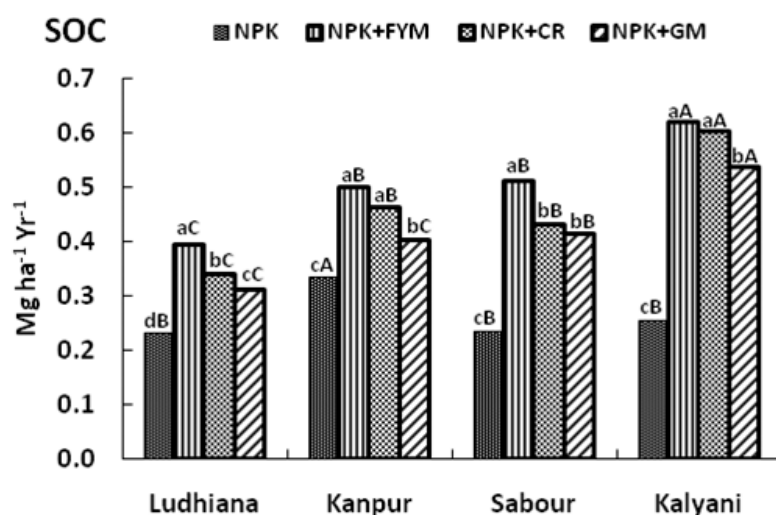


Fig.1 Changes in soil organic carbon pool (Mg ha⁻¹ Yr⁻¹) in different integrated nutrient management system over the control under different agro-climatic situation in Indo-Gangetic Plains. (Means with the same lower case letters are not significantly different in different treatments at same centre, means with the same uppercase letters are not significantly different in a treatment at different centres)

A number of long term studies have been conducted in India on different cropping system with INM in which the primary purpose was to determine their nutrient equivalence in comparison to chemical fertilizers, due to lack of initial data on the parameters required for estimation of sequestration potential reporting have been made on the changes SOC over the control (without N-P-K and manuring) treatment in some of the cases as shown in Table 2.

Table 2. Soil Organic Carbon Sequestration by Use of Cropping system, Manure, Compost and Fertilizer in India

Cropping System	Nutrient management	SOC Change/ sequestration Mg C ha ⁻¹ yr ⁻¹	Place	Years	Reference
Jute – Rice - Wheat	NPK+FYM	0.49*	Barrackpore	34	⁶⁵ Majumdar et al.(2007)
	NPK	0.34*			
Soybean - Wheat	NPK+FYM	0.90	Almora	30	²⁷ Kundu et al.(2007)
	NPK	0.32			
Maize – Wheat - Cowpea	NPK+FYM	1.38	New Delhi	10	²⁶ Purukayastha et al. (2008)
	NPK	0.94			
Rice - Wheat	NPK+FYM	0.99*	Kalyani	19	²⁹ Majumdar et al. (2008)
	NPK+PS	0.89 *			
	NPK+GM	0.82*			
	NPK	0.65*			
Rice - Rice	NPK +Compost	0.33	Cuttack	20	³¹ Nayak et al. (2009)
	NPK	0.14			

**Rate of sequestration /change in SOC calculated over the control treatments.*

In India each year 19.6 million tonnes of straw of rice and wheat are burnt if used as recycled biomass, this potentially translates into 3.85 mt of organic carbon, 59,000 tonnes of nitrogen, 2,000 tonnes of phosphorous and 34,000 tonnes of potassium and could be one of the potential options for improving the SOC stocks of soil. Saline and sodic soils are of widespread occurrence in the arid and semiarid regions of northern India, limiting the productivity of more than 2.5 million ha of otherwise arable lands in the Indo-Gangetic plains (Abrol & Bhumbla 1971). Afforestation and reclamation through agroforestry systems have been reported to increase soil organic matter content and improve the biological properties of sodic soils (Singh 1996; Singh and Singh 1997). When sodic soil was reclaimed and restored, we estimated soil organic carbon sequestration rate of 0.826 Mg C ha⁻¹ year⁻¹ under Prosopis juliflora plantations and 0.689 Mg C ha⁻¹ year⁻¹ under rice-wheat system (Figure 2).

Converting harvestable biomass to more recalcitrant C rather than completely combusting it offers a new approach to terrestrial sequestration as a potential side benefit of bioenergy production and is called Biochar or Biomass carbonization. With low-temperature pyrolysis, biomass is carbonized by heating under low-oxygen conditions while producing liquid and gaseous biofuels. Since combustion would not be complete, char-like substances would also be produced (Post et al. 2009). There is a scope for converting 19.6 million tonnes of straw of rice and wheat which are burnt annually in India into chemically stable forms – through biochar a clean process where heat and combustible gases are captured and used and C is stored in soil.

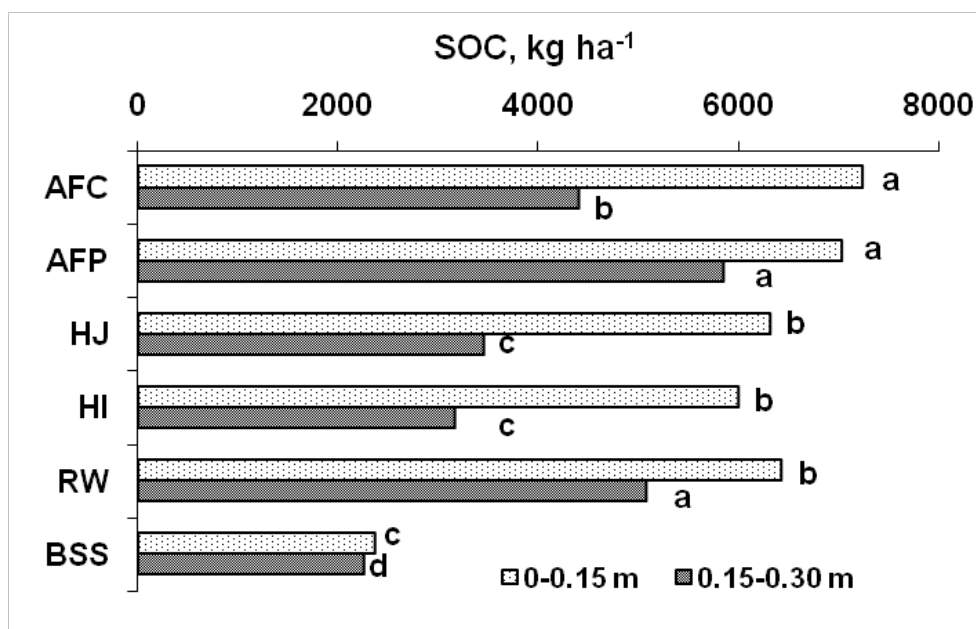


Fig 2. C and N sequestration rates ($\text{Mg ha}^{-1} \text{ year}^{-1}$) taking barren soil as reference after 10 years of land use and soil management systems (RW: Rice-wheat cropping system; BSS: Uncultivated barren sodic soil; AFP: Agro-forestry plantation of *Prosopis juliflora*; AFC: Agro-forestry plantation of *Casuarina equisetifolia*; HI: Horticultural plantation of *Tamarindus indica* locally called Imli; HJ: Horticultural plantation of *Syzygium ciminii*, locally called Jamun. Means with the same letters are not significantly different in same soil depth)

Recent developments in genomics provide an unprecedented opportunity to identify genes, enzymes, biochemical pathways, and regulatory networks that underlie rate-limiting steps in C acquisition, transport, and fate—and thereby yield new approaches to enhance terrestrial C sequestration. An investment in these new approaches to increase biomass production in agricultural crops and fast-growing trees in managed plantations is required to tap the potentials.

Measuring and monitoring change in SOC

To monitor carbon changes in soil and biotic pool, there is a need to improve the accuracy and costs of soil carbon sampling and measurement methodology. Stocks of organic C in soils are determined from two variables, namely SOC concentration and bulk density. Determination of organic carbon concentration is usually done by wet oxidation (Walkley & Black 1934) or dry combustion (Wang & Anderson 1998). The wet oxidation method is known to underestimate the amount of organic C in most samples so a correction factor needs to be applied. The magnitude of the correction factor is known to vary across soil types. Despite more accurate methods being available, the Walkley-Black technique is still used in some laboratories, particularly in India. Significant progress has been achieved during the past 10 years toward refining, enhancing, and adapting the method for measuring and monitoring soil carbon sequestration at field and regional scales. It is now possible to measure soil carbon changes as small as 1 Mg C ha^{-1} in a period of 3 years (McConkey et al. 2000) or estimate it with the use of simple or complex simulation models (Paustian et al. 1997; Smith 2007). Measurement needs to be correct and the measurement process needs to be unbiased, and more accurate measurements will be more broadly accepted. Recently several instruments have been developed for in situ measurements of soil carbon which include laser-induced breakdown

spectroscopy (Cremers et al. 2001), inelastic neutron scattering (Wielopolski 2000), and diffuse reflectance IR spectroscopy (Christy et al. 2006) in the near-infrared and mid-infrared wavelength regions of 400–2500 and 2500–25,000 nm, respectively. Measurement and monitoring approaches using current or advanced methods need to be integrated to field-level and regional scales using computer simulation and remote sensing on some dynamic and geographically appropriate basis (Paustian et al. 1997; Smith 2007). For trading purpose uncertainties in measurement, transparency in reporting, and verifiability should be accounted for when monitoring carbon sink activities.

Monitoring soil carbon changes at the project level are potentially costly and highly variable in carbon stocks on micro and macro scales due to multiple pools and small incremental changes anticipated. Hence estimation of soil carbon change could be undertaken by: 1) using SOC stock change values for specific practices reported in literature based on research studies; or 2) using process-based models of soil carbon dynamics, parameterised from experimental data; or 3) through a combination of baseline measurement to assess the vulnerability of soil carbon pools, and modeling informed by baseline measurements and understanding of the factors driving soil C dynamics. RothC and Century (Cerri et al. 2004), have been demonstrated for several agricultural systems/ soil type combinations in India and abroad.

Summary and conclusion

Many of the management options discussed in the paper tend to increase overall sustainability of existing agricultural systems and as such are required to be adopted in respective agro-ecological situations in India. As a society, we will have to assess whether or not it is acceptable to compromise productivity of certain crops because they are not C neutral or net carbon storing. Overall, it is suggested that farming practices that increase soil C accumulation without compromising yield should be encouraged. However, due to the complex nature of agriculture in India, quantitative predictions of SOC sequestration rates will likely always entail a large degree of uncertainty. However many mitigation options in the agricultural sector have numerous co-benefits in terms of food security, environmental sustainability and farm profitability, we believe that governmental policies that promote adoption of these best management practices should be pursued regardless of the final status of agricultural soils in any carbon pollution reduction scheme. Continued efforts should be made for evaluating different agro- technologies having high sequestration potential and low global warming potential without compromising the yield. For proper accounting at regional and national scale, there is a need for robust modeling coupled with detailed measurements in representative systems combined with verification of management practices and yields via reporting and remote sensing with some economic discounting to factor in verification uncertainty. Developing mechanisms and procedures for carbon trade negotiations and formulation of protocols under CDM projects for making other sink activities in our country such as forest conservation and soil C sequestration eligible for carbon credit is needed so that the farmers and land managers can be benefited.

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2. Greenhouse Gas Emission, Climate Change and Rice Production

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Introduction

Global demand for food is rising because of population growth, increasing affluence and changing dietary habits. The UN/FAO forecasts that global food production will need to increase by over 40% by 2030 and 70% by 2050 (FAO, 2009). Yet globally, water is anticipated to become scarce and there is increasing competition for land, putting added pressure on agricultural production. In addition, climate change will reduce the reliability of food supply through altered weather patterns and increased pressure from pests and diseases. There is big concern about the impacts of climate change and its variability on agricultural especially on rice production worldwide. Current research suggests that, C₃ crops like rice would respond positively to elevated CO₂ but the associated impacts of high temperatures, altered patterns of precipitation, and possibly increased frequency of extreme events, such as drought and floods, will likely combine to depress yields and increase production risks in many parts of the world. Under such circumstances developing countries are more vulnerable to climate change than developed countries, because of the predominance of agriculture in their economies, the scarcity of capital for adaptation measures, their warmer baseline climates, and their heightened exposure to extreme events.

Rice is the most important food crop of the developing world and the staple food for more than 60% of the Indian population. India needs to produce 120 million tons by 2030 to feed its one and a half billion plus population by then. Nonetheless, these challenges also offer opportunities to develop and promote rice production systems that have greater environmental, economic and social resilience to changing climate and associated risks. The strong trends in climate change already evident, the likelihood of further changes occurring, and the increasing scale of potential climate impacts give urgency to address adaptation strategies more coherently.

Green house gas emission

The atmospheric concentration of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) and other greenhouse gases (GHGs) has increased since the industrial revolution (1750 A.D.) due to natural and anthropogenic activities. The atmospheric concentration of CO₂ has increased from 280 parts per million by volume (ppmv) in 1750 to 394 ppmv in 2012 and is currently increasing at the rate of 1.9 ppmv year⁻¹ (NOAA, 2012). Atmospheric CH₄ concentration has increased from about 715 to 1826 parts per billion by volume (ppbv) in 2012 over the same period and is increasing at the rate of 7 ppbv year⁻¹ (IPCC, 2007; EPA, 2013). Similarly, the atmospheric concentration of N₂O has increased from about 270 ppbv in 1750 to 325 ppbv and is increasing at the rate of 0.8 ppbv year⁻¹ (IPCC, 2007; EPA, 2013). The current radiative forcing of these three GHGs are 1.46, 0.5 and 0.15 W m⁻² for CO₂, CH₄ and N₂O, respectively (IPCC, 2001).

The ability of greenhouse gases to absorb radiation differs in the earth. The ability of these GHGs to trap heat depends on its capacity to absorb and re-emit radiation and on how long the gases remain in the atmosphere. In order to compare emissions from different sources, the global warming potential (GWP) of each gas is equated to the GWP of CO₂. For example, the GWP of 1 t (tonne) of CH₄ is 24.5 times more potent than 1 t of CO₂ over a 100 year period (IPCC, 2007).

Agriculture is considered to be one of the major anthropogenic sources of atmospheric GHGs (Lal, 2000). Carbon dioxide is the most important anthropogenic GHG and is mostly originated from industrial activities, deforestation, burning of fossil fuels, land use changes and microbial decomposition of soil organic matter. On the other hand, the increase in CH₄ concentration is predominantly due to agriculture and fossil fuel use while the increase in N₂O is primarily due to agriculture.

Carbon dioxide exchange between terrestrial ecosystems and the atmosphere is one of the key processes that affect atmospheric CO₂ concentration (Conway et al., 2008). In order to assess the role of terrestrial ecosystem in the global CO₂ budget at present, and to predict its changes in the future under global warming, long-term observation of CO₂ exchange has been done in various ecosystems in the world. Worldwide variation in CO₂ concentrations is determined by the balance between sources and sinks (Vinogradova et al., 2007). Photosynthesis and natural respiration processes are linked to the superimposed effects of other factors such as fossil fuel combustion for energy purposes (specifically energy and transport sectors) and land-use changes (Buchmann, 2000; Artuso et al., 2009). Carbon dioxide concentrations are also influenced by atmospheric processes in the boundary layer which affect their transport and dispersion (Ramonet et al., 2010). Soil CO₂ efflux is usually measured with the help of soil respiration chamber or manual closed chamber and using gas chromatography (Bhattacharyya et al., 2012).

Methane has strong infra-red and heat absorption band characteristics and worldwide its increasing concentration in the atmosphere is believed to contribute towards change in atmospheric chemistry as well as global warming (IPCC, 2007). Methane is presently the second most important GHG accounting for 15-20% of the anthropogenic radiative forcing. The major sources of CH₄ production are the rice paddies, ruminants, landfills, natural wetlands and sediments (Zhu et al., 2007). Tropospheric CH₄ has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Although the tropospheric CH₄ is increasing continuously, the rate of increase of CH₄ emission has started to decline during the past two decades (IPCC, 2007). Flooding of irrigated rice fields produces anaerobic soil conditions which are conducive to the production of CH₄ (Neue, 1993; Tseng et al., 2010). Methane emission from agriculture is usually measured by manual closed chamber method using gas chromatography or by micrometeorological method (Lapitan et al., 1999; Hendriks et al., 2008).

Nitrous oxide is generated by the microbial transformation of N in soils and manures, and is often enhanced where available N exceeds plant requirements, especially under wet conditions (Oenema et al., 2005). The rice paddies act as sources of major N₂O emission upon nitrogenous fertilizer (e.g. urea) application. Nitrogenous fertilizer appears to be the single most important factor controlling N₂O emission from flooded rice fields. Wide variation in N₂O production exists in different rice soils. Nitrous oxide is usually measured by manual closed chamber method using gas chromatography or by micrometeorological method (Galle et al., 1994).

Greenhouse gas emission from agriculture

Agriculture accounts for about 15% of the global emission of greenhouse gas (GHGs) (World Bank, 2007), making it the second largest source after the energy sector (63%). Because of this large contribution, continued GHG emission from agriculture will exacerbate global warming. Agriculture is responsible for emission of all three major GHGs, carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). They have different life time and global warming potential (GWP) (Table 3). In particular its, CH₄ and N₂O emission account for about 50 % and 60%, respectively, of global

anthropogenic emission of those GHGs (Smith *et al.*, 2007). Moreover, although the CO₂ budget is almost in balance, CO₂ fluxes between agricultural lands and the atmosphere are large in both directions (120 Pg C yr⁻¹) (Denman *et al.*, 2007). Part of the CO₂ efflux derives from decomposition of soil organic matter. Carbon storage in soils has been estimated to be 1500 Pg C, which is double that in the atmosphere (730 Pg C) (Prentice *et al.*, 2001). To sustain soil carbon storage, it is quantitatively important to reduce CO₂ emission from agricultural soils. Soil carbon sequestration occurs when the amount of carbon input into the land is larger than that emitted to the atmosphere. Soil carbon sequestration has been estimated to account for 89% of the total mitigation potential of agricultural GHG emission, followed by reduction of CH₄ (9%) and N₂O (2%) emission from soils (Smith *et al.*, 2007).

Table 3. Global warming potential and other properties of agriculturally important greenhouse gases in the atmosphere.

GHGs	Pre-1750 concentration (ppm)	Current tropospheric concentration (ppm)	Annual increase (%)	Atmosphere life time (years)	GWP (100 years time horizons)	Increased radiative forcing (Wm ⁻²)	Contribution to global warming (%)
CO ₂	280.0	379.0	0.5	Variable	1	1.46	40-50
CH ₄	0.715	1.740	0.8	12	23	0.50	20-25
N ₂ O	0.270	0.319	1.0	114	296	0.15	5-10

Greenhouse gas emissions from rice

Agriculture accounts for about 15% of the global emission of greenhouse gases (IPCC, 2007). The CO₂, CH₄ and N₂O budget in agricultural fields are affected by structure and dynamics of anaerobic and aerobic conditions in the soil and due to other agricultural management practices. CH₄ emission increases under continuous flooding while N₂O is primarily emitted in pulses after fertilization and strong rainfall events. Various rice growing environments show wide spatio-temporal variability in CH₄ emission. Land-use practices and N-fertilizer applications greatly influence N₂O emission from soil.

In rice fields, CO₂ flux exhibited a clear diurnal pattern ranging from -38 to 10 µmol CO₂ m⁻² s⁻¹ during full heading stage of rice (70-79 DAT) in Boro rice growing season of 2006 in Bangladesh (Hossen *et al.*, 2007). The total carbon budget integrated over the cropping period showed that the net ecosystem CO₂ exchange (NEE) in flooded rice fields (-258 g C m⁻²) was about three times higher than that of aerobic rice fields (-85 g C m⁻²) in IRRI, Philippines (Alberto *et al.*, 2009). The daily CO₂ flux values in rice ecosystem in Taiwan ranged from -17.03 µmol CO₂ m⁻² s⁻¹ to 12.85 µmol CO₂ m⁻² s⁻¹. Fluxes of CO₂ were always positive during night hours, average value being 2.76 µmol CO₂ m⁻² s⁻¹; whereas during the daytime the flux was found to be negative with an average value of -1.22 µmol CO₂ m⁻² s⁻¹ (Tseng *et al.*, 2010).

CH₄ emission varied from 14 to 375 mg m⁻² d⁻¹ in most rice growing areas in the world. Annual global estimation of CH₄ emission from flooded rice fields accounted for 7.08 Tg based on the biomass (Sinha, 1995). In Thailand, Wassmann *et al.* (2000) estimated 99 Kg CH₄ ha⁻¹ season⁻¹ from deepwater rice fields. Average CH₄ emission rates ranged from 11-364 mg m⁻² d⁻¹ from rice fields of Beijing, China (Wang *et al.*, 2000). It is affected by water regimes, soil amendments,

cultivars and type of fertilizers used. In India the mean CH₄ emission from rice fields ranged between 3.5-4.2 Tg yr⁻¹ (Parashar et al., 1996). Bhatia et al. (2004) estimated 4.7 Tg yr⁻¹ CH₄ emission from the Indian paddy fields with the highest emission of 1.379 Tg yr⁻¹ from the irrigated rice fields.

The tentative global estimate of N₂O emission from agricultural land is 2.3-3.7 Tg N yr⁻¹ (Bouwman, 1990). Chao et al. (2000) estimated around 0.67 Mg N₂O-N yr⁻¹ from the paddy fields of Taiwan. N₂O emission from the Chinese rice fields ranged from 39-164 mg N m⁻² hr⁻¹ (Chen et al., 1997). Agriculture related activities account for around 90% of the total N₂O emissions in India (Garg et al., 2001). Parashar et al. (1998) estimated the total N₂O emission from Indian paddy and wheat fields to be 199-279 Gg per annum. Sharma et al. (1995) estimated N₂O emissions from irrigated and upland paddy fields of India at 4-210 and 2-10 Gg yr⁻¹, respectively. N₂O emission from Indian agricultural field was estimated to be 0.08 Tg annually (Bhatia et al., 2004). The irrigated rice-wheat system is a significant source of N₂O, emitting around 15 kg N₂O-N ha⁻¹ yr⁻¹ (Aulakh et al., 2001).

The DNDC model was applied for estimation of GHG emissions from rice fields in India using a compiled soil - climate - land use database. Continuous flooding of rice fields (42.25 million ha) resulted in annual net emissions of 1.07–1.10, 0.04–0.05 and 21.16–60.96 Tg of CH₄-C, N₂O-N and CO₂-C, respectively, with a cumulated GWP of 130.93–272.83 Tg CO₂ equivalent. Intermittent flooding of rice fields reduced annual net emissions to 0.12–0.13 Tg CH₄-C and 16.66–48.80 Tg CO₂-C while N₂O emission increased to 0.05–0.06 Tg N₂O-N. The GWP, however, reduced to 91.73–211.80 Tg CO₂ equivalent (Pathak et al., 2005).

Relationship between greenhouse gas emissions and climate change

Global increases in CO₂ concentrations are primarily due to fossil fuel use, with land-use change providing another significant but smaller contribution. CO₂ is released largely from microbial decay or burning of plant litter and soil organic matter (Janzen, 2004). As agriculture through the process of photosynthesis absorbs CO₂ from atmosphere, there is very small net emission of CO₂ due to agriculture unless it is done by clearing forest land a kind of practice found in part of India and elsewhere. However the observed increase in CH₄ concentration is predominantly due to agriculture and fossil fuel use. Methane is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, from stored manures and from rice grown under flooded conditions. On the other hand, the major source of increase in more than one third in N₂O concentration is due to human activity, primarily agriculture. N₂O is generated by the microbial transformation of nitrogen in soils and manures and nitrogenous fertilizers, and is often enhanced where available nitrogen exceeds plant requirements, especially under wet conditions (Oenema et al., 2005). Thus agricultural GHG fluxes are complex and heterogeneous in source and of nature, but the active management of agricultural systems offers possibilities for mitigation.

Agriculture releases to the atmosphere significant amounts of CO₂, CH₄ and N₂O (Paustian et al., 2004). Agriculture accounted for an estimated emission of 5.1 to 6.1 Gt CO₂-eq year⁻¹ in 2005, almost 10-12% of total global anthropogenic emission of GHGs (IPCC, 2007). Methane contributes 3.3 Gt CO₂-eq year⁻¹ and N₂O 2.8 Gt CO₂-eq year⁻¹. Of global anthropogenic GHG emissions in 2005, agriculture accounts for about 60% of N₂O and about 50% of CH₄ (IPCC, 2007). Despite large annual exchanges of CO₂ between the atmosphere and agricultural lands, the net flux is estimated to be approximately balanced, with CO₂ emissions around 0.04 Gt CO₂ year⁻¹ only. Globally, agricultural CH₄ and N₂O emissions have increased by nearly 17% from 1990 to 2005, an average annual emission increase of about 60 Mt CO₂-eq year⁻¹ (IPCC, 2007).

Climate change and rice production

Elevated CO₂ and temperature

Elevated [CO₂] and air temperature can have marked effects on rice growth and yield. A number of studies have examined the effects of elevated atmospheric [CO₂] or combinations of elevated air temperature and [CO₂] on rice yield and growth during the last several decades (Yang et al., 2006; Sasaki et al., 2007). Most results showed that elevated [CO₂] increased yield. Conversely, several studies have shown that high air temperatures can reduce grain yield even under CO₂ enrichment (Horie et al., 2000, Prasad et al., 2006) owing to increased spikelet sterility (Jagadish et al., 2007). Enclosure studies with CO₂ enrichment have generally shown significant increases in rice biomass (25-40%) and yields (15-39%) at ambient temperature, but those increases tended to be offset when temperature was increased along with rising CO₂ (Moya *et al.*, 1998).

Rice response to elevated CO₂ also depends on nitrogen supply. If additional CO₂ is given when N is limited, lack of sinks for excess carbon (e.g. tillers) may limit the photosynthetic and growth response. There is evidence for genotypic variation in response to increasing CO₂ and temperature (Moya *et al.*, 1998), but as of now genes, traits or mechanisms associated with this have not yet been identified. In a large-scale FACE system dedicated to investigation of rice, located in northern Japan, yield increases due to elevated CO₂ (+200 µmol mol⁻¹) averaged 7 to 15% over three years (Kim *et al.*, 2003).

Effects of increasing minimum temperature on rice growth and yield are less understood than the effects of extremely high day temperatures on spikelet sterility. In a recent climate chamber study, there was first evidence of possible genotypic variation in resistance to high night temperatures (Counce *et al.*, 2005). Carbon losses due to growth and maintenance respiration typically amount to 40 to 60% of the total carbon fixed by a crop (Pritchard and Amthor, 2005). In tropical areas, this percentage may even be higher. According to the food and Agriculture organization of the United Nations, the net impact of projected temperature increase will be to slow the growth of rice production in Asia.

Drought and rice production

Drought is a recurrent climatic phenomenon in India and is caused due to the country's peculiar physical and climatic characteristics as well as resulting economic and agricultural impacts. Goswami *et al* (2006) using a daily rainfall data set found (i) significant rising trends in the frequency and the magnitude of extreme rain events and (ii) a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000 and predicted a substantial increase in hazards related to heavy rain over central India in the future. The rainfed regions encompassing the arid, semi-arid and dry sub-humid regions are more prone to climatic variability as in these ecosystems drought is a regular part of the natural cycles affecting productivity and leading to desertification. The frequency of droughts has varied over the decades in India. Among the drought years, the 1987 drought was one of the worst droughts of 20th Century, with an overall rainfall deficiency of 19%. It affected 59-60% of the crop area and a population of 285 million. In 2002 too, the overall rainfall deficiency for the country as a whole was 19%. Over 300 million people spread over 18 states were affected by the drought in varying degrees. Food grains production registered the steepest fall of 29 million tonnes. Because of its semiaquatic phylogenetic origin and the diversity of rice ecosystems and growing conditions, current rice production systems rely on ample water supply and thus, are more vulnerable to drought stress than other cropping systems.

Flood and rice production

Rising temperatures will accelerate the rate of melting of snow and glacier ice, increasing seasonal peak flows of the Himalayan headwaters. This in turn may lead to an increased frequency of flooding particularly along the rivers whose channel capacity has been reduced by sedimentation (Aggarwal et al., 2004). In India, many parts of the tidal, deepwater and rainfed lowland rice areas are faced with abrupt increases in water level that completely inundate the crop, commonly called flash flood. These floods occur after local or remote heavy rains and may completely submerge the crop for several days with the consequent delays in development and reduced stand. India has almost all the ecologies of flood prone rice ranging from flash floods to semi deep and deepwater, where submergence occurs during early or late vegetative stage for about one to two weeks (in flash flood) and 3-6 weeks in semi deep conditions. Stagnant flooding also occurs in several parts at Bihar, Orissa, West Bengal and Assam inundating rice crops to different depth and duration and adversely affecting growth and yield.

Sea level and rice production

Climate change will also impact on rice production through rising sea level. Observations from tide gauges indicate that the mean global sea level has risen by about 10 to 25 cm over the last 100 years, and it appears that this rise was related to the rise in global mean temperature recorded over the same period. Model projections of future global mean sea level change, based on the temperature change projections, show a rise of between 13 and 94 cm by 2100, with a central estimate of 49 cm. Rice cultivation is the predominant form of land use in many coastal and deltaic regions of the tropics. Sea level rise will affect the vast coastal area and flood plain zone of the Ganges-Brahmaputra and Indus Deltas. The consequences of sea level rise are (i) elevated water levels during tidal cycles and (ii) increasing cyclone frequency; both phenomena lead to increased flooding intensity as well as salt water intrusion. The combined effects of these factors will decrease agricultural production in the coastal zone of South Asia, which is dominated by rice production. A World Bank study concluded that salinity alone from a 0.3 m sea level rise will cause a net reduction of 0.5 million metric tons of rice production in Bangladesh (World Bank 2000).

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NOTES

3. Transformation of Nitrogen and other Macronutrients in Wetland Rice Soil

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Introduction

Nitrogen is the single most important essential nutrient element that has profound effect on growth and yield of rice. About 35% of the total quantity of fertilizer-N consumption in India is accounted for rice crop alone. Most of the Indian soils are deficient in available N. So rice crop invariably responds to application of fertilizer-N in almost all the Indian soils. Besides ensuring food security, its judicious use is equally important for environmental safety. Since rice is the most important food crop of India and about half of the world, improvement of N uses efficiency, especially of urea use efficiency, in rice is essential in the pursuit of Evergreen Revolution.

Urea is a science-gifted miracle agrochemical that has helped in increasing production of rice and other crops enormously. Urea accounts for 80-83% of the total fertilizer-N consumption. But the N utilization efficiency in rice hardly exceeds 30-40% (De Datta 1995). Efficient management of fertilizer N is possible when a clear understanding of nitrogen cycle and nitrogen transformation processes is developed. Atmosphere is the ultimate source of nitrogen which contains about 78% N₂ on volume basis. Nitrogen is added to rice soil through rainfall (natural N₂ fixation), fertilizers (industrial N₂ fixation), organics such as farmyard manure, compost, green manures, crop residues etc, irrigation water, absorption of ammonia from atmosphere and biological N₂ fixation by autotrophs (blue green algae), heterotrophs (*Azotobacter* and *Azospirillum*) and associative/symbiotic N₂ fixers (*Azalia* and legumes). Nitrogen on the other hand, is removed from the rice soil system through the desirable processes such as crop uptake and immobilization and undesirable processes such as run-off, soil erosion, leaching, ammonia volatilization, denitrification and weed removal. A novel N management practice ensures adequate addition of N to soil minimizes the N losses and maximizes N utilization by rice plant without adversely affecting the quality of environment.

Chemistry of nitrogen transformation in submerged rice soil

When urea is applied to moist aerobic or flooded rice soil, it hydrolyses to ammonium carbonate by the enzyme, urease principally produced by soil microbes (Gould et al. 1986). Depending upon the alkalinity and pH buffering capacity of soil, ammonium carbonate decomposes and ammonia gas escapes to the atmosphere resulting in volatilization loss of ammonia. The ammonium ion resulting from urea hydrolysis also undergoes biochemical oxidation (nitrification) in aerobic soil as well as at three sites in submerged rice soil system, viz. (i) top oxidized soil layer of few mm in thickness, (ii) rice rhizosphere, and (iii) flood water present above the ground. The nitrate formed in a dry seeded rice soil in rainfed lowland ecology undergoes reduction to nitrous oxide or molecular dinitrogen (denitrification) because of subsequent flooding with onset and intensification of monsoonic rain. Similarly, in wetland transplanted rice, the nitrate formed in the three aerobic sites of the submerged soil also undergoes denitrification because of diffusion of nitrate into the anaerobic zone in the submerged soil (Patrick and Reddy 1976). Besides these two major losses, N from rice field can also be lost through leaching, runoff, weed removal, soil erosion etc.

More than 95% of the total N present in soil is organic, which is mostly found in the form of proteins derived from plant and animal residues and microbial biomass. Besides applied N, the native soil-N also undergoes transformation by microbial action. Nitrogen transformations in wetland soils has been thoroughly reviewed by Savant and De Datta (1982), De Datta (1995) and Panda (2005). In the mineralization process proteins are converted into ammonium and then to nitrate in aerobic soil. In anaerobic soil, however, the mineralization stops at ammonium formation stage causing accumulation of $\text{NH}_4^+/\text{NH}_3$. Mineralization is slow in anaerobic soil but the accumulation of ammonia is greater and faster in anaerobic soil because of less immobilization. The products of mineralization such as ammonia and nitrate are also subjected to various loss processes.

Hydrolysis of Urea

Urea hydrolysis involves initial cleavage of urea molecule into ammonia and carbamic acid by the enzyme urease and the subsequent chemical hydrolysis of carbamic acid into ammonia and carbon dioxide. Urease enzyme is derived from microbes in soil system. It is also derived from higher plants. Presence of adequate amount of urease enzyme was detected in seeds of legumes viz. pigeonpea, horsegram and soybean (Panda and Patnaik 1985; Nayak 1996). Urea hydrolysis is maximum in soils with high organic C or added organic manure or green manure, pH around 8.0, moisture status at field capacity and temperature around 35 °C. Complete hydrolysis of urea in rice field occurs in 2-3 days with its broadcasting onto flooded soil, in 5-7 days with deep placement of urea super granules (USG) in flooded soil and in 7-14 days with its basal application in dry soil (Nayak and Panda, 2002). Acid concentrations $\geq 0.02N$, hydroquinone at a concentration of 1mg L⁻¹ or higher (Kabat, 2001), high concentrations of applied urea, metal ions, thiourea, phenyl phosphorodiamidate (PPD) and N-(n-butyl) thiophosphoric triamide (NBPT) inhibit urea hydrolysis (Byrnes *et al.* 1983; Singh and Nye 1984; Panda and Patnaik 1985; Gould *et al.* 1986; Yadav *et al.* 1986; Buresh *et al.* 1988; Kabat 2001).

Ammonia volatilization

Transformation of applied ammonium or amide fertilizers and decomposition of added or native organic matter in soil produce ammonium ions or unionized ammonia among other reaction products. Depending upon the alkalinity and pH buffering capacity of the system, ammonia gas escapes to the atmosphere resulting in its volatilization loss. For each mole of NH_3 volatilized, an equivalent amount of acid is produced. Ammonia volatilization occurs when there is sufficient alkalinity to neutralize the acid produced. The pH value at which ammonia loss begins is approximately 7 (Mikkelsen *et al.* 1978). This pH 7 or more may exist because of the nature of the soil (calcareous or sodic) or due to flooding and algal growth or the alkalinity may be generated by the reaction that occurs after fertilization as in case of urea. The enzymatic hydrolysis of urea produces ammonium carbonate, which is unstable under alkaline conditions and decomposes to ammonia, carbon dioxide and water. The magnitude of ammonia loss depends on wind speed, temperature, rainfall, ammoniacal-N ($\text{NH}_4^+ + \text{NH}_3$) concentration, pH and cation exchange capacity of soil (Freney *et al.* 1983).

A compilation on measurement of ammonia volatilization loss by micro-meteorological technique and total N loss by 15N balance technique for urea applied to transplanted lowland rice showed that the ammonia loss reported all over the world varied from 7 to 54% as against total N loss ranging from 13 to 64%(Fillery and Byrnes 1984; Cai *et al.* 1986; Fillery and De Datta 1986; Fillery *et al.* 1986; De Datta and Buresh 1989). Under upland conditions ammonia loss was 15-20% with surface application, 10% with soil incorporation and less than 5% with side-banding of urea (Sarkar *et al.* 1991).

In order to decrease the loss of N due to ammonia volatilization from applied urea in flooded rice, various techniques such as deep placement of urea supergranules (USG), urea mudlumps, coated urea fertilizers, soil incorporation of urea with suitable water management and use of several urease inhibitors, have been suggested. Humphreys *et al.* (1988) observed negligible ammonia loss when urea was applied to dry soil surface at seeding and subsequently flooded after two days. Ammonia volatilization from hydrolyzed urea followed the first order reaction kinetics with rate constants of 0.173-0.231 d⁻¹ and half lives of 3-4 days (Panda 2005). Relative ammonia loss from rice field at Cuttack ranged from 0.4% with USG deep placement to 6.0% with urea broadcasting on saturated soil. (Panda *et al.* 1989). Use of urea coated with neem cake or shellac for basal dressing reduced ammonia loss (Mishra *et al.* 1990). Ali and Singh (1994) reported that ammoniacal N concentration and partial pressure of ammonia in flood water were lowest with deep placement of USG. Ammonia loss can be reduced by incorporating N fertilizer into soil and further substantially reduced by dry soil application followed by irrigation (Singh *et al.* 1995).

Nitrification –denitrification

Nitrification is a de-electronation process that takes place in aerobic soil in two sequential steps: ammonium to nitrite and then from nitrite to nitrate by specific purpose autotrophic bacteria, viz. *Nitrosomonas* and *Nitrobacter*, respectively. The nitrate thus formed undergoes denitrification when the dry soil is flooded by rainfall or irrigation or by diffusion of nitrate from aerobic sites to the anaerobic zone in submerged soil (Patrick and Reddy 1976). The process of denitrification is a sort of anaerobic respiration by bacteria, viz. *Pseudomonas*, *Micrococcus*, *Alcaligenes*, *Bacillus* etc. during which nitrate and nitrite are reduced sequentially through NO and N₂O to N₂. The denitrifying organisms are heterotrophs and use organic carbon compounds as electron donors for energy and synthesis of cellular constituents. Although denitrification in soil is mostly a biological process, there are also reports of non-respiratory production of N₂O from oxides of nitrogen (Tiedje 1988), chemodenitrification by abiotic agents mostly in acidic and frozen soils (Christianson and Cho 1983) and dissimilatory nitrate reduction into ammonia.

Nitrous oxide from applied fertilizer

Nitrogen contributes to 10% of the annual rise in N₂O load of atmosphere. It is a green house gas (GHG), and contributes to global warming. It is also capable of destroying ozone layer which protects the earth from ultraviolet rays. On the other hand, if fertilizer N loss is reduced by 10% in India more than 1 Mt of N can be saved, which works out to a saving of Rs 7 billion per year or an additional production of 10 Mt of food grains (Katyal 2001).

Optimum soil pH (7.0-8.5), adequate oxygen supply in soil (Eh value more than 200 mV), soil moisture content equivalent to 60% of the water holding capacity and soil temperature ranging from 25 to 35 °C favour nitrification process. Nitrification of added urea in aerobic moist soil followed zero order kinetics with rate constants higher in black soil than in alluvial or laterite soils. Among nitrification inhibitors, hydroquinone was more effective in alluvial and laterite soils and alcoholic extract of neem cake was better in black soil than dicyandiamide (DCD) (Nayak and Panda 1999). Denitrification, on the other hand, is influenced by soil factors such as pH, texture, organic carbon, temperature, NO₃⁻-N content, soil aeration, soil water status, activity of denitrifiers, degree of puddling or aggregation etc. and management factors such as crop residue management, flood water regime, fertilizer N management, pesticides used, presence of crop plant, etc. (Savant and De Datta 1982, Aulakh *et al.* 1992). A pH range of 6-8, Eh less than 200 mV, water-filled pore space beyond 80%, high organic carbon content and temperature range of

25-35 °C, are optimum conditions for denitrification process. Rice fields subjected to alternate wetting and drying create favourable conditions for increased denitrification loss.

Although denitrification is one of the major pathways of N loss from flooded soils, its direct measurement in the field is hampered due to lack of suitable methodology. In wetland rice, while total gaseous N loss measured by ¹⁵N balance ranged between 10-53%, the loss measured using ¹⁵N chamber ranged from less than 0.1 to 20% of applied N (Buresh and Austin 1988; John *et al.* 1989; Buresh and De Datta 1990; Mohanty and Mosier 1990). Coating or blending of urea or other N fertilizers with several natural and synthetic products like neem (*Azadirachta indica*) cake, *karanj* (*Pongamia glabra*) cake, neem oil, nimin, dicyandiamide (DCD), N-serve, thiourea, hydroquinone etc. have been reported to inhibit nitrification and thereby reduce the loss of N through denitrification (Prasad 1975; Panda 1986; Wittaya and Thongpan 1988; Mishra *et al.* 1990; Nayak and Panda 1999; Kabat 2001).

Mohanty and Mosier (1990) and Mosier *et al* (1990) from ¹⁵N studies reported that N₂ was the major denitrified gas and comprised about 94% of the total denitrification loss and N₂O was only 6%. Mohanty and Mosier (1990) reported 5-10% loss of applied urea- ¹⁵N due to denitrification by direct measurement. Application of coated calcium carbide @ 20 kg ha⁻¹ along with urea checked denitrification loss through inhibition of nitrification. Experiments conducted in India and other countries of the world showed that deep placement of USG or urea mud balls in the reduced zone of submerged rice soil, subsurface placement of urea through thorough incorporation of applied urea into wet soil by puddling in absence of any standing water decreased N losses and improved N use efficiency in rice (Savant *et al.* 1982; Panda 1986; Panda and Patnaik 1989; Humphreys *et al.* 1992; Nayak 1996; Kabat 2001).

Phosphate transformation

Phosphate transformation in paddy soils has been reviewed by Patrick and Mahapatra (1968). When a soil is submerged, concentration of water soluble and available P increases and reaches a peak in 20-30 days of flooding. (Mohanty and Patanaik 1976). The increase in P availability due to submergence of acid soils is attributed to (a) hydrolysis of Fe (III) – P and Al-P (b) reduction of Fe (III) to Fe (II)-P, (c) release of P from anion exchange site of clays and hydrous oxides of Fe and Al, and (d) release of occluded P on reduction of hydrated ferric oxide coatings.

In alkaline soils, P availability increases due to decrease in pH causing higher solubility of hydroxyapatite. Tracer studies showed that inorganic P was converted into more labile forms of P in waterlogged soils (Gupta and Singh 1975). Murty and Singh (1975) observed that available P increased slightly due to flooding and decreased after 5 to 6 weeks due to reprecipitation and resorption.

Effect of soil submergence on availability of K, Ca and Mg

Ramanathan and Krishnamoorthy (1973) reported increase in K availability with increasing periods of submergence of black and alluvial soils due to release of non-exchangeable- K. Singh and Ram(1978) observed increase in exchangeable-K upon continuous submergence. Murthy and Singh (1975) recorded a sharp increase in Ca concentration in soil solution within the first week of submergence, after which the change was inconsistent. The availability of K, Ca and Mg increased due to soil submergence, reached a peak at 30 days and then decreased (Mohanty and Patnaik 1977). Increase in their availability was due to their displacement from the exchange site, hydration and hydrolysis.

Sulphur transformation in submerged soils

Transformation of S in submerged soils included reduction of SO_4^{2-} to sulfide and dissimilation of S containing amino acids to H_2S , thiols, ammonia and organic acids (Freney 1967). Redox potential below -160 mV and pH range of 6.4 -7.7 favour SO_4^{2-} reduction (Rao 1980). In soils low in iron, hydrogen sulfide may be toxic to rice. But in soils rich in iron formation of ferrous sulfide can decrease iron toxicity as well as sulfide injury in rice. Sulphate reduction is brought about by a small group of obligate anaerobic bacteria of the genus *Desulfovibrio*. In rice soils sulfate reduction may cause deficiency of S, Zn and Cu because of formation of insoluble sulphides of Zn and Cu.

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4. Simulating Climate Change Impact on Crop and Soil Processes

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Introduction

The practice of agriculture is based on knowledge, tradition and conjecture and agricultural research improves the knowledge that provides the basis for decision-making. Traditional disciplinary research methods have been used to deal with biological and economic problems but have not been entirely successful in handling the inherent complexities of agricultural activities. However, as knowledge is accumulated, results obtained from observation change from being qualitative to being quantitative and mathematics can be adopted as the tool to express biological hypotheses. Owing to the inherent complexity of agriculture, modeling studies started only in the 1970s. Rapid accumulation of knowledge in the agricultural field and the increased accessibility to information technology has contributed to the development of a wide number of agricultural models.

The models are based on a quantitative understanding of underlying processes, and integrate effects of soil, weather, crop, pests, and management factors on growth and yield. Once integration and validation have been judged successful, the models can help in analyzing the effect of various biotic and abiotic factors on crop growth, yield, losses of N and N-use efficiencies. Such analyses are normally not possible with conventional experimental methods. Together with systems-approach tools such as expert systems, decision-support systems, databases, geographical information system (GIS), and remote sensing, crop models constitute a valuable tool that facilitates integration of knowledge and its use by a variety of users. The objectives of this paper are to provide the basic information on crop modeling and its adoption.

Models in agriculture

Growth of crops obeys certain physiological principles. These may be described in qualitative terms but to a certain extent, various growth processes can be quantified in response to the environment by mathematical formulae by linking the equations to each other, a mathematical model is obtained that, for convenience, can be written as a computer program. Such a quantitative model of crop growth, enables predicting crop growth rates and yields under a variety of environmental and management conditions. This may be used as a tool for the grower to assist in his decisions on management operations (e.g. in scheduling of irrigation, fertilizer application and crop protection), or to be used in process control (e.g. in climate control in greenhouses). A crop model may also be used for yield forecasting, e.g. by the processing industry for predicting and planning the supply, or by the government planners. It may be applied in land use evaluation and planning e.g. to access the production potentials of new cropping areas in dependence of availability of water and fertilizer. At present, the physiological models have mainly been used as a research tool, especially as a framework in analysis of experimental results, and in studying the effect of individual processes on crop growth in relation to the environment.

Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. Owing to the complexity of the system and the incomplete status of present knowledge, it becomes impossible to completely

represent the system in mathematical terms and hence, agricultural models are but crude images of the reality. Unlike in the fields of physics and engineering, universal models do not exist within the agricultural sector. Models are built for specific purposes and the level of complexity is accordingly adopted. Inevitably, different models are built for different subsystems and several models may be built to simulate a particular crop or a particular aspect of the production system.

Features of crop models

The main aim of constructing crop models is to obtain an estimate of the harvestable (economic) yield. Depending upon the amount of data and knowledge that is available within a particular field, models with different levels of complexity are developed. Grouping of models has been attempted by various authors but strong demarcations cannot be made since a model generally possesses the characteristics of more than one group. The most pertinent aspects of crop models are described below.

Empirical model

The empirical or regression models describe the observed plant weight with some empirical function. So they describe the effect only at the level of observation. The physiological models on the other hand explain the observed growth, explain the observed growth rates from the underlying physiological processes and in relation to the environmental factors. They describe the mechanism of crop growth in an explanatory way. These models are direct descriptions of observed data and are generally expressed as regression equations (with one or a few factors) and are used to estimate the final yield. Examples of such models include the response of crop yield to fertilizer application, the relationship between leaf area and leaf size in a given plant species and the relationship between stalk height alone or coupled with stalk number and or diameter and final yield in the sugarcane. These models are crude and are good means for interpolation at the location and the range over which they have been derived but it is advisable to avoid extrapolation.

Mechanistic model

A mechanistic model is one that describes the behaviour of the system in terms of lower-level attributes. Hence, there is some mechanism, understanding or exploration at the lower levels. These models have the ability to mimic relevant physical, chemical or biological processes and to describe how and why a particular response results. The modeler usually starts with some empiricism and as knowledge is gained, additional parameters and variables are introduced to explain crop yield. Thus, the modeler adopts a reductionist approach. Most crop growth models fall within this category.

Static and dynamic models

A static model is one that does not contain time as a variable even if the end-products of cropping systems are accumulated over time, e.g. the empirical models. In contrast dynamic models explicitly incorporate time as a variable and most dynamic models are first expressed as differential equations.

Model development

Model structure

As soon as enough scientific knowledge about the growth pattern, the growth-controlling factors and the interactions that are dominant within a particular cropping system becomes available, model building can be initiated. Knowing the desired output (crop yield), one major equation would be

identified. In the next step, the factors that control daily growth would be identified. Then, the biomass would be partitioned to the economic portion and the stay-over. These would be specified as mathematical functions with conditional rules and would be looped over the selected time-step. In the next step, detailed flow chart is constructed such that the major crop reactions and interactions are specified. Phenological development (vegetative development, canopy expansion, silking, crop-end) is controlled by thermal time. Photosynthesis is then derived as a function of canopy light interception and a radiation use efficiency factor, and as soon as silking occurs, daily biomass is allocated to maintenance and grain filling until crop end is encountered. Finally, the software is written in a computer language, e.g. FORTRAN, C++. Complex equations coupled with extensive looping demand that models be run on computers to ensure error-free manipulation. The first step of model construction is completed when all programming, mathematical, computational and numerical errors are eliminated.

The above-named example of a simulation model gives crop growth under non-limiting conditions, and the main use of such models is to determine potential yields. Since potential growth conditions are not features in cropping system, additional relationship would be specified in order for the model to have an application value. The major limiting factor (e.g. water stress, nitrogen stress, competition from weeds or disease outburst) is then identified and its effects on leaf area development, radiation use efficiency and partitioning factors are then derived and expressed mathematically.

Top model development is a collaborative endeavour that necessitates the expertise of crop specialists with good insights of related disciplines as well as the support of researchers from other scientific areas, mathematics and programmers. Model-building is an expensive enterprise. Therefore, most researchers are involved in the application of existing models to a new situation rather than in model development.

Model calibration

Model calibration involves the modification of some model parameters such that data simulated by the error-free model fit the observed data. In any instances, even if a model is based on observed data, simulated values do not exactly comply with the observed data and minor adjustments have to be made for some parameters. Non-compliance may arise from sampling errors as well as from incomplete knowledge of the system.

Model validation

The model validation stage involves the confirmation that the calibrated model closely represents the real situation. The procedure consists of a comparison of simulated output and observed data that have not been previously used in the calibration stage. Ideally, all mechanistic models should be validated both at the level of overall system output and at the level of internal components and processes. The latter is an important aspect because due to the occurrence of feedback loops in biological systems, good prediction of system's overall output could be attributed to compensating internal errors. However, validation of all the components if not possible due to lack of detailed datasets and the option of validating only the determinant ones is adopted.

The methodology of model validation is still rudimentary. The main reason is that, unlike the case of disciplinary experiments, a large set of hypotheses is being tested simultaneously in a mode. Furthermore, biological and agricultural models are reflections of systems for which the behaviour of

some components is not fully understood and differences between model output and real systems cannot be fully accounted for.

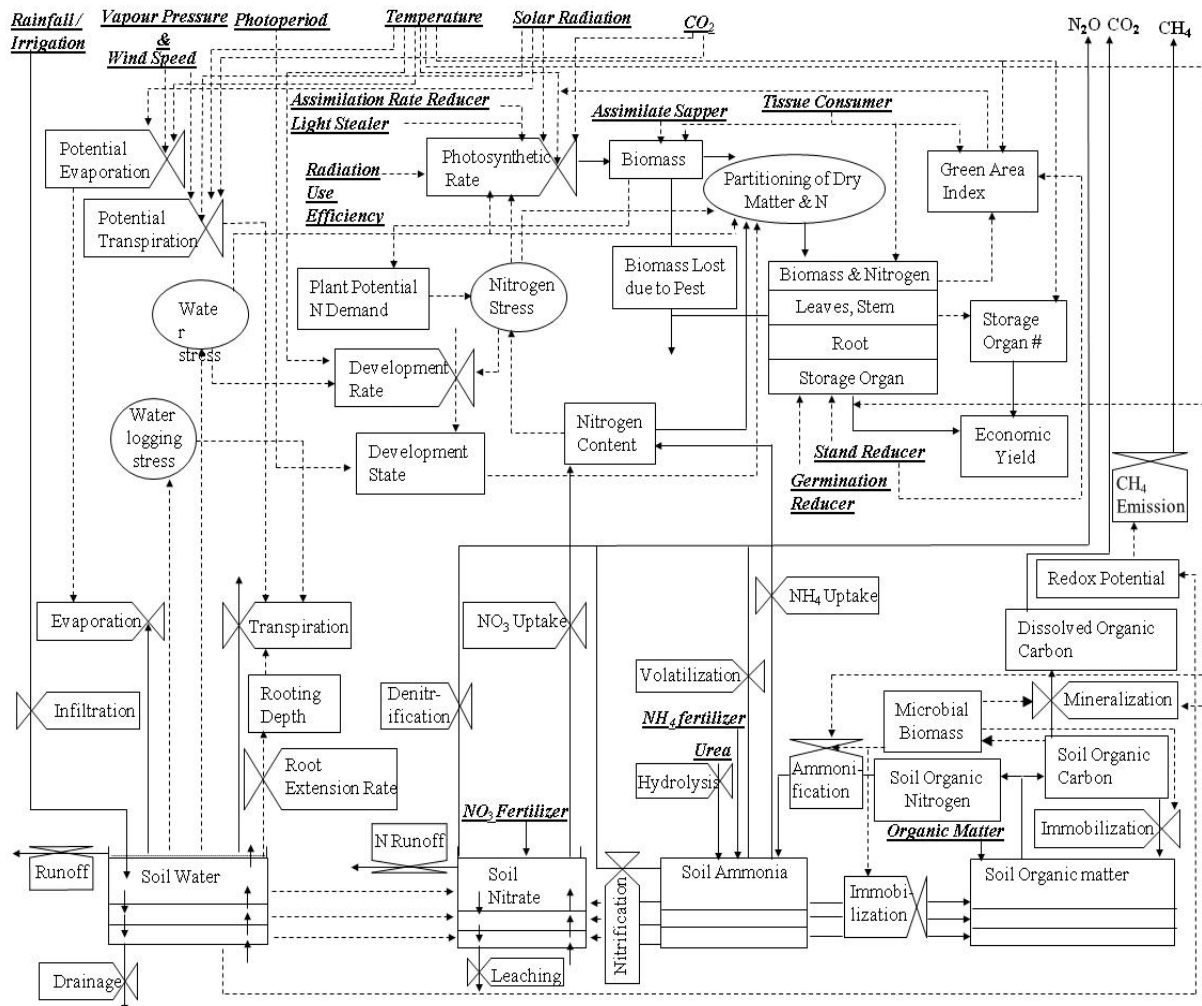


Figure 1. A schematic diagram showing the processes in soil nitrogen balance, their relationships and feedbacks in InfoCrop (Aggarwal et al., 2006).

Simulating nitrogen dynamics using infocrop model

The InfoCrop mode calculates the transformations, movement, leaching, gaseous losses of N and crop N uptake from various soil layers in daily time step. The model computes the dynamics of N in soil through the following processes: mineralization, immobilization, urea hydrolysis, nitrification, volatilization, denitrification, nitrous oxide emission, N movement in soil and N uptake by crops. Figure 1 shows the relational diagram of various soil nitrogen processes in InfoCrop. In the model total soil N pool is divided into organic N, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$. The following sources of N are considered: indigenous soil N, which is derived from soil organic matter, and $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ present in soil at the time of start of simulation; inorganic fertilizer; organic manure; irrigation; rainfall and biological N fixation. The sinks of N include plant uptake and losses of N including leaching, ammonia volatilization, denitrification and nitrous oxide emission. Mass balance of N between various sources and sinks is used with time coefficients (or rate constants) to calculate the rates of flow.

Simulating climate change impact

Agriculture is sensitive to short-term changes in weather as well as to seasonal, annual and longer-term variations in climate. The variations in the meteorological parameters, in combination with other parameters such as soil characteristic, cultivar, pest and diseases, and agronomic practices, have paramount influence on the agricultural systems and determine the production levels. Food grains production/productivity in many countries is still constrained by the unpredictability of rainfall, i.e., inter-annual variation of the total precipitation as well its distribution within the growing season. The given uncertainties in regional climates are even aggravated by global warming, which may have serious direct and indirect consequences on crop production and hence, on food security. It is, therefore, important to have an assessment of the consequences of climatic variability on crops especially cereals and possible adaptation strategies. In the last two decades, there has been a rapid development of crop models that can simulate the response of crop production to a variety of environment and management factors. With such models, it is feasible to assess the variations in yields for different crops or management options under given climate patterns. Thus, crop models can simulate the inter-annual variation of yields for specific crop management options from the available historical meteorological data and, in the next step, facilitate identification of adaptation strategies to reduce adverse effects of climatic variability. Different crop models have been employed for statistical analyses of historical climatic data and simulated crop yields.

Model uses and limitations

Agricultural systems are characterized by high levels of interaction between the components that are not completely understood. Models are therefore, crude representations of reality. Wherever knowledge is lacking, the modeller usually adopts a simplified equation to describe an extensive subsystem. Simplifications are adapted accordingly to the model purpose and/or the developer's views and therefore, constitute some degree of subjectivity.

Models that do not result from strong interdisciplinary collaboration are often good in the area of the developer's expertise but are weak in other areas. Model quality is related to the quality of scientific data used in model development, calibration and validation.

When a model is applied in a new situation, the calibration and validation steps are crucial for correct simulations. The need for model verification arises because all processes are not fully understood and even the best mechanistic model still contains some imperialism making parameter adjustments vital in a new situation.

Model performance is limited to the quality of input data. It is common in cropping system to have large volumes of data relating to the above-ground crop growth and development, but data relating to root growth and soil characteristics are generally not as extensive. Using approximations may lead to erroneous results. Limitations of model inputs include cost of obtaining data e.g. purchase from weather service for application, or purchase of research instruments for measurement, spatial variability like field applications, soil traits vary considerably within a single field, the technical knowledge required for some input (to compute water release curves), temporal variability like pest out breaks and data quality (poorly calibrated sensors). Most simulation models require that meteorological data be reliable and complete. Meteorological sites may not fully represent the weather at a chosen location. In some cases, data may be available for only one (usually rainfall) or a few (rainfall and temperature) parameters but data for solar radiation, which is important in the estimation

of photosynthesis and biomass accumulation, may not be available. In such cases, the uses would rely on generated data. At times, records may be incomplete and gaps have to be filled. Using approximations would have an impact on model performance.

Model users need to understand the structure of the chosen model, its assumptions, its limitations and its requirements before any application is initiated. At times, model developers may raise the expectations of model users beyond model capabilities. Users, therefore, need to judiciously assess model capabilities and limitations before it is adopted for application and decision-making purposes.

Generally, crop models are developed by crop scientists and if interdisciplinary collaboration is not strong, the coding may not be well structured and model documentation may be poor. This makes alteration and adaptation to simulate new situations difficult, especially for user with limited expertise. Finally, using a model for an objective for which it had not been designated or using a model in a situation that is drastically different from that for which it had been developed would lead to model failure.

Summary and conclusions

Agricultural systems are complex entities involving a large amount of technical data from various disciplines for adequate elaboration of crop growth models. As investments in model development are high, most researchers are involved in model application rather than in model development. With decreasing costs of computing facilities, models are becoming accessible to a wide range of users with differing degrees of expertise in the modeling field. Knowledge of crop growth and development being incomplete, even the most rigorous model includes some approximations and therefore, possesses some limitations. Proper understanding of these limitations is important when models are used.

Nevertheless, crop models can be used for a wide range of applications. As research tools, model development and application can contribute to identify gaps in our knowledge, thus enabling more efficient and targeted research planning. Models that are based on sound physiological data are capable of supporting extrapolation to alternative cropping cycles and locations, thus permitting the quantification of temporal and spatial variability. Over a relatively short time span and at comparatively low costs, the modeller can investigate a large number of management strategies that would not be possible using traditional methodologies. Despite some limitations, the modeling approach remains the best means of assessing the effects of future global climate change, thus helping in the formulation of national policies for mitigation purposes.

Crop growth modeling is a potentially valuable tool in research, crop management technology, and in policy decisions. We encourage crop model developers and user's to be aware of the limitations and their possible misuse. Despite concerns about the difficulty of validating models, crop models proposed for broader crop management applications should be tested widely and in diverse field environments. Researchers can make use of crop growth models to conduct hypothetical studies and compared outcomes with their own experiments. The widespread use of computers and the releases of documented, comprehensive crop models make it relatively easy for crop physiologists and other discipline scientists to test models, use them and modify them. There is less cost of reinventing the wheel. The crop model improvement will be facilitated by such studies, through insight gained from testing the process relationships and thorough ideas for model simplifications.

The simplifications can help one understand basic responses, but those using simplifications in models should be aware of the limitations.

Commonly used simulation models for studying soil-plant systems

- APSIM (McCown et al., 1998)
- BLASTSIM (Teng et al., 1991)
- BLIGHT (Ellings et al., 1995)
- CANDY (Franko et al., 1995)
- FUSSIM2 (Willigen and M Heinen, 2003)
- Hydrus-2D (Simunek et al. 1999)
- SWAGMAN[®] Destiny (Godwin et al., 2002)
- CENTURY (Parton et al., 1994)
- CERES (Crop Estimation through Resource and Environment Synthesis, Hanks and Ritchie, 1991)
- DAISY (Jensen *et al.*, 1994)
- DNDC (DeNitrification and DeComposition, Li et al., 1994)
- DSSAT v. 4.0 (Decision Support Systems for Agrotechnology Transfer, Jones et al., 2003)
- NWHEAT (Keating et al. 2001)
- I-WHEAT (Meinke et al. 1998)
- MERES (Methane Emission from Rice EcoSystems, Matthews et al., 2000)
- EPIBLAST (Kim et al., 1991)
- EPIC (Erosion/Productivity Impact Calculator, Williams, 1995)
- InfoCrop (Aggarwal et al., 2006)
- InfoRCT (Pathak et al., 2008)
- InfoSoil (Pathak et al., 2006)
- INTERCOM (Kropff et al., 1994)
- IRRIMOD (McMennamy et al., 1983)
- LEACHM (Leaching Estimation and Chemistry Model, Hutson, 2000)
- MACROS (Penning de Vries et al., 1989)
- NCSOIL (Molina, 1996)
- NTRM (Nitrogen, Tillage and crop-Residue Management, Shaffer and Larson, 1987)
- ORYZA_1 (Kropff et al., 1994)
- ORYZA_1N (Aggarwal et al., 1996) ORYZA_N (Berge et al., 1994)

- ORYZA2000 (Bouman et al., 2003)
- RICAM (Yin et al., 1994)
- Ricesys (Graf et al., 1991)
- ROTH-26.3 (Coleman and Jenkinson, 1996)
- RZWQM (Root Zone Water Quality Model, Ahuja et al., 2000)
- SIMRIW (Horie et al., 1992)
- SOMM (Chertov and Komarov, 1996)
- TechnoGAS (Pathak et al., 2007)
- TRYM (Williams et al., 1994)
- VERBERNE (Verberne *et al.*, 1990)
- VSM (Kobayashi et al., 1994)
- WTGROWS (Aggarwal and Kalra, 1994)

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5. Soil Organic Carbon Pools and Climate Change Feedback

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Introduction

The soil organic matter (SOM) is of fundamental importance in soil fertility. It is a storehouse of all essential plant nutrients and provides energy material for the soil organisms. The maintenance of SOM in agricultural soils is primarily governed by climate, particularly annual precipitation, temperature and cropping practices. Further, there are severe problems of degradation of soil and water resources leading to reduction in use efficiency of inputs, pollution of surface and ground waters, and emission of greenhouse gases (GHGs) from terrestrial ecosystems into the atmosphere. Soil organic carbon play multifunctional role to improve this degradation. The majority of carbon is held in the form of soil organic carbon, having a major influence on soil structure, water holding capacity, cation exchange capacity, the soils ability to form complexes with metal ions to store nutrients, improve productivity, minimize soil erosion etc. This organic carbon is highly sensitive to changes in land use and management practices such as increased tillage, cropping systems, fertilization etc., leading to soil organic carbon decline. Conversely, land use change and the appropriate management of soils also provide us with the potential to sequester carbon in soils.

Although amount of SOM in soils of India is relatively low (ranging from 0.1 to 1.0% and typically less than 0.5%), its influence on soil fertility and physical condition is of great significance. Conversion of land from its natural state to agriculture generally leads to loss of SOM. The maintenance of soil organic carbon (SOC) in tropical soils to a desirable level of 0.5 to 1.0 percent is extremely important for sustainable crop production. It may take up to 50 years for the organic matter of soils in the temperate climate to reach a new equilibrium level following a change in management, but this time period is much shorter in the semiarid and tropical environment like India. Intensive cropping and tillage systems have led to substantial decrease in the SOM levels under semiarid and sub-humid regions, through enhanced microbial decomposition, wind and water erosion of inadequately protected soils. This decrease in SOM level has often been accompanied with the decline of soil productivity.

SOM changes in rain fed semiarid and sub-humid regions did not throw much light on the carbon functional pools, which are highly sensitive indicator of soil fertility and productivity. The distribution of soil organic matter into five functional pools is:

1. Structural litter fraction: This consists of straw, wood, stems and related plant parts. The C: N ratio varies around 150:1. These are high in lignin content.
2. Metabolic pool fraction: It comprises plant leaves, bark, flower, fruits and animal manure. The C: N ratio ranges from 10 to 25. This fraction gives up mineral nitrogen as it is decomposed with loss of CO₂.
3. Active pool of soil carbon: This is microbial biomass and their metabolites. The C:N ratio is around 5 to 15. This fraction gives up mineral nutrients and it gives life to the soil. Besides soil microbial

biomass carbon (SMBC), light fraction of organic matter, water-soluble carbon and water -soluble carbohydrates are also active pools of organic matter.

4. Slow decomposable soil fraction: This fraction is comparable to nature of composting having C: N ratio around 20:1. It makes temporary stable humus in soil, which is slowly decomposable.
5. Passive soil organic fraction: This is the highly recalcitrant organic matter with C:N ratio of 7:1 to 9:1. It is resistant to oxidation and is not readily involved in dynamic equilibrium with other types of organic fractions in soil.

Soil carbon pools

In general, SOC concentration increases with increase in clay content and rainfall, and decreases with increase in mean annual temperature. Some of these soils have been cultivated for centuries, and often with low off-farm input, based on systems that involve removal of crop residue and cow dung for fuel and other purposes. Diverse soils are also characterized by a wide range of SOC concentration, which is generally related to clay content (Ali et al., 1966) and climate (Jenny and Raychaudhary, 1960). The principal cause of decline in SOC pool in degraded soils is a reduction in biomass productivity and the low amount of crop residue and roots returned to the soil. A typical example of the low SOC pool is in salt-affected soils of Haryana, Andhra Pradesh, Orissa and West Bengal. Even in the surface 0 to 15 cm layer, the SOC pool may be lower than 5 g kg⁻¹ (Singh and Bandyopadhyay, 1996). Accelerated soil erosion depletes the SOC pool severely and rapidly. The SOC fraction is preferentially removed by surface runoff and wind because it is concentrated in the vicinity of the soil surface and has low density (1.2 to 1.5 Mg m⁻³ compared with 2.5 to 2.7 Mg m⁻³ for the mineral)

Active pools of carbon

(Soil microbial biomass carbon (SMBC), water soluble carbon (WSC), acid hydrolysable carbohydrates (AHC))

Active pool is a small fraction of SOM, it is considered as buffering agent and found useful in replenishment mechanisms like desorption from soil colloids, dissolution from litter, and exudation from plant roots. The contribution of water-soluble fractions in the inorganic fertilized treatment was less because aboveground biomass was neither used nor returned to the soil in any form in rice-based cropping system. The reduced amount of active pools of C and N after long-term cultivation of fertile virgin soil leads to depletion of soil fertility in three ways i.e. through reduced labile sources of nutrients; reduced rate of mineralization, and lower bioavailability of nutrients. Furthermore, continuous cultivation with cereal based cropping reduced total amount of nutrients as well as soil microbial biomass, which could lead to biological degradation of soil. Similarly, continuous application of inorganic fertilizer and removal of aboveground biomass significantly reduced not only total amount of nutrients but also the active pools of C and N resulting in decline of crop yields. It is often difficult to maintain or enhance the organic matter and N in cultivated soil unless a cover/legume crop is included in the rotation or a heavy application of manures and crop residues is made. Therefore, balanced plant nutrition (fertilizer in combination with manure) every year may contribute more labile fraction of C, which acts as a source of bioenergy and helps to improve mineralization process.

Slow pool of carbon

(Particulate organic matter carbon (POMC), light fraction carbon (LFC) and Light fraction nitrogen (LFN) in aggregates)

In general, the aggregates size distribution was dominated by micro-aggregates (53- to 250- μm) followed by small macro-aggregates (250- to 2000- μm) in most of the rice-based cropping systems in Inceptisols. Alternate wetting (anaerobic) and drying (aerobic) condition resulted after continuous intensive conventional tillage operations and removal of aboveground residues induced a rapid mineralization of aggregates associated SOM which collapsed the aggregates (>2-mm diameter size class). The correlation between reduction in aggregates and loss of SOM with cultivation has been used to explain aggregate hierarchy theory by many authors (Camberdella and Elliott, 1993; Six et al., 2000). Increasing cultivation intensity with repeated application of inorganic fertilizers (N, NP and NPK) caused reduction of macro-aggregates (Manna et al., 2005b, 2007a and 2007b). It is because of no significant release of water-soluble carbon and hydrolysable carbohydrates (which acted as binding agents) from belowground biomass decomposition upon microbial action. This perhaps resulted in loss of soil aggregates.

The C mineralization is lower than N mineralization either from slow pools (aggregate size classes) or from mineral-associated organic matter (silt + clay) fraction (Manna et al., 2005b). Further, the less mineralization rate in micro-aggregates may be due to transformation of labile materials to more stable fractions during continuous cultivation. However, more research is required to explain whether significant fraction of labile materials are transformed to stable fraction during different land use management system that may eventually effect nutrient supply to plants. The best approach should be the integrated use of manure and fertilizer in the highly intensive rice based cropping system to maintain SOC. The practice of residue incorporation during transition period of two crops is difficult. For example, after harvest of rice the transitional gap is only 20 to 25 days prior to wheat sowing. There is scope of further investigation to explain as to how residue can be managed in a short period without scarifying the next crop so that regular addition of residue along with balance fertilizer maintain active and slow pools of C and N under high intensive cropping system in a long run. Perturbations to the soil system such as conversion of native vegetation to arable agriculture cause large changes in SOM content in soil. Particulate organic matter carbon (POM) is the precursor for formation of soil microbial biomass carbon, soluble fraction of carbon, humic and non-humic fraction of carbon in soil and thus it is a key attribute of soil quality. It is the major source of cellular C and energy for the heterotrophic microorganisms. The POM accumulation is also the major pathway by which nutrients are recycled from crop residues back to the soil and release nutrients by mineralization during decomposition of POM. The large amount of microbial community associated with the decomposing POM produces binding agent such as exocellular mucilaginous polysaccharides. It acts as a major food and energy for endogenic soil fauna. Thus, POM is associated with a multitude of soil process and functions and is therefore, a key attribute of soil quality.

Passive pools of carbon

(Humic acids and Fulvic acids)

In rice-based cropping system the changes in HA-concentrations and HA/FA ratios is generally higher in the surface soil (0 to 15cm) and decreases with increase in depths. On the contrary, FA-concentrations usually higher at lower depth compared to surface soil. The HA and FA content rarely varied due to treatments in short period of time. Similarly, humic acid and fulvic acid ratios

also less sensitive to temperature in short run. Changes in Acid hydrolysable-N of humic substances in HA-N than FA-N irrespective of fertilizer treatments indicating that more time frame is required to improve passive fraction of C (Manna et al 2005b).

Factors affecting decomposition of soil organic carbon

The stocks of organic matter in soils result from the balance between inputs and outputs of carbon within the belowground environment. Inputs are primarily from leaf and root detritus. Outputs are dominated by the efflux of carbon dioxide (CO₂) from the soil surface, although methane (CH₄) efflux and hydrological leaching of dissolved and particulate carbon compounds can also be important. The production of CO₂ in soils is almost entirely from root respiration and microbial decomposition of organic matter. Like all chemical and biochemical reactions, these processes are temperature- dependent. Root respiration and microbial decomposition are also subject to water limitation. Hence, most empirical models relate the efflux of CO₂ from soils (often lumping microbial and root respiration together as ‘soil respiration’) to temperature and often also to some scalar of soil water content or precipitation. This much is not controversial.

The kinetics of enzymatic reactions in well-mixed media is also not controversial. Activation energies are related to the ambient temperature and to the molecular structure of the organic-C reactant. The temperature sensitivity of decomposition increases with increasing molecular complexity of the substrate. The reaction rates are also modified by substrate concentrations and affinities of the enzymes for the substrates.

Soils contain thousands of different organic-C compounds, each with its own inherent kinetic properties. Not only do plants produce a wide range of carbon substrates, but plant detritus also undergoes transformations by microbial degradation or by abiotic condensation reactions that produce new aromatic structures, larger molecular weights, insolubility, or other molecular architectures that affect the types and efficacies of enzymes that can degrade them. These complex molecular attributes are characterized by low decomposition rates, high activation energies, and inherently high temperature sensitivity. The inherent kinetic properties based on molecular structure and ambient temperature could be called as the ‘intrinsic temperature sensitivity’ of decomposition.

On the other hand, the enzymes for decomposition may be physically or chemically excluded from many of the organic-C substrates within the heterogeneous soil environment, causing substrate limitation at reaction microsites. The observed response to temperature under these environmental constraints, which we shall call the ‘apparent temperature sensitivity’, may be much lower than the intrinsic temperature sensitivity of the substrate. Conversely, if a temperature-sensitive process alleviates an environmental constraint to decomposition, then the subsequent increase in substrate availability could result in the apparent temperature sensitivity temporarily exceeding the intrinsic temperature sensitivity of the substrate. The environmental constraints that can temporarily or indefinitely affect apparent temperature sensitivities of decomposition include the physical, chemical protection, drought, flooding, freezing etc.

Soil organic carbon dynamics and climate changes feedbacks

Climate changes have both direct and indirect effects on the soil organic carbon (SOC) dynamics and its decomposition kinetics as well as microbial activities on SOC decomposition that provide a feedback to the gaseous-C concentrations to the atmosphere and contribute to global

warming. Direct effects include temperature mediated soil respiration, SOC decomposition leading to gaseous-C emission, changes in precipitation and extreme climatic events. The indirect effects result from climate-driven changes in plant productivity and diversity that would alter soil physico-chemical conditions, the supply of carbon to soil and, structure and activity of microbial communities involved in decomposition processes and carbon release from soil. As rates of soil respiration are thought to be more sensitive to temperature than primary production, it is predicted that climate will increase the net transfer of carbon from soil to atmosphere, thereby creating a positive feedback to climate change. Growing stress tolerance species also contribute to a positive feedback to climate change. Increase of primary production (higher photosynthesis) and reduction of the length of growing season causes negative feedback to climate change by reducing the CO₂ emission to atmosphere and absorbing more CO₂ from atmosphere. The indirect effects which includes positive feed backs are i) percolation and runoff losses of dissolved organic carbon (DOC), ii) higher root exudation that causes faster SOC decomposition through “Priming effect” and promote methanogenesis and hence enhance the C losses from soil as methane. The indirect negative feedbacks include i) increasing plant-microbial competition for nitrogen (N) that causes ecosystem carbon (C) accumulation, ii) increasing growth of mycorrhizal fungi causing C accumulation and iii) stimulation of microbial biomass and immobilization of soil N causing limitation of N availability to plant and hence accumulation of C in soil . Another indirect effect on climate change (both positive and negative feedbacks) is through shifts in the functional composition and diversity of microbes and vegetation which occurs over longer time scales of decades and centuries.

Factors affecting to carbon dynamics and climatic feedbacks

Primary productivity in more than half of the world’s ecosystem is substantially limited by the availability of water. Hence, changes in precipitation will have direct effects on ecosystem carbon dynamics. In a warmer world, evaporation is expected to increase, leading to a more negative water balance, whereas decreased water loss through stomata in a CO₂-richer world will tend to mitigate this effect. The net effect (production minus respiration) of a more negative overall water balance probably depends on the water-holding capacity of the soil, the vertical distribution of carbon and roots in the soil, and the general drought sensitivity of the vegetation. For instance, if most of the soil carbon is concentrated at the top of the soil, while roots go deep into a soil with high water-holding capacity, or even tap the groundwater, soil carbon decomposition will initially be more strongly affected by drought than will vegetation productivity, as the topsoil dries out first. Water limitation may even suppress the effective ecosystem-level response of temperature on respiration. Conversely, if soil water-holding capacity is low, as in shallow soils, vegetation productivity will be strongly affected by a negative water balance. Hence, under drier conditions, there are predictions of increased sequestration by suppression of respiration and net loss of carbon through decreased productivity.

A second important interacting factor is the available nitrogen, which often determines the magnitude of the CO₂ fertilization effect and may suppress it completely if nitrogen is limiting. There are also indications of strong interactions between water and nitrogen, with nitrogen becoming more limiting under drier conditions. Other factors to be considered are changes in the amount and quality (direct or diffuse) of light, which can alter vegetation productivity, and increases in air pollutants and ozone, with their detrimental effects on primary production.

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6. The Likely Effect of Climate Change on Quality and Yield of Rice

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Introduction

Climate change is likely to affect rice yield as well as grain quality, which would ultimately affect the food security and the economy of the country, because rice is not only the staple food but also a source of employment to millions of people. Rice cultivation has a wide geographic distribution; it is perhaps the only crop that grows in a variety of climatic conditions varying from mountaintops to the coastal saline areas and accounts for 35-75% of the calories consumed by more than three billion Asians (Khush, 2007). Climate change comprises increase in temperature, increase in frequency, intensity, and duration of droughts, floods, and tropical storms; changes in the intensity, timing and spatial distribution of rainfall; soil degradation; and sea level rise which may amplify soil salinity, reduce rice production in a sizable portion of the highly productive rice land in deltas. The strong effects of drought on grain yield are largely due to the reduction of spikelet fertility and panicle exertion. Rice diseases such as rice blast, sheath, and culm blight may become more widespread. Climate change may also affect weed population. Today, India is self sufficient in rice production and stands among the top three exporters of rice. Thus, the current focus is on improving rice grain and nutritional quality as the consumer now demands quality rice. But the changes in climate scenario as elaborated above are likely to affect the quality and yield of rice adversely. Hence, emphasis is to be given on understanding the impact of global warming and rising levels of greenhouse gases in the atmosphere on rice yield and grain quality. Rice grain quality means different things to different people. Therefore, we need to deliberate briefly on grain quality, before we try to understand how climate change might affect it.

What is rice grain quality?

Rice grain quality is a complex trait; its concept varies with the consumer preference and the purpose (end use). The term refers to the visual (physical) characteristics and chemical composition, which decide the marketing quality, cooking and eating quality and the nutritional quality of rice. Being a varietal trait, the grain quality depends on genetic constitution. However, the cultural practices, environment and post harvest practices play an important role in shaping the final product. It is the individuals, who decide what kind of rice they want; and since taste/likings differ from region to region, the job of the rice quality scientist is to translate the consumer preference for quality (visual, cooking eating, etc.) into measurable physical and chemical parameters, which can be ultimately traced to a particular gene (s). Since most of the rice (almost 95%) is consumed as *cooked whole grain*, the grain quality characteristics assume much more importance for rice compared to other food crops, which are consumed as flour. Grain quality parameters are thus, the prime determinants of market price of rice.

Determining grain quality

The crop is harvested as paddy or rough rice at 20-22% grain moisture with the mature rice grain (caryopsis) enclosed within an inedible cover called hull or husk. Paddy is dried to a moisture content of 14% before processing and to 12%, if it is to be preserved for seed purpose. It takes about 3-4 months (ageing period) for the grain quality characters to stabilize, hence paddy grains are

analyzed for quality parameters after at least 3 months of harvest. Milling is done to remove bran and germ with minimum breakage of whole grain. To determine milling quality, the paddy is made free of immature grains, dockage and brought to 14% moisture level before further processing. It is now dehulled through rubber rollers to minimize breakage of grains to obtain 'brown rice' which has a colored (pink, brown, red, black) coating that is rich in vitamins, minerals, oil and other nutrients and is thus prone to infestation by insects and microbes. When the brown rice is passed through an abrasive whitening machine the colored coat is removed as brownish powder called *rice bran* and white rice grains so obtained called *milled rice*. Milled rice grains are further passed through a friction type whitening machine resulting into a smooth final product called *polished rice*, which we normally eat. It is produced commercially by millers, because it has longer shelf life and has a better appearance than the brown rice, but the latter is better in nutritive value than the former. *Thus, normally, it is the milled rice characteristics we refer to while describing grain quality.* Rice kernel with 75% or more of the average length of the whole kernel is called **head rice**. Percentage of head rice recovered during milling of paddy is called **head rice recovery (HRR)**. High HRR (> 60%) is the first condition for a variety to be successful. For long slender grains it may be between 55-60%. The sum total of the amounts of head rice and broken rice obtained from a paddy sample is called **milling recovery** which is generally about 70%. The millers prefer rice with high percentage of *hulling, milling and head rice recovery (HRR)*. Naturally, the *HRR is the single most important parameter that determines market price of rice, because most of it is consumed as whole grain.*

Physical characteristics of milled rice grains

An image analyzer is used to measure the size and shape of rice grains, which are important determinants of market price. These also form the important criteria to develop new varieties and also for trade. Unfortunately, different countries have their own classification of rice grains. In India, Ramiah's classification (Govindaswami, 1985) is followed to categorize grains and is given below:

Table 1: Rice grain classification followed in India

Grain type	Milled Grain Length (mm)	Length : breadth ratio
Long slender (LS)	≥ 6 mm,	≥ 3
Short slender (SS)	< 6 mm	≥ 3
Medium slender (MS)	< 6 mm	2.5 to 3.0
Long bold (LB)	≥ 6 mm	< 3
Short bold (SB)	< 6 mm	< 2.5

Features of quality rice

The desirable features in quality rice normally include: right shape, translucency, lack of chalkiness and cracks, high HRR%, excellent cooking properties (well separated grains, soft texture), good elongation ratio (ratio of lengths of cooked and uncooked grain) and good aroma (in scented rice). However, medium /long slender and translucent grains with high HRR, good cooking and eating quality (good elongating ability during cooking, tender, well separated grains, good mouth feel) and pleasant aroma are normally preferred.

Cooking quality

The prime indicator of good cooking quality of rice is that the cooked grain retains a firm shape and does not disintegrate during or after cooking. Varieties that do not meet this requirement

are not commercially successful. As starch forms the major part (about 90%) of rice kernel, the **cooking quality** is governed mainly by the packaging of starch molecules and the amylose: amylopectin ratio. The cooking quality is determined by measuring **alkali spreading value** (ASV), **gelatinization temperature** (GT) **water uptake** (WU) **value** , **volume expansion ratio** (VER), **kernel length after cooking** (KLAC), **elongation ratio** (ER), **gel consistency** (GC) and **apparent amylose %** (AC%).

The **Alkali spreading value** (ASV) is measured by treating six rice grains in a Petri plate with 10 ml of 1.7% KOH for 23 hours at 30°C and looking for disintegration of grains, on a 1-7 scale. **Gelatinization temperature**, (GT, the temperature at which the starch granules swell in water irreversibly losing their crystallinity) is indicated by alkali digestion. It ranges from 55-79°C for rice grains. GT is normally high for high amylose rice, but then low amylose rices have also been found to have high GT. The waxy or low amylose rices have more free sugars and maltodextrins giving it sweetness. The differential scanning calorimetry (DSC) gives the accurate measure of GT rather than ASV. These two are indicators of digestibility of a rice grain. **Water uptake value** (WU) is a measure of the volume of water absorbed by 100g of grains. **VER** (volume expansion ratio) is a measure of the increase in volume of rice after cooking. **KLAC** and **ER** (mean length of ten cooked rice grains divided by mean length of the raw milled grains) measure lengthwise elongation during cooking. **Gel consistency** (GC) measures the tendency of cooked rice to harden on cooling, especially for high amylose rices. Rices with soft GC cook tender and remain soft even upon cooling and hence are preferred by consumers. These are priority for breeding programme.

Apparent Amylose Content (AC): As the cooking and eating quality is determined mainly by amylose content, all rice improvement programs include amylose content as a parameter which is normally measured by the iodine binding capacity (IBC), although other methods like near infra red (NIR) grain analyzer, size exclusion chromatography (SEC) and Nuclear Magnetic Resonance (NMR) are also used.

Nutritional Quality: Rice is the staple food for half of the people on the earth. Being a cereal crop, it is rich in starch, contains little fat and on average 7% protein of excellent quality. Milled rice contains more than 80% **carbohydrates**, which include mainly sugars and starch. **In general, a low ambient temperature during grain filling results in increased amylose content in rice and vice-versa.** The high amylose rice shows high volume expansion and flakiness. The cooked grains are dry, less tender and become hard upon cooling whereas the low amylose rice cooks soft and sticky. The intermediate amylose rice is normally preferred the world over, except the places where Japonica rice is liked. Milled rice normally contains about 7% **total protein** though some grains contain up to 16% protein. The brown rice contains up to 2.8% **lipids**. Milled rice has 0.64% lipid and the rice bran contains 19% lipids, from which oil is extracted. Brown rice is richer in **minerals** compared to milled rice. Milling reduces percentage of P (from 0.28 to 0.06), K (0.21 to 0.05), Mg (0.10 to 0.015), Ca (0.013 to 0.008), Mn (17.7 to 5 ppm), Fe (12 to 5 ppm) Zn (27 to 16 ppm) and Cu (3 to 2.5 ppm) {Hunt *et al* 2002}. Brown rice is richer in **vitamins** than the milled rice because they are present mainly in bran. Most of them are lost to different degrees during milling and subsequent washing. Rice is a good source of vitamin E (tocopherols) and tocotrienols. Rice lacks in vitamins A, C and D. It is also poor in fiber. Basmati rices and some small or medium grain non-basmati rices have pleasant **aroma** and are classified under quality rices. The aroma of scented rice is mainly due to 2-acetyl 1-pyrroline (2-AP). Basmati rice contains about 0.09 ppm (milled grains) of 2-AP, which is about 12 times more than that present in non-aromatic rices. The 2-AP content is measured with a

GC-MS. For screening, freshly cooked rice is subjected to a sniff test in a test tube or raw rice is digested with dilute alkali. High temperature is most likely to reduce the 2-AP content in scented rices particularly the basmati rices, as the aroma compound is volatile in nature.

Climate change and rice grain quality

Rising levels of green house gases and increasing atmospheric temperature have already begun to exert adverse effect on global climate. Carbon dioxide level and temperature are two vital factors whose interaction will greatly determine the over all effect of climate change on agriculture in terms of quality as well as quantity of the produce. In India, a National Network Project titled 'Impact, Adaptation, and Vulnerability of Indian Agriculture to Climate Change' with an outlay of Rs 422 crores was launched in 2004 with focus on impacts of climate change on different sectors of agricultural production.

Carbon dioxide is essential to plant growth. Atmospheric carbon dioxide (CO₂) has increased about 35% since 1800 (from 280 to 380 parts per million [ppm]), and computer models predict that it will reach between 530 and 970 ppm by the end of the century (IPCC 2007). Currently, its amount in the atmosphere is 380 ppm, compared to oxygen (210,000 ppm).

Effects of increase in carbon dioxide

Increased CO₂ is expected to have positive physiological effects by increasing the rate of photosynthesis. The effect would be higher on C₃ crops (like rice) than on C₄ crops (such as maize), because the former is more susceptible to carbon dioxide shortage provided that microsporogenesis, flowering, and grain-filling are not disrupted by increase in temperature. For every 75 ppm increase in CO₂ concentration, rice yields will increase by 0.5 t/ha. Though there are some studies made on predicting the effect of climate change on the yield of important crops, studies on quality aspect are very few. Rice quality has the potential to change with elevated CO₂ levels, both alone and with increased temperature. High temperatures during the grain filling period are likely to adversely affect rice quality. Thus, rising CO₂ concentration in the atmosphere can have both positive and negative consequences.

Effects of increase in temperature

Grain yield of major crops including rice is reduced by 5-7% for every 1°C rise in mean daily temperature. This yield reduction is caused by heat stress, decreased sink formation, shortened growing period, and increased maintenance respiration. Temperatures beyond critical thresholds not only reduce the growth duration of the rice crop, they also increase spikelet sterility, reduce grain-filling duration, and enhance respiratory losses, resulting in lower yields and lower-quality rice grain. Rice is relatively more tolerant to high temperatures during the vegetative phase, but highly susceptible during the reproductive phase, particularly at the flowering stage. Unlike other abiotic stresses, heat stress occurring either during the day or the night has differential impacts on rice growth and production. High night-time temperatures have been shown to have a greater negative effect on rice yields, with a 1 °C increase above critical temperature (>24 °C) leading to 10% reduction in both grain yield and biomass. High day-time temperatures in some tropical and subtropical rice growing regions are already close to the optimum levels. An increase in intensity and frequency of heat waves coinciding with sensitive reproductive stages can result in serious damage to rice production (Stigter and Winarto, 2013). A separate study showed that rice yield declines by 10% for each 1°C increased in minimum or night time temperature during the dry season, whereas the effect of maximum temperature was found insignificant. The degree of high temperature damage depends to a

large extent on the rice variety and stage of development. During vegetative stage, an extremely high temperature reduces tiller number and plant height, and negatively affects panicle and pollen development. Rice plant exposure above 35°C for a few hours could lead to increased spikelet sterility by reducing pollen viability. During the reproductive stage, flowering is the most sensitive to high temperature in which heat stress might lead to stagnation in panicle dry weight. During ripening phase, high temperature affects cellular and developmental processes leading to reduce fertility and grain quality. Decreased grain weight, reduced grain filling, higher percentage of white chalky rice and milky white rice, and reduced grain amylose content are common effects of high temperature exposure during ripening stage in rice. An increase in temperature will speed up crop development and eventually shorten the duration of crop growth cycles. The shortening of such a cycle could have an adverse effect on productivity because senescence would occur sooner. Temperature increases are likely to cause increased evaporation from the soil and accelerated transpiration in the plants themselves which might cause moisture stress. Intensified evaporation will also increase the hazard of salt accumulation in the soil affecting grain quality in the process.

Chalkiness in rice as affected by high temperature: Grains with opaque areas (white belly, white centre, white back) in the endosperm caused due to loose packing of single starch granules and protein molecules is an undesirable trait (although Italians like it) as the chalky grains show more breakage on dehulling and milling compared to translucent grains and absorb more water (due to air spaces) during cooking resulting in soft cooked rice. Grain chalkiness is greatly affected by environmental conditions during cultivation. In some seasons, **cracking** of the rice grain is a significant problem. Most cracking occurs in the field and seems to be related to changes in grain moisture or to moisture cycles after the rice matures. It results in reduction in HRR, because cracked grains often break during milling. Such produce fetches low price in the market. Cracking also decreases the cooking quality of the grain. Rough handling of grain during harvest operations and during drying and processing also causes the grains to crack.

The endosperm of waxy rice is opaque but sometimes the endosperm of even the commonly eaten non- waxy rice grains also has opaque areas in an otherwise translucent grain. *Such grains are called chalky grains which break easily during hulling/ milling resulting in poor market price.* Chalkiness in the endosperm is caused due to loose packing of single starch granules and protein molecules and is thus an undesirable trait. Though basically a varietal character, chalkiness is greatly affected by environment.

There were varieties in the Philippines that were rarely chalky. Their panicles had very few secondary branches, indicating that panicle architecture is under genetic control and these genes play a role in chalk. It was reported by Resurreccion and Fitzgerald (2007) that high temperature reduces the time for which the panicle serves as sink. The grains on primary branches are of highest priority in the panicle and are translucent whereas grains on secondary branches are of lowest priority. As the supply of sugars from vegetative parts to panicle (sink) ceases the grain filling stops resulting in immature or chalky grains. Therefore, varieties with large panicles and high number of secondary branches (like IR 8) is more likely to form chalky grains when environmental conditions such as high temperature shortens the grain filling period (time for which panicle is sink) compared to those with a small panicle with fewer secondary branches (e.g., IR 60). The issue assumes importance in view of the present trend towards global warming. A single recessive gene *pgwc-8* (percent grains with chalkiness) is identified which controls chalkiness.

Effect of atmospheric CO₂ levels on chalkiness: In elevated carbon dioxide, the proportion of grains containing a high amount of chalk per grain will decrease, which will increase the market value of the grain and may help to alleviate the burden of climate change on rice farmers. As environmental conditions affect starch content, the climate change is likely to affect chalk, amylose and GT. The positive effect of high CO₂ are not likely to compensate for negative effects of high temperature on grain quality. With a temperature rise of just 2^o C sufficient to trigger the trait, researchers have noted that a 4^o C increase could ruin entire crops, except for particular uses such as *risotto* and *sake*.

Experiments were done with rice plants grown at 26^o C and 33^o C. It was found that at the higher temperature, plants had only half as many days in which to make grain (14 compared with 30). Thus the time devoted to grain production is reduced by high temperature. At one extreme, the plant attempts to fill all grain, resulting in high yields of low-quality, chalky rice. At the other end, the plant sacrifices half the grain, resulting in low yields of high-quality grain. Variation in this stress response was also found to be under genetic control. Thus, scientists suggest for minimizing secondary branching in the panicle, extend the time available for grain filling, and select for a heat-stress response that avoids chalking. In dry season (2013-14), protein rich rice variety Heera showed very high degree of chalkiness as it faced high temperature spell for a long period of time at CRRI farm.

Effect of climate change on amylose content, gel consistency and gelatinization temperature: Amylose content of rice grain, a major determinant of cooking quality is increased under elevated CO₂ conditions. Thus, cooked rice grain from plants grown in high-CO₂ environments in future would be firmer than that from plants grown today. When the quality traits of varieties grown in four combinations of temperature and carbon dioxide levels were assessed (Zhong et al, 2009) the negative impact of temperature on grain quality was unable to be overcome by an increase in carbon dioxide. Four cultivars with different amylose content (AC) were subjected to two temperature treatments, referred as optimum (mean daily air temperature, 22 °C) and high (32 °C) temperature regimes starting from flowering stage until maturity. Effect of high temperature on AC and GC (gel consistency) in milled rice was found to be cultivar-dependent. Under high temperature, AC increased for cv. Jiayu353 and remained little changed for cv. Guangluai4, which had intrinsically higher AC, and decreased for cv. Zhifu49 and cv. Jiazao935, which had lower AC. By contrast, high temperature reduced or kept stable GC values for cultivars with higher AC and increased GC values for those with lower AC. Moreover, high temperature significantly increased the GT of all cultivars. Pasting profiles and X-ray diffraction pattern of rice were also affected by temperature. The results suggest that high temperature during grain filling change the component and crystalline structure of starch and result in deterioration of eating and cooking quality for early-season *indica* rice.

How does climate change affect nutritional quality of rice grains: Rising atmospheric concentrations of carbon dioxide could dramatically influence the performance of crops, but experimental results have been highly variable. For example, when C₃ plants are grown under carbon dioxide enrichment, productivity increases dramatically at first. But over time, organic nitrogen in the plants decreases and productivity diminishes in soils where nitrate is an important source of this nutrient. In C₃ plants, elevated carbon dioxide concentrations inhibit photorespiration, which in turn inhibits shoot nitrate assimilation. Thus, agriculture would benefit from the careful management of nitrogen fertilizers, particularly those that are ammonium based. Many crops depend on nitrate as their primary nitrogen source. As atmospheric carbon dioxide concentrations rise and nitrate

assimilation diminishes, these crops will be depleted of organic nitrogen, including protein, and food quality will suffer (Taub et al 2008).

Grain protein in rice (Terao et al. 2005) declined by about 10% at elevated carbon dioxide concentrations. Similarly, at elevated carbon dioxide and standard fertilizer levels, wheat had 10% less grain protein (Fangmeier et al. 1999; Kimball et al. 2001). In dry season (2013-14), protein rich CRRI variety Heera showed very high degree of chalkiness and reduction in protein content from 11% to 8%, as it faced high temperature spell for a long period of time in the farm. Several approaches could mitigate these declines in food quality under carbon dioxide enrichment. Increased yields may compensate to some degree for total protein harvested. Several-fold increases in nitrogen fertilization could eliminate declines in food quality (Kimball et al. 2001), but such fertilization rates would not be economically or environmentally feasible. Greater reliance on ammonium fertilizers and inhibitors of nitrification (microbial conversion of ammonium to nitrate) might counteract food quality decreases. Moreover, the protein content of the grain decreases under combined increases of temperature and CO₂ (Ziska et al., 1997). Studies have shown that higher CO₂ levels lead to reduced plant uptake of nitrogen (and a smaller number showing the same for trace elements such as **zinc**) resulting in crops with lower nutritional value. However, concentrations of iron and zinc, which are important for human nutrition, would be lower under high temperature stress (Seneweera and Conroy, 1997). This would primarily impact on populations in poorer countries less able to compensate by eating more food, more varied diets, or possibly taking supplements.

In grains of two japonica rice varieties Koshihikari and Sasanishiki, the sucrose synthase activity was higher than that of invertase which was significantly correlated with starch accumulation rate, indicating that the sucrose synthase played an important role in sucrose degradation and starch synthesis. Under high temperature, the significant increase in grain sucrose content without any increase in fructose and glucose contents, suggested that the high temperature treatment enhanced sucrose accumulation, while diminished sucrose degradation in rice grains. (Li Tian et al, 2005).

Summary

The traits of physical quality of rice grain include length, width, uniformity, weight, head rice yield, color (whiteness and translucence), chalk, and cracks. The cooking and eating characteristics of rice are determined by amylose content, gelatinization temperature, viscosity, texture of cooked rice, flavor and aroma. The nutritional quality depends on the chemical composition. Most of these rice grain quality characteristics are likely to be adversely affected by the climate change and global warming.

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7. Climate Change and Rice Cultivation: Special Reference to *SUB1*

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Abstract

Rice is often the only crop that can be grown in flood prone ecosystems whose productivity is greatly affected depending on the intensity and duration of rainfall, quality, depth and duration of standing water, flooding frequency, times of flooding, soil type and topography. India occupies largest area under rainfed low lands and flood prone ecosystem in Southeast Asia where average productivity between 0.5 and 1.0 t ha⁻¹. Uncertainty of rainfall is a major factor affecting the rice yield with flash floods affecting the plant stand seriously depending on duration of submergence stress which is considered the third most important constraint to high yield in India? Quality of flood water (pH, gas diffusion, turbidity) and light intensity affects plant survival tremendously and extrapolation of findings of one place to another is many times not correct due to soil and climate related factors. Submergence enhances ethylene accumulation in submerged internodes leading to their elongation and weakening the antioxidant defense. Rice varieties with higher non-structural carbohydrate content and limited elongating ability together with submergence tolerance are suitable for flood prone ecology. Varieties tolerant of such conditions are becoming available after the recent discovery and incorporation of *SUB1*, a major Quantitative trait locus (QTL) controlling submergence tolerance, into popular varieties. We evaluate the first submergence tolerant version of the popular variety, Swarna, under natural field conditions in flood-prone areas of Orissa, India, together with 3 submergence tolerant and 3 sensitive genotypes. The experiments were conducted under favourable rainfed lowland and controlled submergence at the experimental farm of the Central Rice Research Institute, Cuttack, as well as under natural farmers' field conditions during the monsoon seasons (2005-07). Introgression of *SUB1* had no adverse effect on yield and yield attributes of the popular variety Swarna under favourable rainfed lowland conditions. Under flash-flood conditions, rice cultivars with *Sub1* survived the complete submergence stress. Cultivars without *Sub1* completely perished due to complete submergence and did not produce any grain. The submergence stress was not so severe at farmers' field, yet cultivar with *Sub1* (e.g. Swarna-*Sub1*) gave greater economic yield compared to the cultivars without *Sub1*. Our results suggest that rice cultivar with *Sub1* has great potential in improving the productivity of rainfed lowland prone to flash-flooding. However, we can not get greater submergence tolerance comparable to FR13A. Swarna-*Sub1* was affected most compared to other cultivars under water-logged conditions (45-55 cm of water depth). Swarna-*Sub1* is quite short, and if water depth remains at or above the canopy level for longer than 2 weeks, the plants may not be able to elongate and continue growth, due to the *SUB1*-mediated suppression of elongation. It is advisable not to grow presently available *SUB1* cultivars where probability of waterlogging is more.

Introduction

Flooding affects vast rainfed lowland rice areas in Asia during the monsoon season. In deepwater and floating rice areas, water stagnates for longer duration, commonly more than a month, and genotypes adapt to these conditions through faster shoot elongation to avoid complete inundation (Sarkar et al., 1996; Setter and Laureles, 1996). Transient submergence for periods of up to two weeks can also occur in some areas, at any time and mostly more than once during the growing season because of flash floods caused by either heavy rains or outflow of near by rivers. This type of flooding

affects over 22 m ha of rainfed lowlands in South and Southeast Asia, of which, over 6 million ha are in India (Sarkar et al., 2006). Modern high yielding rice varieties are essentially sensitive to complete submergence; however, numerous tolerant landraces were identified before (Mackill et al., 1993). Physiological mechanisms associated with tolerance to flash-flooding during germination (Ismail et al., 2009) as well as during vegetative stage were extensively studied (Das et al., 2005; Sarkar et al., 2006; Panda et al., 2006, 2008).

In developing countries especially in Asia, food security means the availability of sufficient rice, the principal staple food. The area under rainfed lowland ecosystem is about 25% of the total cultivated area for rice, with the largest area being in irrigated ecosystem (54%) and smaller areas in upland and flood-prone ecosystems (13% and 9%, respectively) (Sarkar et al., 2009b). In the irrigated ecosystem, rice fields have assured water supply for one or more crops a year. The upland rice ecosystem varies from low-lying valleys to undulating and steep slopping lands with high runoff and lateral water movement. The flood-prone rice ecosystem is subjected to uncontrolled flooding, for as long as five months at a time with water depth of 0.5 to 4.0 m or more, and even intermittent flooding with brackish water caused by tidal fluctuations in coastal areas. Flooding is the main problem in these areas but rice could also suffer from intermittent drought and soil problems such as acid-sulfate, excess salinity and alkalinity.

Areas and duration of water stagnation

Rainfed lowland rice areas encompass a great diversity of growing conditions that vary based on the amount and duration of rainfall, depth and extent of standing water, flooding frequency, time of flooding within the growing season, soil type and topography. Based on hydrology, rainfed lowlands are broadly classified into five categories (Singh and Singh, 2000; Sarkar et al., 2009b):

- Shallow and favorable rainfed lowlands: rainfall and water control are more or less adequate. Short period of drought stress or mild submergence may occur, but are not a serious constraint. Supplementary irrigation may be available.
- Shallow and drought prone rainfed lowlands: growing conditions range from upland to lowland, the rainy period is about 90-110 days and water deficit may occur at any growth stage. Crops generally are not subjected to submergence. Soils vary from neutral to alkaline.
- Shallow, drought- and submergence-prone rainfed lowland rice areas: Complete submergence usually takes place due to heavy rains and overflow from adjacent rivers and streams. There also may be extended period of no rain and water deficit during the growing season. Soils generally have light texture and low fertility.
- Shallow, submergence-prone rainfed lowland rice areas: depth of flood water is usually shallow but complete submergence for up to 10 days or more may occur during periods of heavy rainfall.
- Medium deep, water-logged rainfed lowland rice areas: water accumulates and stagnates for 1 - 4 months because of impeded drainage. Water depth may vary from 25 to 50 cm.

Floodwater characteristics and plant physical and biological conditions affect survival during submergence:

Damage to plants caused by submergence could have several causes linked to floodwater conditions, particularly the interference in normal gas exchange and light interception. The adverse effects of flooding on rice varies with the genotype, and of particular importance are carbohydrate

status of the plant before and after submergence, developmental stage at which flooding occurs, duration and depth, and the level of turbidity and turbulence of floodwater (Setter et al., 1995; Jackson and Ram, 2003; Das et al., 2005; van Eck et al., 2005; Colmer and Pedersen, 2008). Aspects of the floodwater environment are commonly variable in different locations, and even over short distances. Since gas diffusion in water is 10,000 times slower than in air (Armstrong, 1979), restricted diffusion of the most important gases, oxygen and carbon dioxide, is considered the most limiting environmental factor under flooded conditions. The plant hormone ethylene also accumulates in plants during submergence because its diffusive escape is inhibited while its synthesis is promoted by flooding (Jackson et al., 1987). Enhanced ethylene concentration in submerged plants could promote (i) underwater elongation during submergence as observed in rice (Jackson, 2008), and in *Rumex palustris* L. (Voeselek et al., 1993) and (ii) chlorophyll degradation and leaf senescence (Sarkar et al., 1996; Panda et al., 2006, 2008; Sarkar and Panda, 2009) that may reduce photosynthetic carbon fixation during and after submergence. Both elongation growth and reduction in concurrent carbon fixation during submergence can result in the depletion of carbohydrate reserves with the consequent increase in plant mortality. Elongation during submergence is undesirable because its demand for energy competes with maintenance processes, and its adverse effects on survival after complete submergence had been reported before (Setter and Laureles, 1996; Das et al., 2005). Processes and conditions that enhance plant elongation under complete submergence could therefore, counteract plant survival.

Another important attribute is the poor light transmission through floodwater, particularly in the presence of thick algal growth or higher water turbidity (Whitton et al., 1988; Setter et al., 1995; Das et al., 2009). Light reaching the leaves of submerged plants is attenuated by water, dissolved organic matter, silt and /or phytoplankton suspended in the floodwater. When floodwater is turbid, only a scanty amount of solar radiation reaches the canopy level and thus limits the capacity of plants for underwater photosynthetic carbon fixation (Setter et al., 1995; Das et al., 2009). Sediment load in floodwater, cloudiness during the monsoon season and the depth of water also affects light transmission and the extent of shading of submerged plants. Increased shading during submergence causes greater injury and promotes plant mortality in rice (Jackson and Ram, 2003). The underwater light regime is also a major controlling factor of CO₂ and O₂ concentrations in floodwater that determine the extent of photosynthesis and metabolism of submerged plants (Ramkrishnayya et al., 1999; Panda et al., 2006, 2008). The importance of photosynthesis during submergence in rice was supported by the results of experiments in which CO₂ concentration was manipulated by altering floodwater pH. Low water pH or enhanced concentration of CO₂ is known to enhance photosynthesis under submerged conditions and improve survival (Ramkrishnayya et al., 1999). Low water temperature may decrease respiratory costs, since both the rates of anaerobic and aerobic metabolism decreased at lower ambient temperature (van Eck et al., 2005; Das et al., 2009). An indirect effect of lower water temperature is the higher solubility of oxygen in cold water compared to warm water, which could help avoid damage due to tissue anoxia.

Discovery of *SUB1* and marker added selection / backcrossing

Submergence tolerance seems genetically simple, though environmental factors play a greater role in survival (Xu and Mackill, 1996; Xu et al., 2006; Das et al., 2009). The Indian cultivar FR13A is the most widely studied and used as a source of submergence tolerance in rice breeding, and a major QTL, designated *SUB1*, was identified that controls most of the submergence tolerance of this genotype (Xu and Mackill, 1996). Mazaredo and Vergara (1982) reported that submergence tolerant

cultivar Goda Heenati did not have the same submergence tolerance gene in the same locus relative to the other tolerant cultivars as demonstrated by the large number of dead plants in the F₂ of the cross of Goda Heenati with three other tolerant cultivars. However, recent studies have shown that the *Submergence-1* (*SUB1*) locus, which encodes a variable cluster of up to three ethylene-responsive factor (ERF) genes: *SUB1A*, *SUB1B*, and *SUB1C* present both in FR 13A and Goda Heenati (Fukao *et al.*, 2009). Interestingly, the occurrence of the submergence tolerance-conferring haplotypes of the *SUB1* locus (*SUB1A*, *SUB1B-1*, -3, -6, *SUB1C-1*) in both *aus* (FR 13A, Orissa, India) and *indica* (Goda Heenati and Kurkaruppan; Sri Lanka) most likely reflects human selection of the submergence tolerance trait in two geographic regions (Fukao *et al.*, 2009). An orally chronicled migration of followers of an outcast prince from the Orissa region to Sri Lanka circa 500 BC is supported by recent molecular studies of the frequency of subtype alleles encoding human leucocyte antigens (HLA-A*02) in Sri Lankan and eastern Indian populations (Malavige *et al.*, 2007). Hence, it is feasible that rice with the submergence tolerance-conferring *SUB1* haplotype was transported by immigrants and subsequently introgressed into local *indica* varieties grown in Sri Lanka. The *SUB1* haplotypes that confer submergence tolerance has limited distribution amongst rice cultivars but may have been prized by rice farmers with submergence-prone paddies in Orissa and Sri Lanka (Fukao *et al.*, 2009).

***SUB1* and submergence**

SUB1, a major QTL for submergence tolerance that accounted for 69 % of the variation in tolerance was mapped on chromosome 9 in a donor line IR40931-26-3-3-5 derived from FR 13A (Xu and Mackill, 1996). Nandi *et al.* (1997) using the amplified fragment length polymorphism (AFLP) technique reported the presence of a major gene for submergence tolerance on chromosome 9. Other QTLs associated with submergence tolerance were also detected on chromosomes 6, 7, 11, and 12. Toojinda *et al.* (2003) found several major QTL determining plant survival, plant height, shoot elongation, visual tolerance score and leaf senescence each mapped to the same locus on chromosome 9. These QTL were detected consistently in experiments across all years and in the genetic backgrounds of all mapping populations. Secondary QTL influencing tolerance were also identified and located on chromosome 1, 2, 5, 7, 10 and 11. These QTL were specific to particular traits, environments, or genetic backgrounds.

SUB1 locus has been fine mapped, paving way for its positional cloning (Xu *et al.*, 2004). Xu *et al.* (2006) mapped the *SUB1* locus to the interval of 0.06 centimorgans, which contained three ethylene-response-factor (ERF) genes *SUB1A*, *SUB1B* and *SUB1C*. *SUB1B* and *SUB1C* were conserved in all analyzed rice varieties; whereas *SUB1A* was absent in some varieties namely M202 and Nipponbare. *SUB1A* and *SUB1C* transcript levels were shown to be up-regulated by submergence and ethylene, with the *SUB1C* allele in M202 also up-regulated by treatment with gibberellic acid (GA). These findings demonstrate that the *SUB1* region haplotype determines ethylene- and GA-mediated metabolic and developmental responses to submergence through differential expression of *SUB1A* and *SUB1C*. Submergence tolerance in lowland rice is conferred by a specific allele variant of *SUB1A* that dampens ethylene production and GA responsiveness, causing quiescence in growth that correlates with the capacity for re-growth upon de-submergence (Perata and Voesenek, 2007; Bailey-Serres and Voesenek, 2008).

SUB1A has two alleles: tolerant allele *SUB1A-1* and intolerant allele *SUB1A-2*. Enhanced tolerance in *SUB1A-1* transgenic in tolerant plants confirmed that *SUB1A-1* was the major genetic determinant for submergence tolerance (Xu *et al.*, 2006). These findings establish the foundations of a marker-assisted scheme for introducing submergence tolerance into agriculturally desirable cultivars

of rice. The *SUB1* region had been successfully introgressed into Swarna, KDML 105 (Siangliw *et al.*, 2003; Neeraja *et al.*, 2007) and many more (Septiningsih *et al.*, 2009). Work is in progress at Central Rice Research Institute, Cuttack to incorporate submergence tolerance gene *SUB1* into popular lowland rice varieties (e.g Savitri, Gayatri and Sarala) using the tolerant line i.e. IR 49830-7 as donor through marker-assisted backcross breeding technique (Reddy *et al.*, 2006). The submergence tolerant elite line IR49830 (-7-1-2-2), whose ancestral line includes FR13A, IR42 and IR48, was originally produced at IRRI in the 1980s.

Impact of Sub1 on plant survival and plant productivity

FR 13A selected from a local cultivar “*Dhullaputia*” grown in Orissa, India and released in the 1950s is the source of *SUB1*. Recently through marker-assisted breeding, *SUB1* has been introgressed in ‘Swarna’, a popular rice cultivar of South and Southeast Asia. Whether introgression of *SUB1* has any adverse effects on yield and yield attributes needs to be understood not only for commercial cultivation but also for future development.

Mechanism associated with submergence tolerance having SUB1 QTL

The cultivar with *SUB1* QTL shows lesser elongation and greater survival under submergence (Sarkar *et al.*, 2006b). Total non-structural carbohydrate (NSC) content after de-submergence was significantly higher in cultivars with *SUB1* compared to the cultivars without *SUB1* with better activities of carbohydrate utilizing enzymes alcohol dehydrogenase (Panda *et al.*, 2007b). Chlorophyll content decreased with increased period of submergence and the rate of degradation was significantly higher in cultivars without *SUB1*. Quantification of chlorophyll fluorescence transients (JIP-test) revealed cultivar with *Sub1* maintained chloroplast structural and functional abilities in a greater extent compared to the cultivars without *SUB1* (Sarkar *et al.*, 2006b; Panda *et al.*, 2007b). Under mild stress, in general, mortality in rice is very less yet extensive damage of leaves occurs, however, the damage is almost nil in Swarna-*Sub1* due to the maintenance of higher antioxidant enzyme activities (Das *et al.*, 2007).

Growth and yield performances of submergence tolerant and intolerant rice cultivars with and without SUB1 under favorable lowland and simulated submerged conditions:

We evaluated the first submergence-tolerant version of a popular variety, Swarna, under natural field conditions in flood-prone areas of Orissa, India, together with a few submergence-tolerant and sensitive genotypes. The experiments were conducted under favorable rainfed lowlands and controlled submergence at the experimental farm of the Central Rice Research Institute, Cuttack, India, as well as under natural farmers’ field conditions during the monsoon seasons of 2005 to 2007. We observed that introgression of *SUB1* had no adverse effect on yield and yield attributes of the popular variety Swarna under favorable rainfed lowland conditions. However, under flash-flooding, genotypes with *SUB1* survived complete submergence stress with turbid water for up to 12 days, whereas genotypes without *SUB1* did not survive. The submergence stress was not so severe in farmers’ fields, yet Swarna-*Sub1* produced higher grain yield than Swarna at all sites, with a yield advantage of up to 1.65 t ha⁻¹ (an average of 0.81 t ha⁻¹ over 5 sites). The results suggest that rice genotypes with *SUB1* have great potential for improving the productivity of rainfed lowland rice prone to flash-flooding (Sarkar *et al.*, 2009).

Stagnant water tolerance

The evaluation of the three converted mega varieties under submergence stress showed that all *SUB1* varieties had significantly higher grain yield under complete submergence compared with the original recipient parents (Fig. 1). Swarna-*Sub1* was affected most compared to other cultivars under water-logged conditions (45-55 cm of water depth). Swarna-*Sub1* is quite short, and if water depth remains at or above the canopy level for longer than 2 weeks, the plants may not be able to elongate and continue growth, due to the *SUB1*-mediated suppression of elongation. This problem does not seem to occur in *SUB1* varieties with taller plant stature, such as IR49830 (personal observation). This variety is taller compared with the first three converted *SUB1* varieties. This observation suggests that *SUB1* should be introgressed into taller plant types for areas where both stagnant water and submergence stress occur.

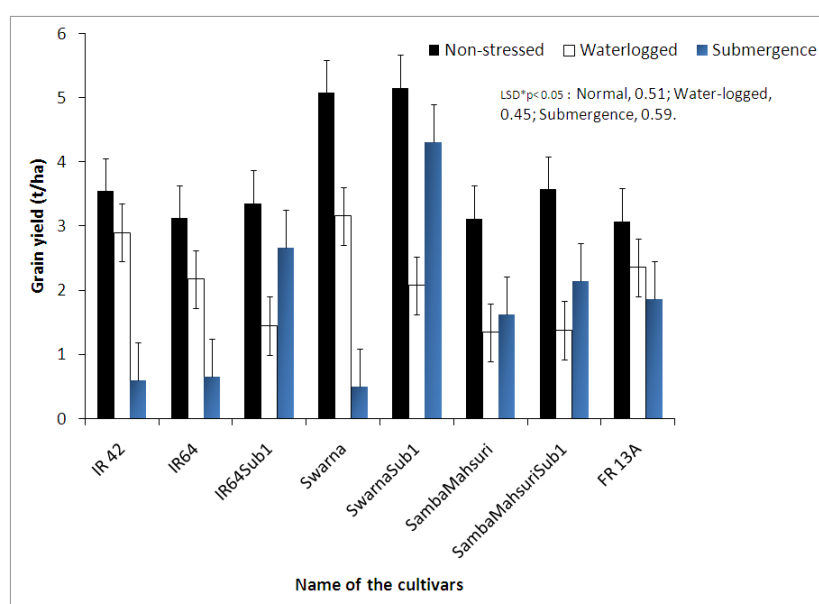


Fig. 1. Grain yield production of cultivars with and without *Sub1* under non-stressed, water-logged and complete submergence.

Inference about *Sub1*

Under favourable rainfed lowland conditions, *SUB1* as such has no deleterious effect on yield and yield attributes. Besides, there was not much variation between Swarna and Swarna-*Sub1* in respect of yield and yield attributes. Greater yield was realized from IR 49830-7, which also possessed *SUB1* QTL. Care should be taken to select the parent materials before introgression of *SUB1*. The cultivar with better initial vigour is the best choice for the introgression of *SUB1*. Introgression of *SUB1* in a cultivar increases its submergence tolerance. However, we can not get greater submergence tolerance comparable to FR 13A. It suggests that we have to look for new Genes/QTL in realizing greater submergence tolerance. The dramatic effect of *SUB1* on what is essentially a quantitative trait suggests a regulatory locus rather than a specific enzyme action. Prolonged stagnation of water decreases the grain yield production in a greater way in cultivars with *SUB1* (e.g. Swarna-*Sub1*) compared to those without it (e.g. Swarna).

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NOTES

8. Nutrient Management in Rice under Flood-Prone Areas

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Introduction

The flood-prone ecosystems of South and Southeast Asia are characterized by a great diversity of conditions, particularly timing, duration, and intensity of rainfall and floods. Soil types, topography, and prevailing biotic and abiotic stresses also vary considerably. These flood-prone ecosystems include shallow, flash-flood areas, medium (partial stagnant), deep and very deep waterlogged areas, and tidal wetlands. In South and Southeast Asia, approximately 22 million ha of rice lands are flood-prone and more than 100 million people primarily depend on this ecosystem for their livelihood (Hossain and Abedin, 2004; Sarkar et al., 2006; Ismail et al., 2013). About 13 million ha of deepwater and tidal wetland rice lands are cultivated every year in South Asia and an estimated additional 18 million ha are not being used in South and Southeast Asia because of floods (Singh et al., 2004). In deepwater areas, rice is dry-seeded in April or May and the crop initially grows on limited soil water, followed by shallow flooding for a couple of months after the commencement of rain in June and July. At the later stages of growth, deepwater rice is subsequently inundated for the remaining period to a depth of more than 1 m. Deepwater rice area is found in river basins of the Ganges and Brahmaputra in India and Bangladesh, Myanmar, Vietnam, Cambodia, and Thailand. Tidal wetlands are located in coastal areas where water regime fluctuates, depending on the tides, and rice in these areas experiences variable levels of submergence and even salinity in areas close to the sea.

The flood-prone ecosystem varies in flooding duration, and intensity, ranging from a short duration of 1-2 week of flash floods to more than 6 months of deep stagnant water logging. This ecosystem is also characterized by a large genetic diversity of adapted rice cultivars, holding enormous potential for crop improvement. Four different types of tolerance responses seem to satisfy the basic requirements of this ecosystem:

- (i) Cultivars with high tolerance for submergence with minimum underwater shoot elongation, for flash-flood-prone areas where complete submergence predominantly occurs for 10–14 d. Now-a-days varieties were developed for submergence tolerance by incorporating SUB1A gene.
- (ii) Cultivars with rapid underwater shoot elongation for deep and very deep water areas,
- (iii) Good submergence tolerance with rapid regeneration ability for repeated intermittent flood conditions, and
- (iv) Cultivars with tolerance for stagnant floods that can occur independently of or subsequent to flash floods and can result in partial submergence for longer duration.

In eastern India, about 13 million ha of rice lands are prone to floods, causing partial to complete submergence every year. The rice crop suffers from too little or too much water during early stages, depending on the onset of rains and time of sowing. At the later stages, mostly a couple of inundations occur due to rains in August and September. High seedling mortality and low tiller production are the main reasons for low productivity of rice in these flood-prone areas.

Factors affecting survival and crop establishment

Crop establishment

Poor crop establishment is one of the major factors contributing to low productivity in flood-prone ecosystems. Successful crop establishment in these ecosystems is dependent on rainfall, land type, rice variety and germination. Direct seeding and transplanting are the two methods adopted by farmers for crop establishment. However, the choice of either method is dependent on the availability of rainwater and other resources. In direct seeded areas, tolerance for flooding during germination is also required as submergence or waterlogging is often experienced as a consequence of early rains, resulting in poor germination and crop establishment (Ismail et al., 2013).

In flood-prone areas, mostly traditional tall and photoperiod sensitive varieties, either with a reasonable level of submergence tolerance to withstand complete inundation or with elongation ability to escape submergence, are grown through direct seeding or transplanting. Farmers in flood-prone areas practice two types of direct seeding: dry and wet. Dry direct seeding is very common in India, Bangladesh, Sri Lanka, Thailand, Indonesia, Myanmar, and the Philippines (Singh et al., 2004). Dry seeding is done by broadcasting seeds on dry soil in May before the beginning of the monsoon rain, which can then germinate and grow after the first showers. This type of direct seeding is risky since germination is poor and seeds are inevitably subject to damage by birds, rodents, and ants. Farmers use higher seed rates than the recommended levels to compensate for these losses.

The most successful direct seeding is in wet soils through drilling or dibbling after the first light shower, which ensures good seed germination. However, the growing crop could also suffer from intermittent early-stage drought if rains are delayed after seeding. Delayed seeding may also subject germinating seeds to water logging or submergence at early stages in July. A sizeable area in semi-deep and deepwater ecosystems in Orissa, West Bengal, and eastern Uttar Pradesh falls under this category.

Both systems of direct seeding have their advantages and disadvantages and can be used depending on the onset and intensity of rains. Late-sown crop after the first showers of rain can result in good germination but is prone to early-stage submergence just after germination. At times, this leads to complete crop failure. The loss in yield with delayed sowing will not be compensated for even by the use of 50% higher seed rate and nitrogen (N) fertilizer (Sharma, 1994). On the other hand, a poor and uneven crop stand usually results from the use of dry seed broadcasting due to loss of seeds and staggered germination, and the resultant plants can hardly withstand eventual submergence caused by subsequent rains. Drilling of seeds at 6 cm depth and light planking are the best options in such areas. However, in some soils, surface crusts are formed when light rains (<10 mm) occur after dry seeding, and then followed by prolonged dry spells, hampering the emergence of young rice seedlings. Dry cluster dibbling/drilling of seeds is a useful technique that results in better crop establishment and also facilitates mechanical weed control and fertilizer application.

Light intensity, water turbidity and flood water conditions

Plant survival after submergence is dependent on various aspects of flood water, including depth, duration of submergence, turbulence and extent of water turbidity (Das et al., 2009). The

greater reduction in survival in turbid water could therefore be partially attributed to the greater impairment of light transmission at the canopy level (Das et al., 2009). Panda et al. (2006) reported that submergence under darkness (due to turbidity) decreased the survival percentage in rice due to the degradation of chloroplast, structural and functional integrity and severe inhibition of photosynthesis. The high amount of water turbidity created lower oxygen concentrations, probably because light intensity at the canopy level was extremely low (Das et al., 2009). Silt deposition might be another reason for decreased photosynthesis in turbid water, as silt particle on the leaf surface clogged the stomata and hampered the stomatal conductance reflecting in lower Pn rate.

Nutrient management during and after submergence

Most of the Asian farmers do not apply the N and P fertilizers with a belief that the rice crop may not give response to fertilization under flood water stress situations and also due to high risk involved in successful production of crop and runoff losses during floods. They normally apply 40–50 kg N, 15–25 kg P₂O₅, and 10–15 kg K₂O ha⁻¹ against the recommended rates of 60–80 kg N and 40 kg P₂O₅ (Pathak, 1991). Most of these farmers do not apply fertilizers before transplanting or direct seeding because of extensive inundation during heavy rains that can break their field bunds and result in fertilizer losses. At the recession of terminal floods, several farmers broadcast only nitrogenous fertilizers at a very low rate against the recommended split dose of fertilizer (1/2 basal before planting and remaining half at panicle initiation). Fertilizer application of 30–40 kg N ha⁻¹ is optimum for deepwater areas, but farmers seldom apply any fertilizer. Deepwater rice areas normally receive sufficient organic matter and nutrients during floods and are supposed to sustain good crop growth. However, nitrogen application at the time of flowering is essential since a sizeable amount of nutrients are lost due to runoff, volatilization, and deep percolation during floods. Since submergence in flood-prone areas affects crop establishment more seriously than other crop performance indicators, the solution lies in nursery management and “hardening” of the seedlings prior to transplanting for better crop establishment.

Nutrient management in rice grown under flood prone situation

Soils in flood-prone ecosystems in India and Bangladesh are rich in nutrients because of deposition of sediments carrying nutrients from the upper catchments during floods. However, the benefits of high fertility are realized in the form of better harvests from succeeding post-flood crops. During the wet season, plants are normally too stressed to exploit the nutrients in floodwater and sediments due to poor crop establishment and growth caused by flooding. A number of new varieties have been developed by the introgression of the Sub1A gene and these varieties can ensure rice production in flood-prone areas because of their tolerance to complete submergence (Mackill et al. 2012). The availability of tolerant varieties provides more opportunities for developing and validating proper management options effective in flood-prone areas, which could further boost and stabilize the productivity of these varieties (Ella and Ismail 2006; Gautam et al., 2014a). However, nutrient recommendations have not been specially developed for flood-prone areas and farmers often avoid using inputs as a risk aversion strategy. Therefore, improving plant health through nutrient management may lead to better crop establishment. It is unclear if some nutrient elements can actually increase submergence tolerance if applied at rates above balanced applications. Nutrient management under submergence particularly N and P can also contribute substantially towards increasing productivity in flood-prone areas. There exists vast possibility for increasing rice production and harnessing the productivity potentials of submergence-affected areas with the use of submergence-

tolerant varieties, particularly when combined with best nutrient management practices specific for these areas.

Nutrient management in the nursery

Submergence greatly affects N and P availability and assimilation, which can influence submergence responses and which have been implicated in differences in tolerance between cultivars. Submergence rapidly depletes the protein reserves of the plants through hydrolysis to amino acids and other soluble N-containing compounds (Yamada 1959). Palada and Vergara (1972) found the normal increase in percentage N content that occurs between 10 and 20 d after germination (from 3.1 to 4.3%) to be hindered by submergence or even reversed if the water was turbid. However, attempts to raise N levels by feeding ammonium sulfate was not beneficial and even prejudicial to survival (79% survival without vs 15% survival with ammonium sulfate application), an effect associated with 61% and 34% decrease in pre-submergence starch and total sugar concentrations, respectively. Furthermore, submergence-tolerant cultivars are not noticeably richer in N after prolonged submergence than intolerant. Yet, when nitrate concentration was analyzed before submergence, the shoots of tolerant lines such as FR13A were found to be much richer in nitrate than that of sensitive types.

The nutritional status of seedlings before transplanting is also of immense importance, especially when plants are submerged during the early growth stages. Farmers' convention of applying only nitrogenous fertilizers in the nursery to get taller and greener seedlings may not have any positive consequence for flood-prone areas, since the high N content in seedlings at the time of transplanting adversely affects survival after submergence and results in poor recovery growth. However, when high N is accompanied by high P content, it seems to improve seedling vigor and tolerance to withstand ensuing submergence stress and with effectively better recovery afterwards (Jackson and Ram, 2003; Ella and Ismail, 2006; Gautam et al., 2014b; Lal et al., 2014). Singh et al (2004) also pointed out the harmful effects of high N application in the nursery when applied 1 week before transplanting. However, application of N 10–15 d prior to planting reduced plant mortality by 50% when the soil is N-deficient. Ella and Ismail (2006) and Gautam et al. (2014b) observed poorer plant survival when high N was applied late (just before transplanting) relative to early N application, irrespective of the tolerance level of the genotype. In contrast, application of P, either alone or together with N, improved the survival of plants in P-deficient soil after 12 d of complete submergence. High leaf N before submergence showed a negative correlation with photosynthetic gas exchange during the recovery phase after desubmergence. Leaf chlorophyll content increased with application of N either alone or in combination with P, and the response was better in P-deficient soil. Late N application showed lower relative chlorophyll content during the first 3 d of recovery, with maximum recovery being noted in control plants (Ella and Ismail, 2006).

Increasing levels of N application before submergence were not beneficial but instead were pre-judicial to survival (Yamada, 1959; Jackson and Ram, 2003; Gautam et al., 2014b; Lal et al., 2014), and resulted in depletion of chlorophyll and NSC (Gautam et al., 2014b; Lal et al., 2014). Soluble carbohydrates after submergence are more important for survival than at the initial level, Gautam et al. (2014a) reported that, IR-64 Sub 1 could survive better under submergence because it possessed 12.5% more NSC after submergence as compared to IR-64. Leaves are known to senesce more rapidly under the conditions of nitrogen deficiency. The senescence is accompanied by enhanced generation of ROS, whereas the activity of antioxidant enzymes could increase or decrease.

In a study, Gautam et al. (2014b) reported that foliar spray of post-submergence N resulted in higher plant survival, and maintained higher level of chl a & b content and NSC with encouraging effects in plants submerged under turbid water might be due to the fact that urea spray removed the adhering silt from the leaf surface and enable the plants to photosynthesize and survive. Foliar spray of post-submergence N with basal P seems to be beneficial, as application of P contributes to submergence tolerance, reduces the ethylene accumulation which ultimately helps in conservation and maintenance of carbohydrates while N spray helps in regeneration and survival, ultimately increasing submergence tolerance.

The yield advantage, achieved by raising crops from seedlings obtained from well nourished seedbeds, was 16–20% in one farmer's field at Faizabad where submergence stress was not very severe. In the other farmer's field, the benefit of nursery nutrient management was about 160%, when multiple floods occurred at three different growth stages (data not shown). This indicates that seedling health in the nursery is extremely important as it affects crop establishment and survival, especially when submergence occurs at the early stages of crop growth and also under recurrent floods. The beneficial effects of seedling health prior to transplanting seem to be more evident following severe submergence conditions and are directly related to seedling survival and rapid recovery growth after the recession of floods.

Proper nursery management can therefore substantially help enhance and stabilize productivity in flood-prone areas, provided that balanced nutrients are used and excessive early seedling growth is avoided (Ella and Ismail 2006; Gautam et al., 2014b; Lal et al., 2014).

Nutrient management in the main field

Nutrient management in the main rice fields before transplanting and also after the floods recede is also important for improving rice productivity in flood-prone ecosystems. Plant growth and yield depend not only on carbohydrate production through photosynthesis but also on mineral absorption by the roots and its assimilation. Rice crops in flooded soil absorb N both from the floodwater and the soil. Absorption of N fertilizer broadcast onto floodwater in the rice field is very rapid if fertilizer application is timed carefully to match the plant's demand. However, the N that is not absorbed rapidly is lost through gaseous emission, percolation, or runoff. Consequently, N fertilizer tends to be used very inefficiently even in irrigated ecosystems, where average recovery across Asia is less than 30%. The rapid uptake of N from the floodwater is due to surface roots in the water and in the adjacent topsoil. These roots differ morphologically and physiologically from those in the anoxic soil bulk. The entire N in flooded soil is absorbed in the form of NH_4^+ , which is the main available form of N. However, N is also absorbed as NO_3^- and amino acids in flooded rice fields, and plant growth and yield are generally improved when plants absorb N as a mixture of NO_3^- and NH_4^+ compared with either of them used separately (Kirk and Kronzucker, 2005).

In flood-prone areas of eastern India and Bangladesh, nutrient management activities are mainly done after the recession of the floods because of the inherent risks of crop loss if submergence is severe. Farmers mostly apply N after the floods for rapid recovery growth of surviving rice plants. Another option followed by the researchers to facilitate the slow release of N is to apply it through urea supergranules or coated urea coated or as foliar spray of post-submergence N for better survival and recovery of rice seedlings (Gautam et al., 2014c). Reddy and Sharma (1992) suggested that if the water level remains at an intermediate depth (~50 cm) in the field, 40 kg N ha⁻¹ as USG or neem cake-coated or coal tar-coated urea may be applied, together with 20–40 kg P₂O₅ in the seed furrow at the time of sowing. However, if the crop is transplanted, fertilizer may be applied as basal at the time of

final puddling or coated USG can be broadcast a few days later after transplanting. Singh et al (1992) reported that the placement of USG in the soil at a depth of 8–10 cm in about 15 cm of standing water resulted in higher yields than the basal application of either prilled urea or neem cake-coated urea during puddling. The efficacy of slow-release nitrogenous fertilizers is yet to be validated at a large scale in farmers' fields and at target locations, together with the consideration of its economic benefits. Submergence-induced membrane damage is one of the most serious threats to plant survival and plants need a large amount of energy for repair and maintenance processes under anaerobic stress. Supply of sufficient P might thus have positive impacts on submergence tolerance of rice plants, presumably through the maintenance of a high level of energy. Application of P at 80 kg ha⁻¹ as diammonium phosphate along with 60 kg N ha⁻¹ at sowing enhanced initial seedling vigor and shoot carbohydrate concentration before submergence. Plant survival after 7–10 d of complete submergence and regeneration growth during recovery were better in P-treated plants of several lowland rice varieties. However, P application 24 h prior to submergence did not show any beneficial effect on plant survival and recovery growth. Rock phosphate is a good source of P in flooded fields because of its slow release, which is further stimulated in acid soils. Ramakrishnayya et al (1999) reported that addition of P to floodwater during submergence reduced rice plant survival by 35%. The adverse effects of high P concentration in floodwater were mainly attributed to enhanced growth of algae that competed with the submerged plants for CO₂ and light. Application of P should therefore be considered both in the nursery and as basal rather than in floodwater.

The response of rice to post-flood nutrient management options in flood-prone ecosystems was least studied so far, though it has a strong bearing on regeneration growth and yield of rice plants after the floods, and suitable nutrient management strategies were highly demanded. Farmers in flood-prone areas mostly broadcast small amounts of urea without any solid recommendations. Possibilities of recurrent submergence during the season are one of the reasons for avoiding nutrient application. Hence, a complete package of post-flood nutrient management is essential to enhance the productivity of flood-prone rice areas. Yamada (1959) and Ella and Ismail (2006) reported that seedling enrichment with N before submergence adversely affected plant survival, later on Gautam et al. (2014a) confirmed that pre-submergence N application enhanced succulence of plants resulted in poor survival. In a study, Gautam et al. (2014c) foliar spray of post-submergence N resulted in higher plant survival, and maintained higher level of chl a & b content and NSC with encouraging effects in plants submerged under turbid water might be due to the fact that urea spray removed the adhering silt from the leaf surface and enable the plants to photosynthesize and survive. Pande et al. (1979) suggested that use of N through foliar spray after flash flooding resulted in better recovery and higher productivity of rice under waterlogged conditions. Basal P and post-flood N application either through broadcasting or foliar spray resulted in significantly higher tiller regeneration, biomass, leaf area, specific leaf weight, Pn rate and ultimately yield. Beneficial effect of N fertilizer on greater tiller survival was due to better initial crop vigor and carbohydrate accumulation, leading to increased tolerance of plants to submergence (Palada and Vergara, 1972). The recovery of plants subjected to simulate flash flooding was better with top dressing of N fertilizer after floods, as some of the partially damaged tillers regained growth and produced more dry matter (Sharma, 1995). Studies conducted in Bangladesh revealed that NPK application during the post-flood period have positive effects on growth and grain yield of rice. Nitrogen alone applied at a rate of 50 kg ha⁻¹ resulted in maximum tillers and grain yield, whereas N and K applied together at 20 kg ha⁻¹ each was most effective, showing a twofold increase in grain yield over unfertilized control. However, further studies are needed to test different nutrient combinations, doses, and the proper time for their application after

the water recedes. Valid recommendations can then be developed for different target sites based on local flood conditions, particularly the speed of water recession, possibility of subsequent floods, and water depth in the field following complete submergence.

Apart from nutrient management in flood prone areas, there is an urgent need to redesign flood-prone rice varieties to improve efficiency in nutrient uptake and utilization. To redesign the plant type for better nutrient use efficiency, we should focus on modifying root-shoot interaction to optimize and prolong root activity, which is strongly related to the system of carbohydrate supply to the roots during regeneration and recovery after the floods. Nodal roots also have an important role to play in nutrient assimilation from floodwater and can help sustain the growth of rice plants under flooded conditions.

Future directions

A wide knowledge gap still exists between researchers and farmers about the need and progress in rice technology development for flood-prone environments. Even the available technologies have not reached their target users because of the poor extension service networks in most of these areas. Poor characterization of the soil and hydrology of flood-prone environments also seems to limit technology development and adoption on a wider scale. One of the major constraints to rice productivity enhancement across flood-prone environments is the lack of seeds of suitable improved and nutrient-efficient and responsive varieties. Post-flood nutrient management for better recovery growth after recession of floods is also least studied and suitable technologies are still not available. Future research should therefore focus on

- i) Developing new varieties with a high level of tolerance for the prevailing flood type but are responsive to inputs and crop management;
- ii) Suitable management packages at different stages of crop growth and extensive testing and validation;
- iii) Integrating research results into extension efforts for rapid transfer to and adoption of effective practices by farmers; and
- iv) Developing strategies to incorporate effective management practices in seed delivery and validation in farmers' fields through farmer's communities, government and other institutional agencies and dissemination as a package with improved varieties to ensure wider adoption.

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NOTES

9. Multivariate Analysis using SAS Software

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Introduction of SAS

SAS is one of the best known and most widely used statistical packages in the world. Analysis using SAS are conducted by writing a program in the SAS language, running the program, and inspecting the results. SAS software is a combination of a statistical package, a data base management system, and a high level programming language. The SAS is an integrated system of software solutions that performs the following tasks:

- Data entry, retrieval, and management
- Report writing and graphics design
- Statistical and mathematical analysis
- Business forecasting and decision support
- Operations research and project management
- Applications development

SAS Foundation is one of the important SAS product. SAS Foundation is a highly flexible and integrated software environment that can be used in virtually any setting to access, manipulate, manage, store, analyze and report on data. SAS Foundation provides the following:

- a graphical user interface for administering SAS tasks.
- a highly flexible and extensible programming language
- a rich library of prewritten, ready-to-use SAS procedures
- the flexibility to run on all operating environments such as Windows, UNIX etc.
- the access to virtually any data source such as DB2, Oracle, SYBASE, SAP and Microsoft Excel
- the support for most widely used character encodings for globalization

At the core of the SAS System is the Base SAS software. In general, the Base SAS software has the following capabilities

- A data management facility
- A programming language
- Data analysis and reporting utilities

Opening SAS software

To open the Base SAS software, click on following commands

Start → All Programs → SAS → SAS 9.2 (English)

as shown in the figure 1 given below.



Fig. 1: SAS menu under the start menu

SAS Windows

When you will open the Base SAS software, you will see the three primary windows (Fig. 2).

- Program Editor: Contains the SAS program to submit.
- Log: Contains information about the processing of the SAS program, including and warning and error messages.
- Output: Contains reports generated by the SAS program.

By default, the output window is positioned behind the other windows. When you create the output, the output window automatically moves to the front of your display.

Apart from these three windows, the other two windows are Results and Explorer (Fig. 2). Result window helps to navigate and manage SAS program that has been submitted. Explorer window can be used to assign and locate SAS libraries, files and other items.

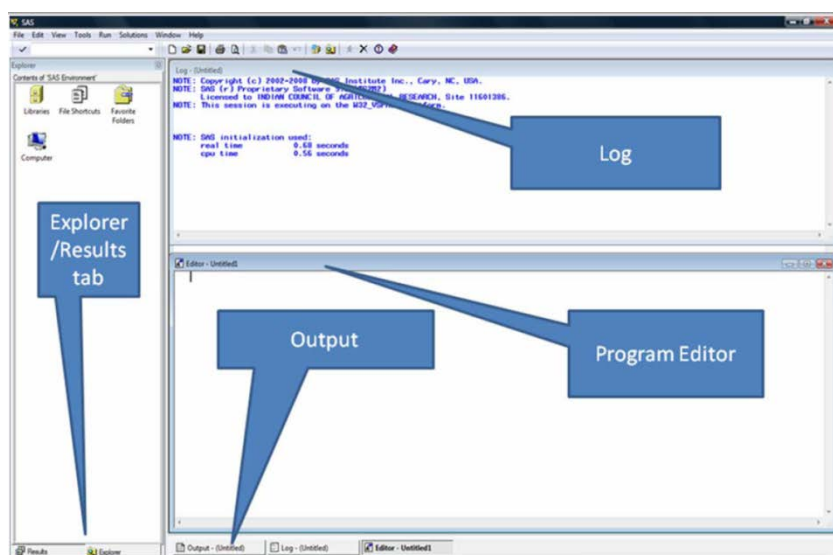


Fig. 2: SAS window

Rules for SAS Statements

- SAS Statements usually begin with an identifying keywords.
- SAS Statement always ends with a semicolon.
- Each SAS program must end with 'run' statement.
- SAS Statement can be started from any column of line and several statements can be written on the same line.
- SAS Statements can be begin on one line and continue it on another line, but cannot split a word between two lines.
- One can use upper case letters, lower case letters or the combination of the two.
- One or more plank spaces can be used to separate the words.

Rules for SAS Syntax

- SAS statements are free-format.
- One can use blanks or special characters can be used to separate words.
- Syntax can begin in any column.
- A single statement can span multiple lines.
- Several statements can be on the same line.

Basic sections of SAS program

Three basic sections of SAS program are

- Data section
- Cards section
- Proc section

The Data section creates the data sets that can be used in SAS program's analysis and reporting procedures. Usually SAS program starts with a Data to create a SAS dataset. Data section provides the information about name of the dataset, input variables used in the dataset etc. The input data are given in cards section. Different procedures applied on the data are given in the Proc section. Consider the following example. In the example, line number 1 and 2 is part of data section. Production is name of the SAS dataset. State and production are the input variable. Dollar sign is used when input variable is character. As states are character value, a dollar sign was used. Line number 3, 4, 5 and 6 are part of cards section. Here semicolon is given at the end of data. Line number 7 and 8 represents the Proc (procedure) section. Print procedure prints the data in the output window.

DATA production;	1
input state\$ production;	2
cards ;	3
Sikkim 24.30	4
Goa 100.6	5
;	6
Proc print DATA= production;	7
run ;	8

Multivariate Analysis

Biological, physical, behavioral, social, and educational phenomena are often determined by multifactor. Therefore, any systematic attempt to understand them requires the examination of multiple dimensions that are usually interrelated. The subject of multivariate analysis deals with the statistical analysis of the data collected on more than one variable. These variables may be correlated with each other. In practical, most data collection schemes or designed experiments results in multivariate data. Various statistical methods for describing and analyzing the multivariate data sets are Multivariate analysis of variance (MANOVA), Hotelling T^2 , Discriminant Analysis, Factor Analysis, Principal Component Analysis (PCA), Cluster Analysis, Canonical Correlation Analysis (CCA), etc. Here an attempt has been made to do some multivariate techniques like Principal Component Analysis, Cluster Analysis and Canonical Correlation Analysis by using SAS software.

Principal Component Analysis (PCA)

The purpose of principal component analysis is to derive a small number of linear combinations (principal components) of a set of variables that retain as much information in the original variables as possible. Often a small number of principal components can be used in place of the original variables for plotting, regression, clustering and so on. Principal component analysis can also be viewed as a technique to remove multicollinearity in the data. In this technique, we transform the original set of variables to a new set of uncorrelated random variables. These new variables are linear combinations of the originals variables and are derived in decreasing order of importance so that the first principal component accounts for as much as possible of the variation in the original data.

It is quite likely that first few principal components account for most of the variability in the original data. If so, these few principal components can then replace the initial variables in subsequent analysis, thus reducing the effective dimensionality of the problem. An analysis of principal components often reveals relationships that were not previously suspected and thereby allows interpretation that would not ordinarily result. However, Principal Components Analysis is more of a mean to an end rather than end in itself because this frequently serves as intermediate steps in much larger investigations by reducing the dimensionality of the problem and providing easier interpretation.

Example : Let us consider the data on average minimum temperature (x_1), average relative humidity at 8 hrs. (x_2), average relative humidity at 14 hrs. (x_3) and total rainfall in cm. (x_4).

The whole data with four variables can be converted to a new data set with two principal components using the SAS code given below:.

```
ods graphics on;
data pca;
input x1 x2 x3 x4;
cards;
25.0 86 66 186.49
24.9 84 66 124.34
25.4 77 55 98.79
```

```

24.4 82 62 118.88
22.9 79 53 71.88
7.7 86 60 111.96
25.1 82 58 99.74
24.9 83 63 115.20
24.9 82 63 100.16
24.9 78 56 62.38
24.3 85 67 154.40
24.6 79 61 112.71
24.3 81 58 79.63
24.6 81 61 125.59
24.1 85 64 99.87
24.5 84 63 143.56
24.0 81 61 114.97

```

```
;
```

```
proc princomp cov out=new;
```

```
var x1 x2 x3 x4;
```

```
proc print data=new ;
```

```
var x1 x2 x3 x4 prin1 prin2;
```

```
proc corr data=new ;
```

```
var x1 x2 x3 x4 prin1 prin2;
```

```
run;
```

SAS Output of the above dataset is:

Output - (Untitled)

Observations	17			
Variables	4			
Simple Statistics				
	x1	x2	x3	x4
Mean	23.55882353	82.05882353	61.00000000	112.9735294
Std	4.12553918	2.74933147	3.96862697	30.0645310
Covariance Matrix				
	x1	x2	x3	x4
x1	17.0200735	-4.1161765	1.5375000	5.1359669
x2	-4.1161765	7.5588235	8.5000000	54.8254044
x3	1.5375000	8.5000000	15.7500000	32.9456250
x4	5.1359669	54.8254044	32.9456250	903.8760243
Total Variance		944.20492132		
Eigenvalues of the Covariance Matrix				
	Eigenvalue	Difference	Proportion	Cumulative
1	916.903119	898.527591	0.9711	0.9711
2	18.375528	10.505165	0.0195	0.9905
3	7.870363	6.814450	0.0083	0.9989
4	1.055912		0.0011	1.0000
Eigenvectors				
	Prin1	Prin2	Prin3	Prin4
x1	0.005564	0.955110	0.141400	0.260269
x2	0.060795	-0.295805	0.484926	0.820762
x3	0.102982	0.011430	0.854784	-0.508536
x4	0.992808	0.011575	-0.119152	0.001031

Output - (Untitled)						
The SAS System 13:34 Wednesday, November 5, 2014 2						
Obs	x1	x2	x3	x4	Prin1	Prin2
1	25.0	86	66	186.49	73.7503	1.1188
2	24.9	84	66	124.34	11.9251	0.8955
3	25.4	77	55	98.79	-14.9967	3.0222
4	24.4	82	62	118.88	5.9681	0.9006
5	22.9	79	53	71.88	-41.8115	-0.2915
6	7.7	86	60	111.96	-0.9579	-16.3359
7	25.1	82	58	99.74	-13.4423	1.3019
8	24.9	83	63	115.20	2.4811	1.0512
9	24.9	82	63	100.16	-12.5115	1.1729
10	24.9	78	56	62.38	-50.9839	1.8388
11	24.3	85	67	154.40	41.9294	0.3860
12	24.6	79	61	112.71	-0.4418	1.8962
13	24.3	81	58	79.63	-33.4729	0.6009
14	24.6	81	61	125.59	12.4672	1.4537
15	24.1	85	64	99.87	-12.5185	-0.4705
16	24.5	84	63	143.56	30.6957	0.7016
17	24.0	81	61	114.97	1.9202	0.7577

Output - (Untitled)						
The CORR Procedure						
6 Variables: x1 x2 x3 x4 Prin1 Prin2						
Simple Statistics						
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
x1	17	23.55882	4.12554	400.50000	7.70000	25.40000
x2	17	82.05882	2.74933	1395	77.00000	86.00000
x3	17	61.00000	3.96863	1037	53.00000	67.00000
x4	17	112.97353	30.06453	1921	62.38000	186.49000
Prin1	17	0	30.28041	0	-50.98386	73.75027
Prin2	17	0	4.28667	0	-16.33590	3.02220
Pearson Correlation Coefficients, N = 17 Prob > r under H0: Rho=0						
	x1	x2	x3	x4	Prin1	Prin2
x1	1.00000	-0.36290 0.1522	0.09391 0.7200	0.04141 0.8746	0.04084 0.8763	0.99241 <.0001
x2	-0.36290 0.1522	1.00000	0.77903 0.0002	0.66329 0.0037	0.66958 0.0033	-0.46121 0.0624
x3	0.09391 0.7200	0.77903 0.0002	1.00000	0.77899 0.0002	0.78575 0.0002	0.01235 0.9625
x4	0.04141 0.8746	0.66329 0.0037	0.77899 0.0002	1.00000	0.99994 <.0001	0.00165 0.9950
Prin1	0.04084 0.8763	0.66958 0.0033	0.78575 0.0002	0.99994 <.0001	1.00000	0.00000 1.0000
Prin2	0.99241 <.0001	-0.46121 0.0624	0.01235 0.9625	0.00165 0.9950	0.00000 1.0000	1.00000

Thus the whole data with four variables can be converted to a new data set with two principal components.

Cluster analysis (CA)

The basic aim of the cluster analysis is to find “natural” or “real” groupings, if any, of a set of individuals (or objects or points or units or whatever). This set of individuals may form a complete population or be a sample from a larger population. More formally, cluster analysis aims to allocate a set of individuals to a set of mutually exclusive, exhaustive groups such that individuals within a group are similar to one another while individuals in different groups are dissimilar. This set of groups is called partition or Cluster. Cluster analysis can also be used for summarizing the data rather than finding natural or real groupings. Grouping or clustering is distinct from the classification methods in the sense that the classification pertains to a known number of groups, and the operational objective is to assign new observations to one of these groups. Cluster analysis is a more primitive technique in that no assumptions are made concerning the number of groups or the group structure. Cluster analysis is used in diversified research fields. In biology, cluster analysis is used to identify diseases and their stages. For example, by examining patients who are diagnosed as depressed, one finds that there are several

distinct subgroups of patients with different types of depression. In marketing, cluster analysis is used to identify persons with similar buying habits. By examining their characteristics it becomes possible to plan future marketing strategies more efficiently. Grouping is done on the basis of similarities or distances (dissimilarities). Some of these distance criteria are Euclidean distance Squared Euclidean distance Statistical distance etc.

Similarity measures

A measure of closeness is required to form simple group structures from complex data sets. A great deal of subjectivity is involved in the choice of similarity measures. Important considerations are the nature of the variables i.e. discrete, continuous or binary or scales of measurement (nominal, ordinal, interval, ratio etc.) and subject matter knowledge. If the items are to be clustered, proximity is usually indicated by some sort of distance. The variables however are grouped on the basis of some measure of association like the correlation co-efficient etc. Some of the similarity measures are:

- ❖ Single linkage method
- ❖ Complete linkage method
- ❖ Average linkage method
- ❖ Average linkage method
- ❖ Ward's method

Example: The data along with SAS CODE belongs to different kinds of teeth for a variety of mammals. The objective of the study is to identify suitable clusters of mammals based on the eight variables.

Data teeth;

Input mammal \$ v1 v2 v3 v4 v5 v6 v7 v8;

Cards;

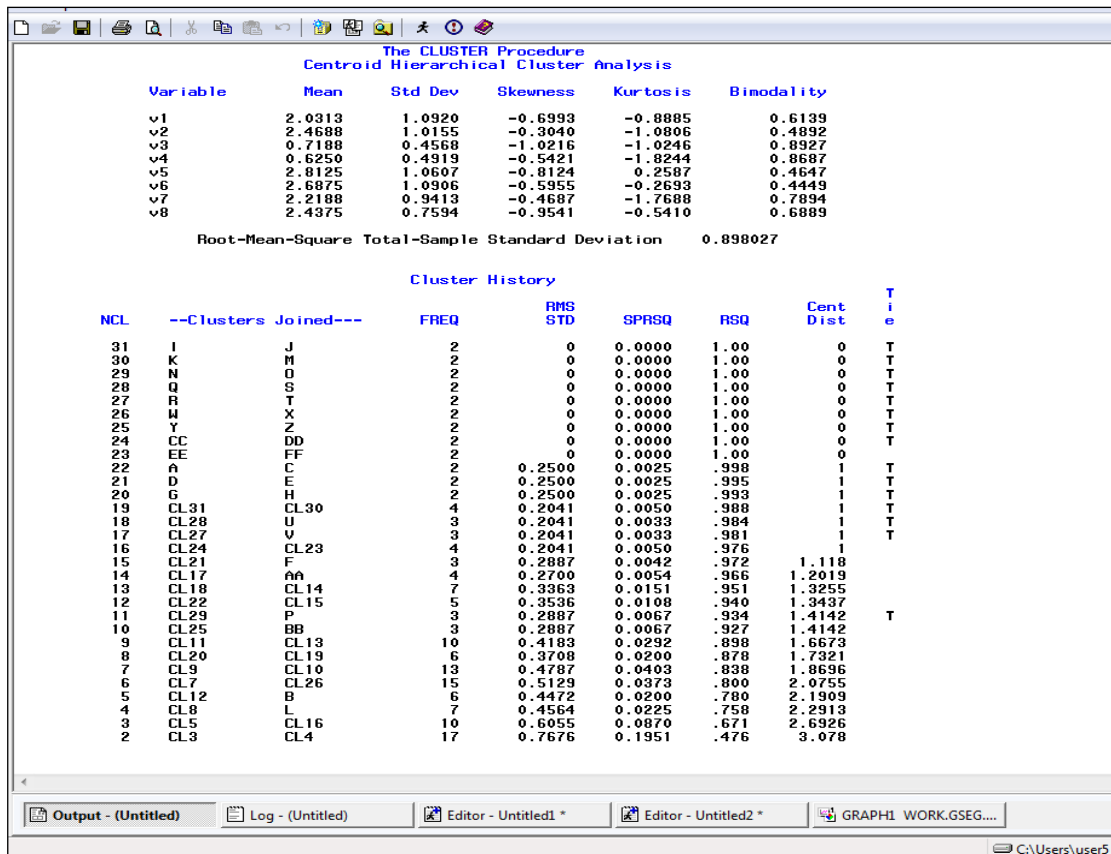
```
A 2 3 1 1 3 3 3 3
B 3 2 1 0 3 3 3 3
C 2 3 1 1 2 3 3 3
D 2 3 1 1 2 2 3 3
E 2 3 1 1 1 2 3 3
F 1 3 1 1 2 2 3 3
G 2 1 0 0 2 2 3 3
H 2 1 0 0 3 2 3 3
I 1 1 0 0 2 1 3 3
J 1 1 0 0 2 1 3 3
K 1 1 0 0 1 1 3 3
L 1 1 0 0 0 0 3 3
M 1 1 0 0 1 1 3 3
```

```

N 3 3 1 1 4 4 2 3
O 3 3 1 1 4 4 2 3
P 3 3 1 1 4 4 3 2
Q 3 3 1 1 4 4 1 2
R 3 3 1 1 3 3 1 2
S 3 3 1 1 4 4 1 2
T 3 3 1 1 3 3 1 2
U 3 3 1 1 4 3 1 2
V 3 2 1 1 3 3 1 2
W 3 3 1 1 3 2 1 1
X 3 3 1 1 3 2 1 1
Y 3 2 1 1 4 4 1 1
Z 3 2 1 1 4 4 1 1
AA 3 2 1 1 3 3 2 2
BB 2 1 1 1 4 4 1 1
CC 0 4 1 0 3 3 3 3
DD 0 4 1 0 3 3 3 3
EE 0 4 0 0 3 3 3 3
FF 0 4 0 0 3 3 3 3
;
proc cluster simple noeigen method=centroid rmsstd rsquare
nonorm out=tree;
var v1-v8;
id mammal;
proc tree data=tree out=clus3 nclusters=3;
id mammal;
copy v1-v8;
proc sort ;by cluster;
proc print ;by cluster;
var mammal v1-v8;
title2 '3-cluster solution';
run;

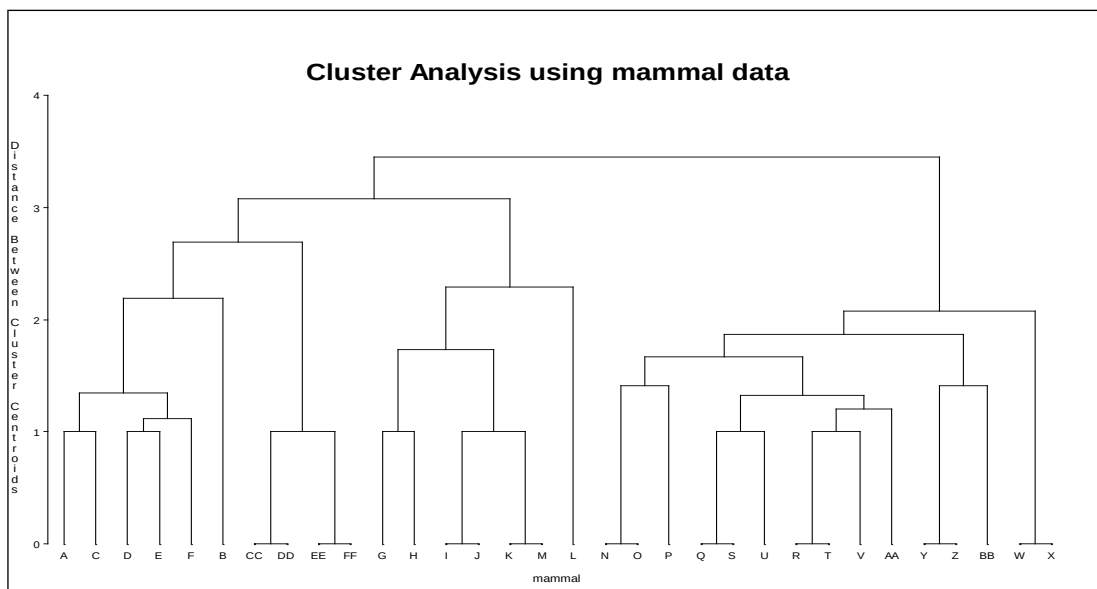
```

SAS output of the above code is:



CLUSTER=1									
Obs	mammal	v1	v2	v3	v4	v5	v6	v7	v8
1	I	1	1	0	0	2	1	3	3
2	J	1	1	0	0	2	1	3	3
3	K	1	1	0	0	1	1	3	3
4	M	1	1	0	0	1	1	3	3
5	G	2	1	0	0	2	2	3	3
6	H	2	1	0	0	3	2	3	3
7	L	1	1	0	0	0	0	3	3
CLUSTER=2									
Obs	mammal	v1	v2	v3	v4	v5	v6	v7	v8
8	N	3	3	1	1	4	4	2	3
9	O	3	3	1	1	4	4	2	3
10	Q	3	3	1	1	4	4	1	2
11	S	3	3	1	1	4	4	1	2
12	R	3	3	1	1	3	3	1	2
13	T	3	3	1	1	3	3	1	2
14	W	3	3	1	1	3	2	1	1
15	X	3	3	1	1	3	2	1	1
16	Y	3	2	1	1	4	4	1	1
17	Z	3	2	1	1	4	4	1	1
18	U	3	3	1	1	4	3	1	2
19	V	3	2	1	1	3	3	1	2
20	AA	3	2	1	1	3	3	2	2
21	P	3	3	1	1	4	4	3	2
22	BB	2	1	1	1	4	4	1	1
CLUSTER=3									
Obs	mammal	v1	v2	v3	v4	v5	v6	v7	v8
23	CC	0	4	1	0	3	3	3	3
24	DD	0	4	1	0	3	3	3	3
25	EE	0	4	0	0	3	3	3	3
26	FF	0	4	0	0	3	3	3	3
27	A	2	3	1	1	3	3	3	3
28	C	2	3	1	1	2	3	3	3
29	D	2	3	1	1	2	3	3	3
30	E	2	3	1	1	2	3	3	3
31	F	1	3	1	1	2	2	3	3
32	B	3	2	1	0	3	3	3	3

Output - (Untitled) Log - (Untitled) Editor - Untitled1 * Editor - Untitled2 * GRAPH1 WORK.GSEG....



Canonical correlation analysis (CCA)

Canonical correlation is a technique for analyzing the relationship between two sets of variables, one representing a set of independent variables, the other a set of dependent variables. Each set can contain several variables. Simple and multiple correlation are special cases of canonical correlation in which one or both sets contain a single variable. Whereas multiple correlation is used for many-to-one relationships, canonical correlation is used for many-to-many relationships. This analysis focuses on the correlation between a linear combination of the variables in one set and a linear combination of the variables in the second set. There may be more than one such linear correlation relating the two sets of variables, with each such correlation representing a different dimension by which the independent set of variable is related to the dependent set. The purpose of canonical correlation is to explain the relation of the two sets of variables, not to model the individual variables. The idea is first to determine the pair of linear combinations having the largest correlation. Next we determine the pair of linear combinations having the largest correlation among all pairs uncorrelated with the initially selected pair. This process continues until the number of pairs of canonical variables equals the number of variables in the smaller group. The pairs of linear combinations are called the **canonical variables** and their correlations are called **canonical correlations**. The canonical correlations measure the strength of association between the two sets of variables. The maximization aspect of the technique represents an attempt to concentrate a high-dimensional relationship between two sets of variables into a few pair of canonical variables.

Canonical correlation analysis through SAS

The PROC CANCORR procedure tests a series of hypotheses that each canonical correlation

and all smaller correlations are zero in population using an F-approximation. At least one of the two sets of the variables should have an approximate multivariate normal distribution. PROC CANCORR can also perform partial canonical correlation, a multivariate generalization of ordinary partial correlation. Most commonly used parametric statistical methods, ranging from t-tests to multivariate analysis of covariance are special cases of partial canonical correlations.

Example: Mean corrected data set of 4 variables have created for illustration purpose and have been shown in SAS code between cards.

SAS Code

```
data cancor;  
input x1 x2 y1 y2;  
cards;  
1.051 -0.435 0.083 0.538  
-0.419 -1.335 -1.347 -0.723  
1.201 0.445 1.093 -0.112  
0.661 0.415 0.673 -0.353  
-1.819 -0.945 -0.817 -1.323  
-0.899 0.375 -0.297 -0.433  
3.001 1.495 1.723 2.418  
-0.069 -2.625 -2.287 -1.063  
-0.919 0.385 -0.547 0.808  
-0.369 -0.265 -0.447 -0.543  
-0.009 -0.515 0.943 -0.633  
0.841 1.915 1.743 1.198  
0.781 1.845 1.043 2.048  
0.631 -0.495 0.413 -0.543  
-1.679 -0.615 -1.567 -0.643  
-0.229 -0.525 -0.777 -0.252  
-0.709 -0.975 0.523 -0.713  
-0.519 0.055 -0.357 0.078  
0.051 0.715 0.133 0.328  
0.221 0.245 0.403 0.238  
-1.399 -0.645 -0.817 -1.133  
0.651 0.385 1.063 -0.633  
-0.469 -0.125 -0.557 -0.393  
0.421 1.215 -0.017 1.838  
;  
proc cancorr all vname= 'y variables' wname='x variables'  
vprefix=response wprefix=explanatory;  
var y1 y2;  
with x1 x2;
```

run;

SAS Output of the above data is:

Canonical Correlation using hypothetical data		
13:34 Wednesday, November 5, 2014		
The CANCORR Procedure		
y variables	2	
x variables	2	
Observations	24	
Means and Standard Deviations		
Variable	Mean	Standard Deviation
y1	0.000083333	1.018454
y2	-0.000041667	1.011011
x1	0.000167	1.052049
x2	-0.000417	1.032847

The CANCORR Procedure		
Correlations Among the Original Variables		
Correlations Among the y variables		
	y1	y2
y1	1.0000	0.5511
y2	0.5511	1.0000
Correlations Among the x variables		
	x1	x2
x1	1.0000	0.5233
x2	0.5233	1.0000
Correlations Between the y variables and the x variables		
	x1	x2
y1	0.7101	0.7551
y2	0.6604	0.8094

Canonical Correlation Analysis		
Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error
1 0.961496	0.959656	0.015748
2 0.111255	.	0.205933
Squared Canonical Correlation		
1 0.924475		
2 0.012378		
Eigenvalues of Inv(E)*H = Canlsq/(1-Canlsq)		
Eigenvalue	Difference	Proportion Cumulative
1 12.2407	12.2202	0.9999
2 0.0125	0.0010	1.0000
Test of H0: The canonical correlations in the current row and all that follow are zero		
Likelihood Ratio	Approximate F Value	Num DF Den DF Pr > F
0.07450976	26.62	4 40 <.0001
0.98762226	0.26	1 21 0.6133
Multivariate Statistics and F Approximations		
Statistic	Value	F Value Num DF Den DF Pr > F
Wilks' Lambda	0.07450976	26.62 4 40 <.0001
Pillai's Trace	0.93685315	8.25 4 42 <.0001
Hotelling-Lawley Trace	12.25325433	60.39 4 23 <.0001
Roy's Greatest Root	12.24072206	128.53 2 21 <.0001
NOTE: F Statistic for Roy's Greatest Root is an upper bound.		
NOTE: F Statistic for Wilks' Lambda is exact.		

Canonical Correlation using hypothetical data			10
13:34 Wednesday, November 5, 2014			
The CANCORR Procedure			
Canonical Correlation Analysis			
Raw Canonical Coefficients for the y variables			
	response1		response2
y1	0.5399285948		-1.045524484
y2	0.5790856145		1.034294423
Raw Canonical Coefficients for the x variables			
	explanatory1		explanatory2
x1	0.4245987011		-1.031441494
x2	0.6689973036		0.9183078485

Canonical Correlation using hypothetical data			11
13:34 Wednesday, November 5, 2014			
The CANCORR Procedure			
Canonical Correlation Analysis			
Standardized Canonical Coefficients for the y variables			
	response1		response2
y1	0.5499		-1.0648
y2	0.5855		1.0457
Standardized Canonical Coefficients for the x variables			
	explanatory1		explanatory2
x1	0.4467		-1.0851
x2	0.6910		0.9485

Canonical Correlation using hypothetical data			12
13:34 Wednesday, November 5, 2014			
The CANCORR Procedure			
Canonical Structure			
Correlations Between the y variables and Their Canonical Variables			
	response1		response2
y1	0.8725		-0.4885
y2	0.8885		0.4588
Correlations Between the x variables and Their Canonical Variables			
	explanatory1		explanatory2
x1	0.8083		-0.5888
x2	0.9247		0.3807
Correlations Between the y variables and the Canonical Variables of the x variables			
	explanatory1		explanatory2
y1	0.8390		-0.0544
y2	0.8543		0.0510
Correlations Between the x variables and the Canonical Variables of the y variables			
	response1		response2
x1	0.7771		-0.0655
x2	0.8891		0.0424

Help

13:34 Wednesday, November 5, 2014

The CANCORR Procedure

Canonical Redundancy Analysis

Raw Variance of the y variables Explained by

Their Own

Canonical Variables

The Opposite

Canonical Variables

Canonical Variable Number	Proportion	Cumulative Proportion	Canonical R-Square	Proportion	Cumulative Proportion
1	0.7753	0.7753	0.9245	0.7167	0.7167
2	0.2247	1.0000	0.0124	0.0028	0.7195

Raw Variance of the x variables Explained by

Their Own

Canonical Variables

The Opposite

Canonical Variables

Canonical Variable Number	Proportion	Cumulative Proportion	Canonical R-Square	Proportion	Cumulative Proportion
1	0.7523	0.7523	0.9245	0.6955	0.6955
2	0.2477	1.0000	0.0124	0.0031	0.6986

Help					
Canonical Correlation using hypothetical data					
13:34 Wednesday, November 5, 2014					
The CANCORR Procedure					
Canonical Redundancy Analysis					
Standardized Variance of the y variables Explained by Their Own Canonical Variables			Explained by The Opposite Canonical Variables		
Canonical Variable Number	Proportion	Cumulative Proportion	Canonical R-Square	Proportion	Cumulative Proportion
1	0.7754	0.7754	0.9245	0.7168	0.7168
2	0.2246	1.0000	0.0124	0.0028	0.7196
Standardized Variance of the x variables Explained by Their Own Canonical Variables			Explained by The Opposite Canonical Variables		
Canonical Variable Number	Proportion	Cumulative Proportion	Canonical R-Square	Proportion	Cumulative Proportion
1	0.7542	0.7542	0.9245	0.6972	0.6972
2	0.2458	1.0000	0.0124	0.0030	0.7003

The CANCORR Procedure			
Canonical Redundancy Analysis			
Squared Multiple Correlations Between the y variables and the First M Canonical Variables of the x variables			
M	1	2	
y1	0.7038	0.7068	
y2	0.7298	0.7324	
Squared Multiple Correlations Between the x variables and the First M Canonical Variables of the y variables			
M	1	2	
x1	0.6039	0.6082	
x2	0.7905	0.7923	

References

- Johnson, R.A. and Wichern, D.W. (2002). *Applied multivariate statistical analysis*. 5th Edition, Pearson Education Inc., New Delhi.
- Levine, Mark S. (1977). *Canonical Analysis and Factor Comparison*. Thousand Oaks, CA: Sage Publications, Quantitative Applications in the Social Sciences Series, No. 6.
- Romesburg, H.C. (1984). *Cluster Analysis for Researchers*. Lifetime Learning Publications, California.
- SAS Institute (2010). SAS/STAT Version 9.2 SAS Institute, Cary, North Carolina, USA.
- Sharma, S. (1996). *Applied Multivariate Techniques*, John Wiley & Sons, New York.

10. Integrated Management of Major Diseases of Rice

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Introduction:

Rice (*Oryza sativa* L.) is one of the most important staple food in India occupying one fourth of the total cropped area contributing around 40% of total food grain production and plays a vital role for the food security in India. To feed the increasing population of India the productivity and total food grain production of rice has to be increased. The target can be achieved through numbers of methods like increasing the area of rice crop, increasing productivity, and avoiding the yield loss of rice. Biotic stresses are some major cause of yield loss *etc.* The introduction of hybrid rice or high yielding varieties have helped the farmers to increase the productivity but diseases caused by fungi, bacteria and virus still remain a major cause of yield loss.

The climate change has brought a huge change in the host–pathogen interaction. It has been observed that the pathogens which were earlier known to attack a specific group of hosts are now attacking new hosts. It has also been observed that in number of crops minor pathogens are emerging as a major one similarly some major pathogens are losing their importance. In case of rice sheath blight disease and bacterial leaf streak diseases which were considered to be minor disease are becoming major now. Proper detection and identification of the disease and its causal organism should be taken seriously for management of the disease. It is always better to detect the pathogens at very early stage like in seeds, mother plants, and vegetative parts to be used as propagules to avoid the further spread of the pathogen and eradicate the disease and the entry of the disease in a new area. A disease is an abnormal condition that injures the plant or causes it to function improperly. Diseases can easily be recognized by their symptoms - associated visible changes in the plant. The organism which causes diseases is known as pathogen.

Identification and management of major rice diseases:

A. Fungal Diseases:

(i) Rice Blast

Causal organism: *Pyricularia oryzae*

Symptoms

- The fungus attacks at any stage of growth of rice from seedlings in nursery to heading in main field.
- The typical symptoms appear on leaves, leaf sheath, rachis, nodes and even the glumes.
- Typical leaf lesions are spindle –shaped and often develop grayish centers and coalesce on leaves of susceptible plants (Plate. 1).
- The spots join together as the disease progresses and large areas of the leaves dry up and wither. Similar spots are also formed on the sheath.
- Severely infected nursery and field show a burnt appearance.
- In infected nodes, irregular black areas encircle the nodes can be noticed.

- The affected nodes may break up and all the plant parts above the infected nodes may die.
- At the flower emergence, the fungus attacks the peduncle which is engirdled and the lesion turns to brownish-black.
- This stage of infection is commonly referred to as rotten neck/neck rot/neck blast/panicle blast.
- In early neck infection, grain filling does not occur and the panicle remains erect like a dead heart caused by a stem borer. In the late infection, partial grain filling occurs. Small brown to black spots also may be observed on glumes of the heavily infected panicles. Generally, the yield losses caused by the pathogen ranges from 30-61 per cent depending upon the stages of infection.

Favourable Conditions:

Application of excessive doses of nitrogenous fertilizers, intermittent drizzles, cloudy weather, high relative humidity (93-99 per cent), low night temperature (between 15-20°C), more number of rainy days, longer duration of dew, cloudy weather, slow wind movement and availability of collateral hosts.

Management

Cultural Control Measures

- Clean bunds and destroy the infected plant debris.
- After harvesting deep ploughing followed by irrigation reduces inoculums present in soil.
- Avoid excessive application of nitrogenous fertilizer. Stop top dressing of nitrogenous fertilizer if the disease is observed.
- It is seed borne hence use clean, healthy seed and adequate soil coverage of planted seed.
- Avoid close spacing.

Chemical Control:

- Seed treatment with Bavistin (Carbendazim 50WP) @ at 2.0 g/kg seed. biocontrol agent *Trichoderma viride* @ 4g/kg or *Pseudomonas fluorescens* @ 10g/kg of seed are recommended for organic rice.
- Spraying of Beam (Tricyclazole 75WP) @0.6 g/litre of water or Bavistin 50WP @ at 2.0 g/ lit. of water when few virulent lesions appear in nursery /field.
- Close spacing of seedlings in the main field should be avoided. Infected nursery should be sprayed with Carbendazim 50WP or Edifenphos.
- Spray the main field with Edifenphos 250 ml or Iprobenphos 500 ml or Carbendazim 50WP 250 g or Tricyclazole 75WP 400 g or Thiophanate Methyl 500 g or Pyroquilon 500 g/ha

(ii) Brown spot

It is caused by the fungus *Helminthosporium oryzae*. The great Bengal famine of 1942 was caused by this disease.

Symptoms:

- Typically ellipsoidal, oval to circular brown colour lesions appear on the coleoptiles, leaf blade, leaf sheath and glume (Plate 2).



Plate 1: Rice Blast



Plate 2: Brown Spot



Plate 3: Sheath Blight



Plate 4: Sheath Rot



Plate 5: False Smut



Plate 6: Bacterial Blight

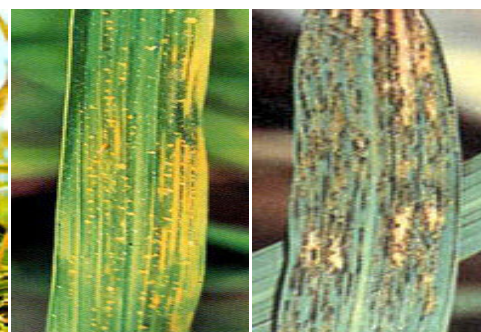


Plate 7: Bacterial Leaf Streak



Plate 8: Rice Tungro Disease

Pre-disposing factors for the outbreak of Brown spot disease:

- The disease occurs in severe form at low N level.
- The plant grown in K, Ca, Mg and Zn deficient soil suffer from the disease severely.
- Relative humidity more than 89%.
- Plants grown in leached soil exhibit severe infection.
- Heavy rainfall in September accompanied by temperature of 25-30°C followed by continuous cloudy weather favours severity of disease.

Management of Brown spot

- Use healthy seeds from disease free crops.
- Adopt deep summer ploughing.
- Apply balanced macronutrients N60P30K30 with soil amelioration by Zinc and Manganese (if necessary).
- Grow resistant varieties.
- Treat the seeds with Captan or Thiram @ 3g/kg seed.
- Spray the crop with Tilt (Propiconazole 25EC) @ 1ml/l or 0.4% Diathane M-45 (Mancozeb) or 0.2% Bavistin (Carbendazim 50WP) or 0.15% Saff 75WP (Carbendazim 12% + Mancozeb 63% WP).

(iii). Sheath Blight

It is caused by the soil borne fungus *Rhizoctonia solani*.

Symptom:

- Disease generally appear at the active tillering stage and noticed by irregular lesions with brownish margin on sheaths near water level.
- Lesions gradually coalesce together and extend to leaf blades and give the appearance of snake scales (Plate 3).
- Later white sclerotia of mustard seed size developed on infected sheaths.

Pre-disposing factors for the outbreak of Sheath blight disease:

- An optimal temperature of 28-34°C with high RH 95%.
- Application of higher dose of N fertilizers, more than 80 kg N/ha.
- More number of seedling > 4/hill invite higher disease incidence.
- Presence of root knot nematodes in the soil renders plants more susceptible to sheath blight.

Management of Sheath blight

- Maintain field sanitation.
- Adopt deep summer ploughing so that sclerotia remaining inside the soil are brought to hot sunlight.
- Use healthy seeds collected from disease free crops.
- Incorporate green manure (dhaincha) *Sesbania* sp in sheath blight endemic areas.

- Do not transplant > 3 seedling/hill.
- Grow sheath blight tolerant varieties in endemic areas
- Give need based spray of effective fungicides- Sheathmar 3L (Validamycin 3L) @ 2ml/l of water) or Rhizocin 3 L (Validamycin 3L) @ 2.5ml/l of water) or Contaf 5 EC (Hexaconazole 5EC) @ 2ml/l of water or Spencer (Thiophan-methyl 24SC) @ 1ml/l of water or Bavistin 50WP (Carbendazim 50WP) 2.5 g/l of water.

(iv). Sheath rot

The disease is caused by the fungus *Sarocladium oryzae*.

Symptoms:

- Panicle exertion from sheath is prevented and in severe infection the panicle fails to come out from panicle sheath cover and resulted chaffy grains.
- Spots are oblong to irregular with gray centre and brown margins (Plate 4).

Management of Sheath rot

- Use healthy seeds from disease free crops.
- Treat the seeds with Bavistin (Carbendazim 50WP) @ 2g/kg seed.
- Grow resistant varieties.
- Spray twice at 10 days interval starting from boot leaf stage with 0.15% Benlate or Carbendazim 50WP or 0.25% Mopsin-M 70 WP. An insecticide can be mixed for control of insects which predispose the plants to attack of this disease.

(v). False smut

It is caused by the fungus *Ustilaginoidea virens*.

Symptoms:

- The disease is found on the ear heads only.
- Individual grains are transformed initially into large velvety green masses which later on become black in colour (Plate 5).

Predisposing factors

- High moisture favours disease development
- High fertility is favourable for disease development
- Cloudy weather followed by continuous drizzling rain at milky stage of the crop favours disease development

Management of False smut

- Use healthy seeds collected from disease free crop.
- Treat the seeds with Carbendazim 50WP @ 2g/kg seed.
- Pesticides spray should be taken up 2 week before Panicle Initiation.
- Spray 0.2% Kocide 101 (Copper hydroxide 77%) or 0.15% Carbendazim 50WP or 0.25% Captafol or 0.4% Mancozeb or 0.2% Saff twice at seven days interval at boot leaf stage.
- Drain out water from the field after grain formation.

(vi). Udbatta disease

Causal Organism: The disease is caused by the fungus *Ephelis oryzae* Syd

Damage symptoms:

- Stunted growth of affected seedlings.
- The panicle emerges from the leaf sheath as a straight, dirty coloured, hard, cylindrical spike, considerably reduced in size, much resembling an agarbatti or udbatta.
- No grains are formed on the infected ear instead white mycelium and conidia form narrow stripes on the flag leaf along the veins before the panicle emergence.

Management

The disease is mainly seed borne. Hence,

- Use disease free seeds for sowing.
- Hot water treatment of seeds at 52°C for 10 min.
- Removal and destruction of diseased panicles in field.

B. BACTERIAL DISEASES

(i). Bacterial blight

It is caused by the bacterium *Xanthomonas oryzae* pv. *oryzae*.

Symptoms:

- Water soaked lesions start from tip and move downwards along the edges of leaves.
- Gradually symptoms turn into yellow and straw coloured stripes with wavy margins (Plate 6).
- In early morning in humid areas yellowish, opaque, turbid drops of bacterial ooze may be seen.
- In Kresek (wilt) phase, leaves roll completely, droop and plants die completely.

Pre-disposing factors for the outbreak of Bacterial blight disease:

- Lateritic and alluvial soil favour more bacterial blight diseases.
- Waterlogging condition encourages disease development.
- Excessive use of N fertilizers from tillering stage to maximum tillering stage encourages disease development.
- Growing of the crop under shade favours disease development.
- Pruning of leaves at the time of transplanting favours disease development.

Management of Bacterial blight:

- Use disease free seeds.
- Avoid field to field irrigation.
- Drain out excess water from the field.
- Apply moderate level of Nitrogen (80 kg N/ha) in 3 splits.

- Potash application, alternate drying and flooding in the field help in reducing infection.
- Avoid pruning the tips of seedling at the time of transplanting.
- Avoid raising the crop under the shade.
- Grow resistant varieties viz; IR 64, Ajaya, Ramakrishna, Naveen, Lalat, Gayatri, Mahalaxmi, Varsadhan, Malviya Dhan 36, Nerendra User Dhan 2, Narendra User Dhan 3, Sarjoo 52, Saket
- Seed treatment by soaking 10kg seeds x 20 liters' of water containing 1.5gm Streptocycline + 20 gm Captan for 8-10 hours.
- Hot water treatment by soaking the seed for 12 hours in hot water at 53°C for 30 minutes.
- Dip roots of the seedlings in solution of plantomycin (0.1%) or Streptocycline (0.01%) for 30 minutes.
- Give the spray of Plantomycin @ 1gm/l of water or Streptocycline (150mg) + copper oxychloride (1gm)/l of water.
- Spray fresh cow dung extracts (1kg cow dung in 5 liter water).

(ii). Bacterial leaf streak

It is caused by the bacterium *X. oryzae pv.oryzicola*

Symptoms

- Initially, small, dark-green and water-soaked streaks on intervenes from tillering to booting stage.
- Streaks dark-green at first and later enlarge to become yellowish grey and translucent (Plate 7).
- Numerous small yellow beads of bacterial exudates on surface of lesions on humid conditions.
- Very small yellow beads instead of bacterial exudates during dry season.
- Lesions turn brown to greyish white then dry when disease is severe.
- Yellow halo around lesions on susceptible cultivars.
- Browning and dying of entire leaves.
- Bleached and greyish white leaves.

Predisposing factors

- Presence of the bacteria on leaves and in the water or those surviving in the debris left after harvest.
- Temperature range 26-32°C
- High humidity between 80-94%
- More no. of rainy days with cloudy weather and less sun shine hours.

Host range

Species of wild rice such as *Oryza spontanea*, *O. perennis balunga*, *O. nivara*, *O. breviligulata*, *O. glaberrima*, and some grasses like *Leersia hexandra*, *Cyperus rotundus*, *Panicum repens* are alternate hosts of the bacterial diseases.

Management of Bacterial Diseases:

- Use disease free seeds.
- Avoid field to field irrigation.
- Apply moderate level of NPK (40:20:20 kg /ha) during sowing.
- Potash application in the field helps in reducing infection.
- Avoid pruning the tips of seedlings at the time of transplanting.
- Avoid raising the crop under the shade.
- Grow high yielding, intermediate height or tall, long duration photo period sensitive rice varieties with inbuilt tolerance to pest and diseases viz; Gayatri, Durga, Varsadhan, Rambha and Kanchan.
- Seed treatment by soaking 10kg seeds in 20 liters of water containing 1.5gm Streptocycline + 20 gm captan for 8-10 hours.
- Hot water treatment by soaking the seed for 12 hours in hot water at 53°C for 30 minutes.
- Dip roots of the seedlings in solution of plantomycin (0.1%) or Streptocycline (0.01%) for 30 minutes.
- Just at the appearance of the disease, spray plantomycin 1g + copperoxychloride 1g/ lt. twice at an interval of 8 days.
- Spray fresh cow dung extracts (1kg cow dung in 5 liter water) thrice at eight days interval.
- Spray Amritjal and Pot manure three times at eight days interval which is quite effective for controlling micro organisms and repelling the insect pests.

Preparation of Amritjal: Mix 1 lit fresh cow urine + 1 kg fresh cow dung + 250gm jaggery in 10 lit of water in an earthen pot. The mixture is allowed for fermentation for 24 hours and diluted with water in the ratio of 1:10 then filtered and sprayed on the crop. This mixture may be stored for 30 days but it requires stirring every day. This preparation provides Nitrogen, repels insects and controls the micro-organisms.

Preparation of Pot manure: Mix 1 lit fresh cow urine + 1 kg fresh cow dung + 50gm jaggery in an earthen pot. To this slurry, 1 kg chopped leaves each of Neem, Callotropis (Arakha) and Pongamia (Karanja) are added. The pot is covered with a cloth and kept for 8 days to ferment. After 8 days, it is diluted with water 50 times then filtered and sprayed. This preparation provides Nitrogen, repels insects and controls micro-organisms

C. VIRAL DISEASE

Rice Tungro

It is caused by joint infection of two viruses' *Rice Tungro Spherical RNA virus* and *Rice Tungro Bacilliform DNA virus*.

Symptoms:

- Freshly emerged leaves exhibit inter-venal chlorosis.
- Gradually leaves turn pale yellow and later reddish orange in colour (Plate 8).
- Plants get stunted growth and numbers of tillers are reduced.
- At the maturity stage panicles do not exert completely.
- Tungro infected plants show impaired root growth.

Vectors and transmission:

It is transmitted by the insect *Nephotettix impicticeps*. *N. apicalis* and *Recilia dorsalis* are also slow transmitter of virus. About 83% of population of *N. impicticeps* are active transmitters. The minimum acquisition and inoculation feeding periods are 30 minutes and 15 minutes respectively. The latent period in the plants is 6-9 days. There is no apparent incubation period in the insect which may transmit the virus in two hours including acquisition and inoculation feeding. The insects only retain the virus for not more than 5 or 6 days. After that the insects are not effective unless they acquire the virus again. The virus is not transmitted through the eggs, not by seed, soil or any other mechanical means.

Host range:

Many species of wild rice and grass weeds such as *Eleusine indica*, *Echinochloa colonum* and *E. crusgalli* are good alternative hosts of Tungro virus. The host range includes 63 species in 26 genera and 8 tribes of wild grasses and many species and strains of wild rice.

Pre-disposing factors for the outbreak of Tungro disease:

- Early rain during April-May.
- Late planting (After Aug 15th).
- Nursery raising near the ratoon crops.
- Appearance of green leaf hopper within 50 days of the transplanting.

Management of Rice Tungro disease

- Avoid raising nursery near ratoon crop fields.
- Avoid late planting (beyond 2nd week of August) in Eastern India states.
- Clean out weeds *C.rotundus*, *H.compressa*, *Hydrolyia Zeylanica* and *Phyllanthus niruri* from surrounding of the rice fields.
- Disease spread can be checked by controlling vectors population.
- Give need based application Caldan 4 G @ 10kg/ha or Carbofuran @ 12kg/ha.
- Give need based spray of Monocrotophos 36 EC @ 3ml/l of water or Imidacloprid 200 SL @1ml/l of water.
- Grow resistant varieties.

NOTES

11. Status and Source of Major Green House Gases and their Mitigation through Biological Means

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Introduction

The greenhouse gases (GHGs), mainly the CO₂, CH₄, N₂O and several other minor ones (fluorocarbons) (Table 1) have abiotic and biotic originations. Average atmospheric residence time of the GHGs is variable and for the major gases viz. CO₂, CH₄ and N₂O, it is about 500, 7-10 and 140-190 years, respectively (Table 1). Anthropogenic activities have increased CO₂, CH₄ and N₂O by 30, 145 and 15%, respectively over the pre-industrial period. The greenhouse gases (GHGs) and water vapor absorb most of the longer infrared radiation emitted by the Earth and reflect back resulting in rising of atmospheric temperature effecting climate change or global warming which would have been about 33°C lower than the current temperature. Since the 20th century, earth's average temperature had increased by 0.6±0.2°C which would continue to upsurge by 1.4 to 5.8°C by the end in the 21st century. The GHGs would not only raise the earth surface temperature but would also effect precipitation, soil moisture, sea level and glaciers. Among the biological sources, agriculture is the important factor of the major GHGs (Table 2) with global warming potential (GWP) of CH₄ and N₂O is 20 and 300 times more than CO₂ (Table 3).

Table 1. Recent greenhouse gas concentrations

GAS	Pre-1750 tropospheric conc.	Recent tropospheric conc.	GWP (100 yr time horizon)	Atmospheric lifetime (yr)	Increased radiative forcing (W/m ²)
Concentrations in parts per million (ppm)					
Carbon dioxide (CO ₂)	280	388.5	1	~ 100	1.76
Concentrations in parts per billion (ppb)					
Methane (CH ₄)	700	1870/1748	25	12	0.50
Nitrous oxide (N ₂ O)	270	323/322	298	114	0.17
Tropospheric ozone (O ₃)	25	34	n.a.	hours-days	0.35
Concentrations in parts per trillion (ppt)					
CFC-11 (trichlorofluoromethane) (CCl ₃ F)	0	241/239	4,750	45	0.063
CFC-12 (CCl ₂ F ₂)	0	534/532	10,900	100	0.17
CF-113 (CCl ₂ FFClF ₂)	0	75/75	6,130	85	0.024
HCFC-22 (CHClF ₂)	0	218/194	1,810	12	0.041
HCFC-141b (CH ₃ CCl ₂ F)	0	22/19	725	9.3	0.0025
HCFC-142b (CH ₃ CClF ₂)	0	22/19	2,310	17.9	0.0031

Halon 1211 (CBrClF ₂)	0	4.3/4.1	1,890	16	0.001
Halon 1301 (CBrClF ₃)	0	3.3/3.2	7,140	65	0.001
HFC-134a(CH ₂ FCF ₃)	0	62/52	1,430	14	0.0055
Carbon tetrachloride (CCl ₄)	0	87/86	1,400	26	0.012
Sulfur hexafluoride (SF ₆)	0	7.12/6.73	22,800	3200	0.0029
Other Halocarbons	0	Variable			Total 0.021

Table 2. Annual GHG emissions from Indian rice fields

Emission (Tg/y)	Continuous flooding		Midseason drainage	
	Minimum	Maximum	Minimum	Maximum
CH ₄ (C)	1.07	1.10	0.12	0.13
N ₂ O (N)	0.048	0.038	0.060	0.056
CO ₂ (C)	21.16	60.96	16.66	48.80
GWP (CO ₂ eq.)	130.93	272.83	91.73	211.80

Table 3. Global warming potential (GWP) and other properties of CO₂, CH₄ and N₂O

Gas	Concentration	Annual increase	Life time (yr)	Relative absorbance capacity	Global warming potential
CO ₂	370 ppmv	1.8 ppmv (0.5%)	50-200	1	1
CH ₄	1.72 ppmv	13 ppbv (0.8%)	12-17	58	24.5
N ₂ O	310 ppbv	0.8 ppbv (0.25%)	150	206	320

Agriculture accounts for approximately one-fifth of the annual increase in anthropogenic greenhouse gas emission and contributes 20% enhancement of radiation energy through emission of CO₂, CH₄ and N₂O (Cole et al. 19995, IPCC 1996). The main sources of these gases are flooded rice fields, nitrogen fertilizers, improper soil management, land conversion, biomass burning and livestock production and associated manure management. The livestock alone accounts for 5-10% of overall contribution to global warming. However, the other GHGs (Table 1) are emitted from the industrial activities and have variable climate change effects (Tables 1, 3). Among the GHGs, N₂O diffuses into the atmosphere from agricultural soils and destructs the protective ozone layer in the stratosphere. Increased abundance of the GHGs in the atmosphere would result in global warming, destruction of the stratospheric ozone layer, decrease in the tropospheric ozone due to the increased emission of NO_x, CO and hydrocarbons; and change the cloud density in the troposphere and aerosol in the stratosphere due to changed conditions of dimethyl sulfate (DMS) and OCS. Thus GHGs are the global concern and attempts are being made to reduce their further release in the atmosphere.

A. Carbon dioxide

Status and source

Atmospheric CO₂ concentration estimation revealed that the mean concentration of CO₂ has risen from 316 ppmv in 1959 to 364 ppmv in 1997, increasing at this rate of 0.5% per year (IPCC 2001). In 21st century, atmospheric CO₂ will be 510-760 ppm. More than 80% of carbon dioxide is emitted by burning fossil fuels in industries. Automobile exhaust generates @ 22 lb CO₂/gallon of gasoline and over 600 million motor vehicles in the world today will double CO₂ in the next 30 years. Besides, deforestation and land acquisition, burning of agricultural wastes etc. are the major sources of CO₂ emission which contribute approximately one-third (~20%) of the global CO₂ release. Deforestation in temperate zones released most of the CO₂ until 50 years ago but presently the tropical deforestation is the largest source of CO₂ emission. Furthermore, in addition to animal metabolism, about 10¹¹ ton CO₂/yr is incorporated in biosphere through the metabolic activities of plants and microbes. Thus, the net CO₂ level in the atmosphere would make the globe 1.5-4.5°C warmer.

Mitigation

In the higher CO₂ and temperature regimen, mitigation would be possible through the photosynthetic microbes which evolved under similar conditions in 3.8 - 2.7 giga (10⁹) annum (Ga) period. Four bacterial groups perform photosynthesis under anaerobic conditions and do not oxidized water to molecular oxygen. These anoxygenic photosynthetic bacteria viz. the purple sulfur bacteria (*Chromatium*, *Ectothiorhodospira* etc. spp.), purple non-sulfur bacteria (*Rhodospirillum* spp.), green sulfur bacteria (*Chlorobium* spp.) and the multicellular filamentous green bacteria (*Chloroflexaceae* spp.) would fix atmospheric CO₂ and maintain balance in the atmosphere. Besides, the cyanobacteria (obligate photo-litho-autotrophs) are the only group of oxygenic photosynthetic bacteria (viz. cyanobacteria and prochlorophytes) that have oxidative electron cycle (OEC) for splitting water as source of electrons would be effective bioremediating microbes. Reduction of fossil fuel use, minimum tillage, irrigation scheduling, solar drying of crops and improved fertilizer management, aforestation which would enhance C storage i.e. CO₂ assimilation by plants/microbes would reduce CO₂ emission.

B. Methane

Status and source

Methane is generated by natural and anthropogenic activities from various abiotic and biotic sources (Table 4). It is produced mainly by the methanogens of marshes, swamp and wet land soils in nature. Each year about 350 to 500 million tons of methane is added to the air mainly by raising livestock, coal mining and drilling for oil and natural gas, rice cultivation, disposing of garbage in landfills, burning forests and fields. Ruminant bacteria in the gut of cattle i.e. sheep, goats, buffalo, camels etc. produce methane and each animal can belch up to a half-pound of methane a day. In 2006, research has shown that permafrost melting in the arctic is releasing methane trapped in formerly frozen sediments. From the agricultural sector, CH₄ is released by about 91% from the paddy fields, 7% from animal husbandry and 2% from burning of agricultural wastes. CH₄ emission from the paddy fields depends on fertilizer use, water management, density and biomass of rice plants, and other cultural practices. Among Asian countries, India and China are thought to be the major contributors to global CH₄ budget because of large areas under paddy cultivation. However, a realistic CH₄ budget for Indian rice fields was estimated to be 3.6 Tg/yr in 1998, which was found less than one-tenth of the projected figure (37.8 Tg/yr) of EPA (Parashar et al. 1996). Presently, the atmospheric CH₄ concentration is 1.73 ppmv which has doubled from the pre-industrial level of 0.82 ppmv in 200 years time (Parashar et al. 1996) is increasing @ 16 ppbv or 1% each year from 1979 to

1989, 20% of which was anthropogenic (IPCC 1996). However, growth rate fell to about 10 ppbv/yr (Steele et al. 1992, Dlugokencky 1998) in late 1980s, further in early 1990s and stopped at some locations in 1992 (Parashar et al. 1996). In 1994, it recovered to about 8 ppbv/yr associated with Pinatubo eruption (Khalil and Rasmussen 1993). However, the reasons for long-term global decline in CH₄ growth are still not clear.

Table 4. Sources of atmospheric methane

Source	Estimate (Tg/yr)
Submerged soil	115
Other natural source	50
Rice fields	60
Enteric fermentation	105
Energy production and use	100
Land fills	30
Biomass burning	40
Domestic sewage	25
Total	525
Sink	
Consumption in atmosphere	470
Oxidation- upland	30
Total	500

In the paddy fields, fermentative decomposition of organic material (Table 5) by strictly anaerobic methanogenic bacteria viz. *Methanobacterium thermoautotrophicum*, *Methanotrix*, *Methanosarcina thermophila* etc. produce CH₄. Although a major portion of CH₄ is oxidized by methanotrophs in the oxic zones of the rhizosphere, the remainder is released to the atmosphere through aerenchyma of the rice plants (Dlugokencky et al. 1996), ebullition or molecular diffusion. Livestock and associated manure management contribute about 16% of CH₄ out of which cows and buffaloes make 80%. About two thirds of the CH₄ produced in nature derives from the reduction of the methyl group of acetate and about one third from reduction of CO₂ with electrons from H₂ or formate (Ferry, 1992).

Table 5. Major substrates for CH₄ production and the trophic groups

Trophic group	Substrates utilized
Hydrogenotrophs	H ₂ + CO ₂
Formatotrophs (All formatotrophs are hydrogenotrophs)	Formate
Acetotrophs	Acetate
Methylotrophs	Methylated compounds
Alcoholotrophs (no strict forms)	Alcohols I, II

Mitigating

Improved cultivation practices, better water management, intermittent drying of soils, reduced land disturbances such as zero tillage, mulching, shifting cultivation from transplantation to direct seeding, reduced unfermented organic materials, use of mineral fertilizer containing sulphate, inhibitors of methanogenic bacteria, high yielding rice varieties and non-rice crops could mitigate CH₄ emission. Monogastric animal husbandry viz. poultry and pigs produce lesser CH₄ than large ruminants, improved diet, treatment and management of animal wastes and reduction of biomass burning would reduce 15-56% CH₄ by integrated approach.

C. Nitrous oxide

Status and source

Nitrous oxide (N₂O) is emitted from the nitrogen fertilizers, legume cropping, animal waste and biomass burning. The denitrifying bacteria produce N₂O under partial anaerobic conditions and by nitrifying bacteria in aerobic conditions from the unused N-fertilizer. The N₂O concentration has increased to 311 ppbv from a pre-industrial level of 275 ppbv with a current growth rate of 0.2-0.3% per year (Nouchi 1990, IPCC 1996). Agriculture contributes around 25% of the global N₂O emission (Table 6). The projected global annual flux of N₂O ranges between 5.1 – 16.9 Tg N₂O/yr. It is also released naturally from oceans and by bacteria. In soils, each year about 7 to 13 million tons of nitrous oxide is added to the atmosphere mainly by using nitrogen-based fertilizers, disposing of human and animal wastes, automobile exhausts etc. Although atmospheric N₂O is very low compared to CO₂ and CH₄, but its global warming potential is 310 times more than CO₂ due to its high residence time (120 yrs) and radiative forcing (206 times to CO₂) which causes global warming and catalytic destruction of ozone layer in stratosphere (Khalil et al. 1992). Estimates of direct and indirect emissions of N₂O from synthetic fertilizer, animal waste N and from biological N fixation in seven regions of the world are presented in Table 6. Cropping systems, soils management and unpredictable rainfall inputs influence N₂O emissions more than different mineral N sources. Limited data also indicate that organic N sources such as animal manures and sewage sludge induce larger N₂O emissions per unit of N added to the soil than does mineral N.

Table 6. Estimates of direct and indirect emissions of N₂O from fertilizer N in agricultural soils and from soils growing biological N-fixing crops (IPCC, 1996).

Region	Estimated N₂O (Tg N₂O-N yr⁻¹) from			Total	Range
	Mineral N	Animal waste	N-fixation		
Africa	0.04	0.21	0.05	0.30	0.15-0.45
N. America and Canada	0.26	0.11	0.11	0.48	0.24-0.72
S. America	0.03	0.22	0.09	0.34	0.17-0.51
Asia	0.75	0.52	0.19	1.46	0.73-2.19
Europe	0.27	0.22	0.02	0.51	0.26-0.77
Oceania	0.01	0.03	0.01	0.05	0.03-0.08
PSU	0.17	0.18	0.03	0.30	0.19-0.37
Total	1.53	1.49	0.50	3.50	1.8-5.3

Mitigation of N₂O

N₂O emissions could be decreased with better treatment and management of animal wastes and nitrogen fertilizers, split application of chemical fertilizers, ammonium-based and controlled release fertilizers, chemical inhibitors of nitrifying and denitrifying bacteria etc. (Crutzen and Ehhalt 1977). Soil moisture, fertilizers, organic manures and crop residues significantly affect N₂O emission. Drainage in rice fields, use of organic manures including green manures and farmyard manure and regulation of inorganic fertilizer reduce overall emission of greenhouse gases from rice fields. Nitrification inhibitors viz. nitrapyrin, dicyandimide and encapsulated calcium carbide (ECC) limit N₂O production in corn, wheat and rice (Aulakh and Kuldip-Singh, 2001). The measures to restrain N₂O emission are given in Table 7.

Table 7. Estimated mitigation potential of N₂O emissions from agriculture (IPCC, 1996)

Source	Estimated amount emitted	Potential decrease	
	(Tg/yr)	(Tg/yr)	%
Mineral fertilizer	1.5 (0.5-2.5)	0.3 (0.15-0.45)	20
Animal wastes	1.5 (0.5-2.5)	0.3 (0.15-0.45)	20
N-fixation	0.5 (0.25-0.75)	-	?
Biomass burning	0.2(0.1-0.3)	0.02 (0.01-0.03)	10
Soils after burning	0.1 (0.05-0.2)	0.01 (0.005-0.015)	10
Forest conversion	0.4 (0.1-1)	0.08 (0.04-0.12)	20
Total	4.2 (1.5-7.25)	0.71 (0.36-1.1)	17

D. Fluorocarbons

Fluorocarbons come almost entirely from human activities. They are synthesized by humans for refrigeration and other uses. Some fluorocarbons, including chlorofluorocarbons (CFCs), CFC along with chlorine and bromine containing compounds also involve in acceleration of ozone hole formation. It also results in increasing the amount of hydrogen peroxide in the atmosphere and induces acid rain.

E. Effects of GHGs

GHGs could increase global temperature i.e. cause global warming from 1.4 to 5.8°C resulting in large scale melting of ice cap. Doubling of the atmospheric N₂O would cause a 10% decrease in the ozone layer, increase about 20% ultraviolet radiation on the Earth surface resulting in increase in skin cancer and other health hazards. Furthermore, the soil scientists and agronomists are concerned about the nitrogen losses from the applied fertilizers and manures (Aulakh et al., 1992). Increased abundance of halogenated compounds and N₂O would destroy the stratospheric ozone layer due to the increase in the amount of tropospheric ozone due to the increased emission of CH₄, NO_x, CO and hydrocarbons. The sea level may rise from 9 to 88 cm which would submerge the low lying areas such as Bangladesh, Maldives and some other tropical islands.

Temperature rise by increased GHGs would shorten development time, reduced yield, grain quality of crops. At elevated CO₂ (700 ppm), C₄ plants (maize) would not respond and the C₃ plants (rice, wheat) yield more at normal temp but declines at higher temp. Higher temperatures are expected

to expand the range of some dangerous "vector-borne" diseases. Malaria, dengue and yellow fever would occur at higher latitudes. Heat stress would increase death of humans (particularly elders) and animals, and would increase air conditioning needs. Rapidly reproducing species of weeds, rodents, insects, bacteria and viruses may occur at higher latitudes. Temporarily crop may be susceptible to new insect and disease problems. Reduced forest health and changes in tree species . A doubling of atmospheric N₂O would cause 10% decrease in the ozone layer that would increase the incidence of skin cancer by 40 – 60 %. Where dry land agriculture relies solely on rain, as in sub-Saharan Africa, yields would decrease dramatically even with minimal rise in temperature.

Global edges

Strategies to be developed for modest reduction of GHGs viz. CO₂ by about 5% below 1990 levels according to Kyoto Protocol. However, it would cost the farmers between one quarter and nearly one-half of his income i.e. would increase farm production expenses between \$ 10 and 20 billion per year and decrease farm income by 24 to 48%. Global climate change will not only impact plants and animals but will also affect bacteria, fungi and other microbial populations that perform a myriad of functions important to life on earth. It is not entirely certain what those effects will be, but they could be significant and will probably not be good, say researchers at a scientific meeting in Boston. Burning oil and coal more efficiently, switching to renewable forms of energy, such as solar and wind power, and developing new technologies for industry and transport can attack the problem at the source. Trees that can remove carbon dioxide, the dominant greenhouse gas, from the atmosphere, the more we have, the better. But deforestation -- the current trend -- liberates additional carbon and makes global warming worse.

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12. Effect of Climate Change on Soil Microbial Community

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Importance of soil for life-ecosystems

Soil is one of the vital-support systems on the Earth, responsible for following ecological functions i) supply of water and nutrients for plant growth within agricultural and forest ecosystems, ii) regulation of the water and nutrient cycle, iii) storage of carbon and regulation of greenhouses gases, iv) trapping of contaminants as buffer, v) source of raw material as clay minerals, vi) preservation of cultural heritage, vii) habitats for animal and plant species, viii) maintaining their biological and genetic diversity, ix) support to human settlements, x) providing a basis for buildings and infrastructures and xi) also have disposal of waste materials.

Soil vs climate change

Climate is an important factor in soil development and a major driver of the processes of soil formation. At the same time, changes in the bio-physical nature of soil, due to rising temperatures, changing precipitation intensity and frequency and more severe droughts, are likely to release substantial amounts of greenhouse gases. Changing climate will also affect these characteristics and may also have serious consequences for the well-being of people, who are dependent on the broad range of environmental goods and services regulated by soil. To date, assessments have relied mainly on local case studies that have analysed how soil reacts under changing climate in combination with evolving agricultural practices.

Soil microbes vs climate change

Soil microbes are inherent to all life on the Earth, exhibiting vast diversity in form and function. One teaspoon of top soil contains around one billion individual microscopic cells and around 10,000 different species. These organisms perform many functions and are central to crop fertility, recycling nutrients, detoxifying pollutants, regulating carbon storage and controlling the production and absorption of greenhouse gases mainly carbon dioxide, methane and nitrous oxides. Soil microbial populations determine key soil functions, thereby directly affecting the value of land. Microbial processes also have an essential role in the global fluxes of the key biogenic greenhouse gases and are likely to respond rapidly to climate change. Whether changes in microbial processes lead to a net positive or negative feedback for greenhouse gas emissions is unclear. To improve the prediction of climate models, it is important to understand the mechanisms by which microorganisms regulate terrestrial greenhouse gas flux. This involves consideration of the complex interactions that occur between microorganisms and other biotic and abiotic factors. The potential to mitigate climate change by reducing greenhouse gas emissions through managing terrestrial microbial processes is a tantalizing prospect for the future (Singh et al, 2010). Future climate scenarios may affect microbial populations in soil with many potential consequences, including loss of soil carbon; changes in soil-borne greenhouse gas levels; and alterations to the important plant-soil feedbacks giving rise to soil fertility. By making nutrients available are intimately associated with plant growth and productivity are the engine for cycling major nutrients such as nitrogen, phosphorus and potassium and between

organic matter, minerals and the environment are the start of food webs supporting invertebrates and higher life forms regulate soil-borne diseases of plants and animals provide balance to soil composition by adapting and purifying the chemical components and by detoxifying what would become pollutants. Bacteria and fungi recycle carbon in soils from living and dead plants whilst plants are good CO₂ absorbers, it is the activity by soil microbes that determines whether the carbon is stored underground or released back into the atmosphere. Different types of microbes produce and consume major greenhouse gases. More than three times as much carbon is stored in soil than in the atmosphere. Temperature rises are predicted to increase bacterial respiration, leading to release of CO₂ and methane into the atmosphere.

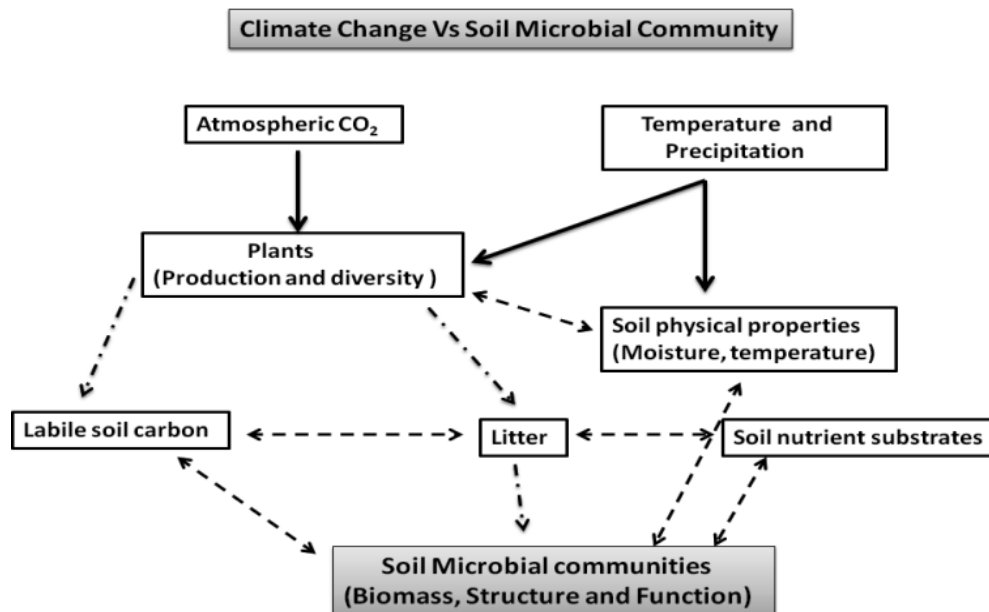


Fig. 1. Illustration of direct (solid line) and indirect (dashed line) effects of climate change factors on soil microbial community as adapted by Balser et al, 2010. Most direct effects of these factors on soil microbes will occur either at the soil surface via drought stress and response to changes in surface temperature or above ground by influencing plant productivity and species composition, crop selection and nutrient management dynamics. The belowground effects of altered CO₂, temperature and precipitation are largely indirect, and are related through resource availability and use between plants and soil microbial community.

Climate change factors such as increased atmospheric CO₂, altered temperature and precipitation regimes are expected to affect the soil microbial community in various ways. The alteration of surface soil temperature and moisture regimes is likely to have direct effects on soil microbes, as studies show community structure and function are responsive to changes in environmental extremes (Waldrop and Firestone, 2006). However, if plant activity, allocation, exudates, or community compositions are altered by the climate change factors, then the microbes may be indirectly affected via changing substrate availability and potentially microclimatic effects (Figure 1).

Increasing temperatures can increase in microbial activity, processing, and turnover, causing the microbial community to shift in favour of representatives adapted to higher temperatures and faster growth rates. Atmospheric and climatic changes are happening in concert with one another so that ecosystems are experiencing higher levels of atmospheric CO₂, warming, and changes in precipitation regimes simultaneously. Although the many single factor climate change studies

described above have enabled a better understanding of how microbial communities may respond to any one factor, understanding how multiple climate change factors interact with each other to influence microbial community responses is poorly understood. For example, elevated atmospheric CO₂ and precipitation changes might increase soil moisture in an ecosystem, but this increase may be counteracted by warming. Similarly, warming may increase microbial activity in an ecosystem, but this increase may be eliminated if changes in precipitation lead to a drier soil condition or reduced litter quantity, quality, and turnover. Such interactive effects of climate factors in a multifactorial context have been less commonly studied even in plant communities, and detailed studies are rarer still in soil microbial communities. Clearly, understanding how microbial communities will respond to these atmospheric and climate change drivers is important to make accurate predications of how ecosystems may respond to future climate scenarios. To address how multiple climate change drivers will interact to shape soil microbial communities, the long-term experiments are going on using multifactor climatic change that manipulated atmospheric CO₂ (>300 ppm, ambient), warming (>3 °C, ambient) and precipitation (wet and dry) in a constructed old-field ecosystem. The current state of knowledge on the direct and indirect effects of three key climate change factors (atmospheric CO₂, temperature and precipitation) and their interactions with the plant community and each other will be explored. Further, depending on what limits ecosystem productivity, precipitation and soil moisture changes may increase or decrease the ratio of bacteria and fungi, as well as shift their community composition.

Although microbial communities regulate important ecosystem processes, it is often unclear how the abundance and composition of microbial communities correlate with climatic perturbations and interact to effect ecosystem processes. As such, much of the ecosystem climate change research conducted to date has focused on macroscale responses to climatic change such as changes in plant growth (Norby et al, 2001), plant community composition (Bakkenes et al, 2002) and coarse scale soil processes (Emmett et al, 2004), many of which may also indirectly interact to effect microbial processes. Studies that have addressed the role of microbial communities and processes have most often targeted gross parameters, such as microbial biomass, enzymatic activity, or basic microbial community profiles in response to single climate change factors (Haase et al, 2008).

Impact of elevated CO₂ on soil microbial community

Carbon dioxide is one of the main greenhouse gases (GHG) contributing to global warming. Soil microbial communities are responsible for the cycling of carbon (C) and nutrients in ecosystems, and their activities are regulated by biotic and abiotic factors such as the quantity and quality of litter inputs, temperature, and moisture. Atmospheric and climatic changes will impact both abiotic and biotic drivers in ecosystems and the response of ecosystems to these changes. Feedbacks from ecosystem to the atmosphere may also be regulated by soil microbial communities (Castro et al, 2010).

In the global carbon cycle, annual emissions of CO₂ from the burning of fossil fuels are dwarfed by the natural fluxes of CO₂ released from the land, oceans and atmosphere. Current levels of atmospheric CO₂ depends largely on the balance between photosynthesis and respiration. In oceans, photosynthesis is primarily carried out by phytoplankton, whereas autotrophic and heterotrophic respiration return much of the carbon taken up during photosynthesis to the dissolved inorganic carbon pool. For terrestrial ecosystems, the uptake of CO₂ from the atmosphere by net primary production is dominated by higher plants, but microorganisms contribute greatly to net carbon exchange through the processes of decomposition and heterotrophic respiration (Figure 2), as well as

indirectly, through their role as plant symbionts or pathogens and by modifying nutrient availability in the soil.

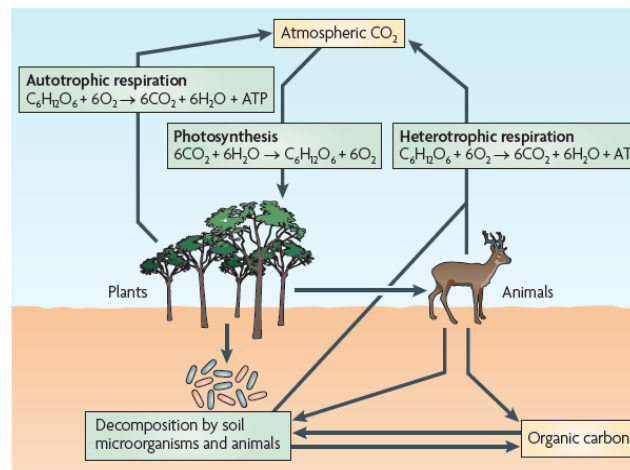


Fig. 2 Influence of atmospheric CO₂ on terrestrial ecosystem (Singh et al, 2012)

Approximately 120 billion tonnes of carbon are taken up each year by primary production on land and ~119 billion tonnes of carbon are emitted, half by autotrophic (mainly plant) respiration and half by heterotrophic soil microorganisms. Together, the land and oceans constitute a net sink of ~3 billion tonnes of carbon each year, effectively absorbing about 40% of current CO₂ emissions from fossil fuel use. In addition, 1 billion to 2 billion tonnes of carbon are added to the atmosphere each year through changes in land use. Furthermore, because soils store ~2,000 billion tonnes of organic carbon, their disturbance by agriculture and other land uses can greatly stimulate the rates of organic matter decomposition and net emissions of CO₂ to the atmosphere. For example, deep ploughing or drainage of organic, carbon-rich soils is known to stimulate rates of decomposition and respiration, because it gives microorganisms greater access to both buried organic carbon and oxygen. Through such cultivation and disturbance, soils are estimated to have already lost 40 billion to 90 billion tonnes of carbon since human intervention began. Although these responses are mediated by microbial activity, it is generally thought that changes in the structure and diversity of terrestrial microbial communities will have little effect on CO₂ production at the ecosystem level because, unlike CH₄ and N₂O production, CO₂ production results from numerous microbial processes. However, recent findings have challenged this assumption by providing evidence of a direct link between CO₂ fluxes and changes in the structure and physiology of the microbial community (Singh et al, 2010).

The response of soil microbial communities to changes in atmospheric CO₂ concentrations can be positive or negative, and consistent overall trends between sites and studies have not been observed. An increase in atmospheric CO₂ may be one of the effects of climate change, can significantly change soil environment mainly by modifying the distribution of above and belowground nutrients. For example, an increase of atmospheric CO₂ could lead to an increased plant growth, since CO₂ is the molecular building block for photosynthesis. This may lead to an increase in litter production rate and a modification in litter chemical composition, which may in turn lead to a change in its digestibility. Such modifications will then influence the nature of organic matter available for soil microorganisms (Zak et al, 2000). As a consequence, a modified litter production may modify the overall carbon supply and the nitrogen flow between plants and microorganisms (Berntson and Bazzaz 1997). In addition, elevated CO₂ may lead to an increased root growth which will have a significant impact on soil structure and major consequences for soil biota. The effects of

increased atmospheric CO₂ on bacterial biomass, richness, and community composition have been shown to vary between ecosystems, resulting in no common trends, except a 3.5- fold decrease in the relative abundance of Acidobacteria Group 1 bacteria (Dunbar et al, 2012).

Impact of elevated methane (CH₄) and nitrous oxide (N₂O) on soil microbial community

Methane (CH₄) production also occurs as a part of the carbon cycle. It is produced under anaerobic condition by the action of micro-biota. Methane is about 21 times more potent as a greenhouse gas than carbon dioxide. Nitrous oxide (N₂O) is produced as a part of the nitrogen cycle through different processes (nitrification and denitrification) which is also carried out by the soil micro-biota. Nitrous oxide is 310 times more potent as a greenhouse gas than carbon dioxide. Of the totals emitted, 80% of N₂O and 50% of CH₄ emitted from are produced by soil processes in managed ecosystems. Since these gases are more potent greenhouse gases than CO₂, only approximately 8% of emitted greenhouse gases are CH₄ and only 5% are N₂O, with CO₂ making up approximately 83% of the total greenhouse gases emitted.

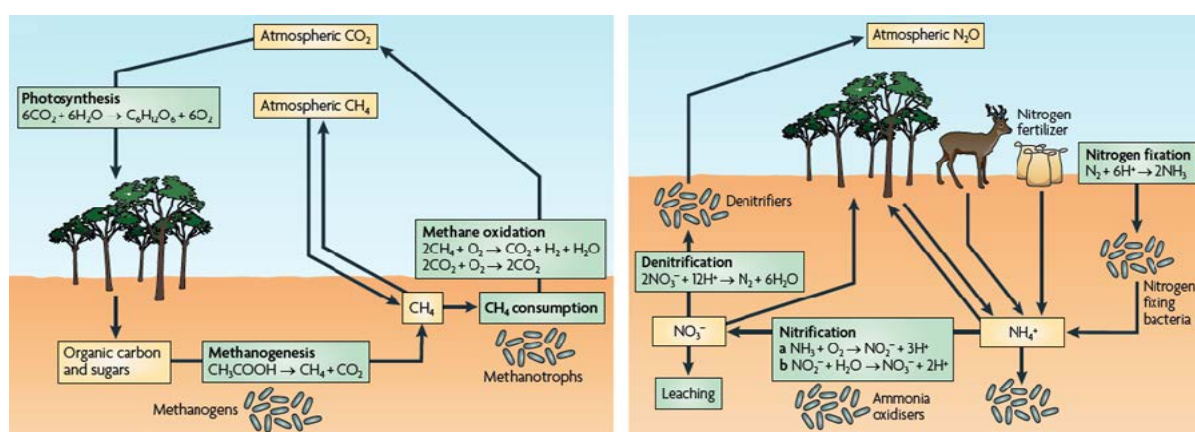


Fig. 3 Influence of CH₄ and N₂O on terrestrial ecosystem as adapted by Singh et al, 2010

Global emissions of CH₄ are arguably even more directly controlled by microorganisms than emissions of CO₂. Natural emissions (~250 million tonnes of CH₄ per year) are dominated by microbial methanogenesis, a process that is carried out by a group of anaerobic archaea in wetlands, oceans, rumens and termite guts (IPCC 2007). Methanotrophic bacteria serve as a crucial buffer to the huge amounts of CH₄ produced in some of these environments. The so-called ‘low-affinity’ methanotrophs (active only at a CH₄ concentration of >40 ppm; also called type I methanotrophs), which mainly belong to the class Gammaproteobacteria, can often consume a large proportion of the CH₄ produced in soils before it escapes to the atmosphere. For CH₄ already in the atmosphere, methanotrophic bacteria may also act as a net CH₄ sink. The so-called ‘high-affinity’ methanotrophs (active at a CH₄ concentration of <12 ppm), which mainly belong to the class Alphaproteobacteria (also known as type II methanotrophs), remove approximately 30 million tonnes CH₄ from the atmosphere each year (Reay 2003). However, these natural sources are exceeded by emissions from human activities (mainly rice cultivation, landfill, fossil fuel extraction and livestock farming) (~320 million tonnes of CH₄ per year), which, aside from some emissions from fossil fuel extraction (Figure 3).

Similarly to CO₂ and CH₄ emissions, global N₂O emissions have a predominantly microbial basis. Natural and anthropogenic sources are dominated by emissions from soils, primarily as a result of microbial nitrification and denitrification. For each tonne of reactive nitrogen (mainly fertilizer) deposited on the Earth’s surface, either naturally or deliberately, 10–50 kg are emitted as N₂O. several

studies have been carried out to distinguish the relative contributions of nitrification and denitrification to net N_2O flux, although little is known about the degree of microbial control of these processes at the ecosystem level. Most N_2O produced by nitrification is a result of the activity of autotrophic ammonia (NH_3)-oxidizing bacteria belonging to the class betaproteobacteria. However, recent studies suggest that some archaea also have an important role in nitrification, although their relative contribution to this process is still debated. By contrast, denitrification is a multistep process in which each step is mediated by a specific group of microorganisms that have the enzymes necessary to catalyse that particular step. The production of N_2O is typically the result of incomplete denitrification. Denitrifying activity is distributed among phylogenetically diverse bacterial populations, although each denitrifying enzyme catalysing a specific step in the process (for example, nitrate reductase) is highly conserved genetically. A recent study provided direct evidence of a strong link between denitrifying bacterial communities and the rate of N_2O emissions from soils (Crutzen et al, 2007).

Effect of temperature on soil microbial community

Because temperature is generally known to exhibit a strong influence on microbial activity, understanding the effects of temperature change, such as is likely to accompany climate change (i.e., warming), is important for assessing impacts on the soil microbial community and predicting its response. Increased temperature is generally known to increase decomposition of organic matter (Wallenstein et al, 2012). Increased temperature often affects 'recalcitrant' SOM more than 'labile' SOM because warming increases the likelihood of passing the critical activation energy (E_a) needed for decomposing resistant compounds (Dungait et al, 2012). This may allow soil microorganisms to access older soil C stocks under climate warming and release more C into the atmosphere. However, temperature sensitivity of soil respiration has also been shown to acclimate to warming conditions over time which could mitigate the initial release of C into the atmosphere that is typically observed with soil warming.

One possible mechanism by which microbes may acclimate to warming is by altering their physiology, specifically their carbon use efficiency (CUE) or the amount of carbon utilized by the soil microbial community that is allocated to growth (Allison et al, 2010). If microbial CUE is reduced with warming because microbial activity (respiration) is increased and prevents C-allocation to microbial growth (biomass), then respiration losses may initially be higher, but may decline over time as decomposer microorganism biomass is reduced, which may reduce future C-losses from respiration over time. However, warming effects on CUE and the resulting amounts of CO_2 released from decomposition vary and may even differ based on quality and complexity of substrates, suggesting that research on temperature and CUE responses, as well as energy use for microbial maintenance and growth, is incomplete. Research has shown that microbial biomass increases initially in direct response to heat, but may actually decrease over time as microbial growth efficiency is altered. While increasing temperature is generally known to increase decomposition of soil organic matter, biological responses to temperature, such as enzyme activities (Koch et al, 2007) and substrate utilization patterns (Dell et al, 2012), can also affect temperature sensitivity of decomposition (Wallenstein et al, 2012). Long-term warming could induce changes in plant species composition, which can significantly affect soil microbial production of extracellular enzyme activity (Henry 2012). Changes in extracellular enzyme activities and production may influence which compounds are most effectively utilized by soil microorganisms under warming conditions and potentially result in altered nutrient pools. Taken together, these studies suggest that the effects of elevated temperature on the

soil microbial community activity, biomass, and function as related to decomposition, and the resulting influence on C stocks and soil nutrients are more complex than previously thought and may vary over time.

Effect of precipitation on soil microbial community

Unlike temperature, in which climate change predictions suggest increases (i.e., warming) will occur for most of the planet (IPCC 2007), changes in precipitation are likely to be more regionally variable, with some areas experiencing increases in total quantity and others reductions, as well as the possibility of altered spatial or temporal patterns of distribution. More specific projections of precipitation regimes vary between climate models, especially by region, making it difficult to assess the potential impacts of precipitation on a biologically meaningful scale (Weltzin et al, 2003). Less is known about the variable and complex soil microbial community response to alterations in precipitation or moisture than that of temperature or increased atmospheric CO₂, although it is widely accepted that precipitation, in how it alters soil moisture regimes, regulates decomposition in periods of water stress (drought) or anoxia (wet) (Balser et al, 2010). Microbial communities are able to adapt to local precipitation regimes and respond to moisture stressors such as drying/rewetting in different ways, in part depending on the historical variability of the system. This complexity of response inhibits generalizations about microbial response to soil moisture across biomes (Evans and Wallenstein 2011). Despite this, soil moisture has often been found to be the primary variable associated with microbial community structure and function and enzyme activities (Guenet et al, 2012), even dominating activity in other spheres of soil biota such as microarthropod populations (Kardol et al, 2011). Terrestrial ecosystem responses to altered precipitation regimes are likely to vary depending on the interactive effects of timing and duration of events, intensity, and total amount of rainfall delivered. All of which will influence plant-microbe ecosystem functions, such as plant productivity and soil microbial respiration, and determine ecosystem carbon dynamics (Fay et al, 2008). Predicting soil microbial responses to altered precipitation is difficult and will depend on a variety of factors such as regional and historical variation, and changes in the pattern, intensity and total amount of rainfall, and the response of the existing vegetation.

Mitigation strategies to restore soil microbial community

Soil management practices have important and sometimes immediate effects on soil biodiversity and the resulting ecosystem services. The main mechanism explaining the changes in soil biodiversity with increased intensification of management practices is linked to organic matter input. Organic matter drives the soil food web, and depending on the type, it will drive bacteria (low C: N) or fungi (high C: N) dominated food webs. Greater litter inputs in grasslands encourage fungal dominated microbial communities and a greater diversity of nematodes and micro arthropods. The enhanced microbial activity may also enhance the biological regulators, and thus reduce nematode and soil pathogen incidence. In contrast, in intensively managed (fertilized) grasslands or croplands, microbial communities are depressed and shift to opportunistic bacteria-dominated communities. In turn, this tends to favour opportunistic bacteria feeding fauna. Soil tillage practices disturb fungal hyphae and the larger earthworm species that visit the soil surface to obtain plant material for food, such as earthworms. Biomass and abundance of earthworms are reduced by a factor of 1.3-3 in conventionally managed soils when compared to organic management types. Conventional management also results in poorer soil aeration and soil drainage (Mandal and Neenu 2012).

Some methods to protect soil microbial communities

1. Mulching / light soil sealing

Mulching consists of covering the soil surface to protect against erosion and to enhance its fertility. Mulch is usually applied towards the beginning of the crop growing season, and may be reapplied as necessary. It serves initially to warm the soil by helping it retain heat and moisture. A variety of materials can be used as mulch, including organic residues (e.g. crop residue, hay, bark), but also manure, sewage sludge, compost, rubber or plastic films.

2. Application of organic residues (compost/ manure/ sludge)

Application of animal manure, sludge or other carbon-rich wastes, such as coffee-berry pulp or compost, improves the organic matter content of the soil. For agricultural purpose, it is usually better to allow decomposition of organic residues for a period before applying them to the field. This is because addition of carbon-rich compounds immobilises available N in the soil temporarily, as micro-organisms need both C and N for their growth and development.

3. Fertilizers

High levels of some inorganic nitrogenous fertilizers provide microbes with easy to use nitrogen, thereby boosting their activity. This increases the rate of decomposition of low quality organic inputs and soil organic matter, resulting in the continuing decline of soil organic matter content which, ultimately, results in loss of soil structure and water holding capacity.

4. Crop management

4a. Choice of the crops species

The choice of the cultivated crop is important as it defines the kind of habitat available to soil fauna. For example legumes can act as natural fertilisers, improving the nitrogen concentration in soil, thanks to the symbiotic relationship they establish with Rhizobia.

4b. Crop rotations

Crop rotations can also help avoid the buildup of pathogens and pests, as the alternation of crops modifies the associated communities of biological regulators.

5. Landscape management

Hedgerows and grassy field margins Establishing hedgerows or grassy strips at the edge of arable fields offer a stable habitat, food, and a protective environment for soil fauna next to the intensively managed fields. Hedgerows are even more favourable to soil organisms, in particular biological regulators, than grassy field margins, however, due to their low mobility; the soil organisms will have only limited dispersal into the fields. That also counts for field margins, in which 10% of the soil dwelling species present in farmland were found to occur exclusively.

Conclusion

On the basis of the above information, we recommend several topics of research that need to be prioritized to develop microorganism-mediated approaches to alleviate climate change. First, we need to better understand and quantify microbial responses to climate change to realize future ecosystem functioning. second, we need to classify microbial taxa in terms of their functional and physiological capabilities and to link this information to the level of ecosystem function. Third, we need to improve our mechanistic understanding of microbial control of greenhouse gas emissions and

microbial responses to simultaneous climatic factors, such as warming, altered precipitation and increased CO₂ levels, across different ecosystems. Fourth, we need to develop a framework to incorporate microbial data (biomass, community, diversity and activity) into climate models to reduce uncertainty and to improve estimation and prediction. Fifth, we need to better understand the effect of climate change on above-ground and below-ground interactions and nutrient cycling, as well as the role of these interactions in modulating the response of ecosystems to global change. Finally, we need to develop a framework based on the above five points to potentially manage natural microbial systems to enhance carbon sequestration and/or reduce net greenhouse gas emissions.

To answer the above challenges, we need to use an interdisciplinary approach that includes microbial ecology, environmental genomics, soil and plant science, and ecosystem modelling. There have been substantial advancements in the technologies that can be used to examine microbial communities and to relate them to ecosystem functions. These technologies should be applied to study how particular taxa respond to individual and multiple climate variables and how such responses influence ecosystem functions.

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13. Exploiting the Potential of Biochar for Improving Soil Health and Carbon Sequestration

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Abstract

Biochar is a new word for many, but the technology is a traditional one in several regions of the world. Biochar refers to a kind of charcoal made from biomass. Unlike charcoal made for fuel, biochar has properties which make it a valuable soil amendment. The decrease in biomass production, decrease in organic matter supply and increased decomposition rate are the primary factors to reduction in soil organic matter. Biochar is a stable carbon compound created when biomass is heated to temperatures between 300 and 1000°C, under low oxygen concentrations. Biochar is attracting attention as a means for sequestering carbon and as a potentially valuable input for agriculture to improve soil fertility and sustainable production. Soil health management with biochar is evaluated globally as a means to improve soil fertility and to mitigate climate change.

Introduction

Soil health is the foundation of vigorous crop productivity with higher opportunity for income and employment which in turn provides sustainable food system. Soil health management forms the basis for sustainable system of productive agriculture as the Indian population, which increased from 683 million in 1981 to 1210 million in 2010, is estimated to reach 1412 million in 2025 and to 1475 million in 2030. To feed the projected population of 1.48 billion by 2030, India needs to produce 350 million tonnes of food grains. The expanded food needs of future must be met through intensive agriculture without any expansion in the arable land. The per capita arable land decreased from 0.34 ha in 1950-51 to 0.15 ha in 2000-01 and is expected to shrink to 0.08 ha in 2025 and to 0.07 ha in 2030. The current food-grain production of 218 mt (2009-10) is obtained from the net arable land of 141 m ha.

Plants obtain their nutrition from organic matter and minerals found in soils. As the land is farmed, the agricultural processes disturb the natural soil systems including nutrient cycling and the release and uptake of nutrients (Bot and Benites 2005). Modern agriculture is apt to mine the soil for nutrients and to reduce soil organic matter levels through repetitive harvesting of crops. This decline of the soil continues until management practices are improved, additional nutrients are applied, rotation with nitrogen-fixing crops is practiced, or until a fallow period occurs allowing a gradual recovery of the soil through natural ecological development. As the natural stores of the most important nutrients for plant growth decline in the soil, growth rates of crops are inhibited. Soil organic matter plays key role in soil fertility sustenance. In soybean-wheat system, without balanced input of nutrients, organic matter status of soil declined over a time in Alfisols of Ranchi. Whereas, balanced fertilization with NPK and NPK+FYM improved the organic matter status in Vertisols under soybean-wheat system at Jabalpur. It is crucial to maintain a threshold level of organic matter in the soil for maintaining physical, chemical and biological integrity of the soil and for sustained agricultural productivity. Thus, assessing soil organic carbon (SOC) sequestration under intensive cropping with different management practices plays an important role in long-term maintenance of soil quality.

Efficient use of biomass, available as crop residues and other farm wastes, by converting it to a useful source of soil amendment/nutrients is one way to manage soil health and fertility. The current

availability of biomass in India is estimated at about 500 million tons/year. These residues are either partially utilized or un-utilized due to various constraints. It is estimated that about 93 million tons of crop residues are burnt in each year in India. Residue burning traditionally provides a fast way to clear the agricultural field of residual biomass, facilitating further land preparation and planting. However, in addition to loss of valuable biomass and nutrients, biomass burning leads to release of toxic gases including GHGs. In this context, biochar, a pyrolysis product of plant biomass offers a significant, multidimensional opportunity to transform large scale agricultural waste streams from a financial and environmental liability to valuable assets. Use of biochar in agricultural systems is one viable option that can enhance natural rates of carbon sequestration in the soil, reduce farm waste and improve the soil quality.

In India, about 435.98 million tons of agro-residues are produced every year, out of which 313.62 million tons are surplus. These residues are either partially utilized or un-utilized due to various constraints (Murali *et al.*, 2010). Koopmans and Koppejan (1997) estimated that about 507,837 thousand tons of field crop residues were generated in India during 1997 of which 43% was rice and 23% wheat. The estimates from Streets *et al.* (2003) reveal that 16% of total crop residues were burnt. The results from Venkataraman *et al.* (2006) suggest that 116 million tons of crop residues were burnt in India in 2001, but with a strong regional variation (Gupta, 2010). Studies sponsored by the Ministry of New and Renewable Energy (MNRE), Govt. of India have estimated surplus biomass availability at about 120–150 million tons/ annum (MNRE, 2009). Of this, about 93 million tons of crop residues are burned in each year (IARI 2012).

Generation of crop residues is highest in Uttar Pradesh (60 million t) followed by Punjab (51 million t) and Maharashtra (46 million t). Maharashtra contributes maximum to the generation of residues of pulses (3 million t) while residues from fibre crop is dominant in Andhra Pradesh (14 million t). Gujarat and Rajasthan generate about 6 million t each of residues from oilseed crops. Among different crops, cereals generate maximum residues (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt) and sugarcane (12 Mt). The cereal crops (rice, wheat, maize, millets) contribute 70% while rice crop alone contributes 34% to the crop residues (Fig 1). The surplus residues i.e., total residues generated minus residues used for various purposes, are typically burnt on-farm. Estimated total amount of crop residues surplus in India is 91-141 Mt (IARI, 2012). Cereals and fibre crops contribute 58% and 23%, respectively and remaining 19% is from sugarcane, pulses, oilseeds and other crops. Out of 82 Mt surplus residues from the cereal crops, 44 Mt is from rice followed by 24.5 Mt from wheat. About threefourths of greenhouse gas (GHG) emissions from agro-residues burning were CH₄ and the remaining one-fourth was N₂O. Burning of wheat and paddy straws alone contributes to about 42% of GHGs. Hence, conversion of organic waste to produce biochar using the pyrolysis process is one viable option that can enhance natural rates of carbon sequestration in the soil, reduce farm waste and improve the soil quality (Srinivasarao *et al.*, 2012, 2013). Biochar has the potential to increase conventional agricultural productivity and enhance the ability of farmers to participate in carbon markets beyond the traditional approach by directly applying carbon into the soil (McHenry, 2009). Converting waste biomass into biochar would transfer very significant amounts of carbon from the active to inactive carbon pool, presenting a compelling opportunity to intervene in the carbon cycle. The use of biochar as soil amendment is proposed as a new approach to mitigate man-induced climate change along with improving soil productivity. The use of biochar in agriculture is not new; in ancient times farmers used it to enhance the production of agricultural crops. In order to sequester carbon, a material must have long residence time and should be resistant to chemical processes such as oxidation to CO₂ or reduction to methane. It has been suggested by many authors (Izaurrealde *et al.*, 2001; McHenry, 2009) that the use of biochar as soil amendment meets the above requirements; since the biomass is protected from further oxidation as

compared to material that would otherwise have degraded to release CO₂ into the atmosphere. Such partially burnt products, more commonly called pyrogenic carbon or black carbon, may act as an important long-term carbon sink because their microbial decomposition and chemical transformation are probably slow.

What is biochar?

Lehmann and Joseph (2009) define biochar as the carbon-rich product when biomass, such as wood, manure or leaves, is heated in a closed container with little or no available air. In more technical terms, biochar is produced by so-called thermal decomposition of organic material with limited supply of oxygen, and at relatively low temperatures (<700 °C) (Stockmann, 2011). This process often mirrors the production of charcoal, which is one of the most ancient industrial technologies developed by mankind (Barrow 2012). However, biochar can be distinguished from charcoal and similar materials in that it is produced with the intent it be applied to soil as a means of improving soil productivity, carbon (C) storage and possibly filtration of percolating soil water (to try and cut pollution of surface and groundwater bodies). The production process and the intended use, forms the basis for distinguishing biochar (Lehmann et al., 2006). Biochar is the appropriate term where charred organic matter is applied to soil in a deliberate manner, with the intent to improve soil properties. This distinguishes biochar from charcoal that is used as fuel for heat, as a filter, as a reductant in iron making or as a colouring agent in industry or art (Lehmann et al., 2006). Biochar is the most widely used and arguably the best term. Biochar is very variable in quality, depending on raw material, pyrolysis conditions, whether it is enriched with other compounds and how finely it is ground. The problem is that biochar is a generic term and standards have not been established but are much needed (Barrow 2012).

Slow pyrolysis is said to minimize the risk of producing dioxins and harmful polyaromatic hydrocarbons, which could contaminate biochar and/or escape with exhaust gases and solid or liquid wastes. Low temperature pyrolysis gives a material with more desirable soil improvement properties than charcoal or ash that is also richer in aromatic carbon and humic substances (Barrow 2012). The pyrolysis can generate useful heat, biofuel or syngas as by-products. It may be possible to sequester more carbon dioxide in the soil than is liberated to the atmosphere during biochar pyrolysis: making it a carbon negative activity, which can enhance profitability (Fowles, 2007; Lal, 2007; Lehmann & Joseph, 2009; Matthews, 2008b). Sohi, Loetz-Capel, Krull, and Boll (2009) noted biochar seems capable of remaining in soil without releasing carbon for centuries, even millennia and it enhances microbial activity. The mean soil carbon residence time for buried biochar is likely to be at least 1000 years, possibly longer (Nguyen & Lehmann, 2009).

Some burnt materials like ash can be hydrophobic; so if added to soil they reduce moisture storage and enhance runoff resulting in poorer crops and even erosion; care needs to be exercised to ensure biochar does not have these qualities (Renner, 2007). So far the indications are that it enhances soil moisture. Beneficial applications might not need to be very frequent (compared with fertilisers, compost or manures). Ideally, biochar should have a long residence time in soil and actively support beneficial soil microorganisms. More research is needed to check these qualities. Also, successful biochar programmes will require more than technical know-how if they are to avoid unwanted socio-economic impacts; there must be political will, farmer support, organisational skills and the ability to cover the costs of raw material transportation and application to the land.

Important Feedstock for Biochar

Biochar can also be produced from manures and other animal wastes, including bone (Fig 1.). For instance, dairy shed waste and chicken litter have been used to produce biochar (Cao & Harris 2010; Joseph et al. 2010; McHenry 2009). There are also obnoxious weed viz. *Parthenium*, *Lantana*

etc. having characteristic woody stem can be used for making biochar. Many types of manure are anaerobically digested to produce biogas (a mixture of methane and carbon dioxide) and it is possible that the remaining solid by-products could be used in pyrolysis reactions to produce biochar. When considering a potential feedstock for biochar production, biomass availability and moisture content must also be considered to ensure continual operation of the processing plant, with minimal energy input requirements. Pyrolysis of these types of waste may produce both energy and a biochar product with relatively high levels of plant nutrients, such as phosphorous, potassium, nitrogen, magnesium and calcium. Containment and use of nutrient-rich manures and animal products for production of biochar may also have positive environmental effects including reduced nutrient run-off and corresponding reductions in greenhouse gas emissions, such as methane and nitrous oxide (He et al. 2000). Although manure and municipal waste may be used in pyrolysis, the high risk of contamination from toxic chemicals and heavy metals may limit its use on agricultural soils. The mineral content of potential biomass feedstocks must also be considered. Nik-Azar et al. (1997) found that impregnating woody biomass with sodium, potassium and calcium increased biochar yields by up to 15 per cent. These findings are in agreement with other studies, where addition of inorganic salts (magnesium chloride, sodium chloride, iron sulphate and zinc chloride) increased production of char from 5 per cent (control feedstock; no addition of salts) to 8, 14, 17 and 28 per cent respectively (Varhegyi et al. 1988). However, addition of any minerals to feedstocks to increase biochar yield would, from an agricultural productivity perspective, have to be weighed against the effect of those minerals on soil structure, soil fertility and plant growth, and the cost of supplying these nutrients through other means.

Not all agricultural waste materials are suitable for biochar production for agricultural purposes (Lehmann et al. 2006; McHenry 2009). Some production conditions and feedstock types can cause the resulting biochar to be ineffective in retaining nutrients and susceptible to microbial decay (McHenry 2009). Depending on the biomass source, some biochar products, such as municipal waste, may contain high levels of toxic substances (heavy metals and organic pollutants) which must also be considered in the context of adding biochar to agricultural soils (Lehmann et al. 2006).

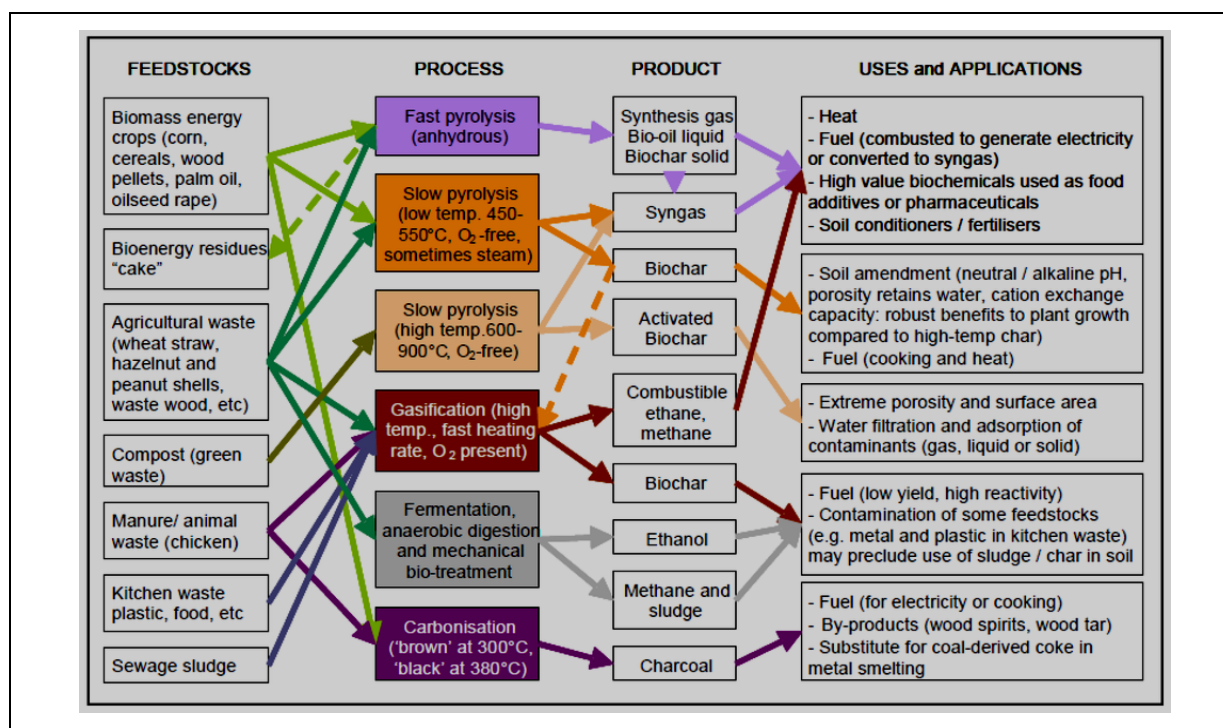


Fig 1. Potential biomass feedstocks for various pyrolysis conditions (Sohi et al. 2009)

Potential benefits of biochar

- ✓ Store recalcitrant form of carbon in soil. Compost and manures are subject to rapid microbial breakdown. Sequestration in biochar is likely to be for centuries, possibly for thousands of years.
- ✓ Enhance plant growth and sustain crop yields. Help improve good and problematic nutrient-poor soils, including acidic tropical humid and drier environment soils. (Table 2)
- ✓ Help compensate for greenhouse gas emissions associated with agricultural development.
- ✓ Biochar may improve soil moisture retention, increasing agricultural resilience and provides support to intensive sustainable agriculture which could help to cut pressure for new forest clearances and enhances biodiversity conservation benefits.
- ✓ Enable production of useful materials from uncropped land making use of unused wastes with increased adaptability to environmental change by making production more resilient.
- ✓ Reduce the need for fertiliser/manure/compost. Reduce costs of sewage and animal waste treatment and cut emissions that they would otherwise cause if held in lagoons or heaps. Application of manure or compost to the soil may stimulate bacteria and cause methane and N₂O to the atmosphere. Composting also releases greenhouse gases and compost may have a limited residence time in soil. Pyrolysis destroys microorganisms and some veterinary pharmaceuticals. It also reported by many researchers worldwide to Suppress methane and N₂O (nitrous oxide gas) emission from cultivated soil thereby reduces global warming).
- ✓ Offer a more environmentally-friendly way of processing plastics and refuse if biochar is too contaminated for agricultural use for growing non-food crops or send to landfill to sequester carbon.
- ✓ Nutrient affinity i.e. retention of plant nutrients, notably retention of N on permeable soils under rainy conditions is found higher with biochar application. Biochar may bind agrochemicals and help reduce phosphate and nitrate and agrochemicals pollution of streams and groundwater. Thus helping resolve major problems hindering sustained and improved agriculture. Reduce plant uptake of pesticides from contaminated soils (Xiang-Yang Yu. et al., 2009). A form of bioremediation.
- ✓ Reduce soil acidity/raise pH (Rodriguez et al. 2009). Reduce aluminium toxicity and increases cation exchange capacity (Table 1). The published data suggest that biochars from woody materials tend to provide low CEC values, while non-woody plant materials such as sugarcane trash (leaf) or tree bark tend to have higher CEC values (Yamamoto *et al.*, 2006; Chan *et al.*, 2007; Major et al., 2009; Singh and Gu, 2010; Van Zwieten *et al.*, 2010).
- ✓ By improving moisture retention biochar may reduce the demand for irrigation and make cropping more secure.
- ✓ Support biofuel production and reduce its carbon footprint and even enable it to move toward being carbon neutral.
- ✓ Increase soil microbial biomass and support other beneficial organism like earthworms. Support nitrogen fixation. Increase arbuscular mycorrhizal fungi in soil.

- ✓ Opportunities for poor to benefit from carbon offset market and also reduce dependency of farmers on input suppliers.
- ✓ Periurban/urban agriculture: biochar may be a useful input to counter harmful compounds like heavy metals, dioxins, PAHs (polycyclic aromatic hydrocarbons) present in sewage or refuse inputs.

Biochar and soil properties

Available crop residues and other farm wastes such as obnoxious weeds can be converted into a useful soil amendment/ source of nutrients i.e. biochar. It is one way to manage soil health and fertility. The use of biochar is reported to increase the resilience of agricultural systems by introducing the recalcitrant form of carbon with a reasonable increase in the CEC (Yamamoto *et al.*, 2006 and Glaser *et al.*, 2002). There are so many published studies which advocate the beneficial effect of biochar on soil physical and chemical properties (Table 1).

Table 1. Effect of biochar on different soil properties (Srinivasarao et al. 2013)

Some selected soil properties	Findings	Reference
Cation exchange capacity	50% increase	Glaser <i>et al.</i> , 2002
Fertilizer use efficiency	10-30 % increase	Gaunt and Cowie, 2009
Liming agent	1 unit pH increase	Lehman and Rondon, 2006
Crop productivity	20-120% increase	
Biological nitrogen fixation	50-72% increase	
Soil moisture retention	Up to 18 % increase	Tryon, 1948
Mycorrhizal fungi	40 % increase	Warnock <i>et al.</i> , 2007
Bulk density	Soil dependent	Laird, 2008
Methane emission	100% decrease	Rondon <i>et al.</i> , 2005
Nitrous oxide emissions	50 % decrease	Yanai <i>et al.</i> , 2007

Biochar and plant growth

Most of the currently published studies (Table 2) assessing the effect of biochar on crop yield, are generally small scale, almost all short-term, and sometimes conducted in pots where environmental fluctuation is removed. These limitations are compounded by a lack of methodological consistency in nutrient management and pH control, biochar type and origin. It is not therefore possible at this stage to draw any quantitative conclusion, certainly not to project or compare the impact of a particular one-time addition of biochar on long-term crop yield. Nonetheless, evidence suggests that at least for some crop and soil combinations, moderate additions of biochar are usually beneficial, and in very few cases negative.

Table 2. Effects of biochar on plant growth and yield

Crop	Experimental summary	Findings	Reference
Pea	Char @ 0.5 t/ha	biomass increased by 160%	Iswaran <i>et al.</i> (1980)
Mungbean		biomass increased by 122%	
Soybean	Crops were grown on volcanic ash loam, Japan with char @ 0.5 , 5, 15 t/ha	Char @ 0.5 t/ha increased yield by 151% whereas, Char at 5 t/ha and 15 t/ha decreased yield by 63% and 29%, respectively	Kishimoto & Sugiura (1985)
Sugi trees	Crops were grown on clay loam, Japan Wood charcoal, bark charcoal and activated charcoal at 0.5 t/ha	increased biomass by 249, 324 and 244%, respectively	
Bauhinia trees	Crops were grown on Alfisol/Ultisol	Charcoal application increased biomass yield by 13% and height by 24%	Chidumayo, (1994)
Cowpea	Grown on xanthic ferralsol char @ 67 and 135 t/ha	Char @ 67 and 135 t/ha increased biomass by 150% and 200%, respectively	Glaser <i>et al.</i> (2002)
Cowpea	Planted in pots and rice crops in lysimeters, Brazil	Soil fertility and nutrient retention. Biochar additions significantly increased biomass production by 38 to 45%	Lehmann <i>et al.</i> (2003)
Maize	Comparison of yields between disused charcoal production sites and adjacent fields, Ghana	Grain and biomass yield was 91 and 44% higher on charcoal site than control	Oguntunde <i>et al.</i> (2004)

Maize, cowpea and peanut	Trial in area of low soil fertility Acacia bark charcoal plus fertilizer	Increased in maize and peanut yields but not cowpea	Yamamoto et al. (2006)
Radish	Pot trial on heavy soil using commercial green waste biochar (three rates) with and without N	Biochar at 100 t/ha increased yield 3 times; linear increase 10 to 50 t/ha, but no effect without added N	Chan et al. (2007)
Beans	Enhanced biological N ₂ fixation (BNF) by common beans through biochar additions, Colombia	Bean yield increased by 46% and biomass production by 39% compared to control at 90 and 60 g biochar/kg, respectively	Rondon et al. (2007)
Four cropping cycles with rice (<i>Oryza sativa</i> L.) and sorghum (<i>Sorghum bicolor</i> L.)	Charcoal amended with chicken manure amendments	Charcoal amended with chicken manure amendments resulted in the highest cumulative crop yield (12.4 t/ha)	Steiner et al. (2007)
Maize	Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya	Doubling of maize grain yield in the highly degraded soils from about 3 to 6 t/ha	Kimetu et al. (2008)
Rice	Pot experiment in alluvial soil with rice husk biochar @ 0, 4, 8 and 16 t/ha	Non significant increase in the grain yield and dry matter accumulation due to biochar application	Singh 2013
Rice	Pot experiment in alluvial soil with rice husk biochar @ 5 and 10 t/ha	Dry matter increased by 11 and 17% as compared to control @ 5 and 10 t/ha, respectively	Rani 2013

Biochar and GHGs emission

Burning of residues emits a significant amount GHGs. For example, 70, 7 and 0.66% of C present in rice straw is emitted as CO₂, CO and CH₄, respectively, while 2.09% of N in straw is emitted as N₂O upon burning. One ton straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO₂, 199 kg ash and 2 kg SO₂. This change in composition of the atmosphere may have a direct or indirect effect on the radiation balance. Besides other light hydrocarbons, volatile organic

compounds (VOCs) and semi-volatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) and SO_x, NO_x are also emitted. These gases are important for their global impact and may lead to a regional increase in the levels of aerosols, acid deposition, increase in tropospheric ozone and depletion of the stratospheric ozone layer.

Biochar production does emit carbon dioxide and other greenhouse gases but combined with waste disposal or biofuel production it appears to offer a practical way to mitigate global warming. Soil is a significant source of nitrous oxide (N₂O) and both a source and sink of methane (CH₄). These gases are 23 and 298 times more potent than carbon dioxide (CO₂) as greenhouse gases in the atmosphere. Biochar is reported to reduce N₂O emission could be due to inhibition of either stage of nitrification and/or inhibition of denitrification, or promotion of the reduction of N₂O, and these impacts could occur simultaneously in a soil (Berglund *et al.*, 2004; DeLuca *et al.*, 2006). Biochar potential is attracting much attention as a safe, practical, technically simple, and affordable method of sequestration, which has a chance of spreading fast enough to have real effect. If enough farmers, larger agricultural enterprises, biofuel producers, and waste treatment plants are established it could become an important means of carbon sequestration. This potential is a little better researched than biochar agricultural value; although, there is insufficient data on biochar-burial soil carbon mean residence times. However, according to Sohi *et al.* (2010), no peer-reviewed studies documenting suppression of nitrous oxide emissions in field experiments have been reported. There are, however, conference proceedings and laboratory-based peer-reviewed studies reporting reductions in nitrous oxide emissions (Clough & Condon 2010). Rondon *et al.* (2005) found that adding biochar significantly reduced net methane and nitrous oxide emissions when infertile Colombian savannah soils were amended with biochar at a rate of up to 30 grams per kilogram of soil. Researchers found that nitrous oxide and methane emissions were reduced by up to 50 and 100 per cent respectively, at an optimal application rate of 20 grams of biochar per kilogram of soil (Rondon *et al.* 2005). Similarly, Spokas *et al.* (2009) found suppression of both methane and nitrous oxide at levels up to 60 per cent inclusion rates in laboratory trials (corresponding to 720 tonnes biochar per hectare). Yanai *et al.* (2007) also found that addition of biochar up to 10 per cent reduced nitrous oxide emissions by 89 per cent, but only when the soil was rehydrated with 73 to 78 per cent waterfilled pore space. However, biochar added to soils rehydrated at 83 per cent water-filled pore space significantly stimulated nitrous oxide emissions compared with the control (Yanai *et al.* 2007). Increased soil aeration from biochar addition reduces denitrification and increases sink capacity for CH₄. Biochar addition induces microbial immobilization of available N in soil, thereby decreasing N₂O source capacity of soil. Increased pH from biochar addition drives N₂ formation from N₂O. When applied to the soil, biochar can lower GHG emissions of cropland soils by substantially reducing the release of N₂O (Lehmann *et al.*, 2003). Reduction of N₂O and CH₄ emission as a result of biochar application is seen to attract considerable attention due to the much higher global warming potentials of these gases compared to CO₂ (Steiner, 2010). Rondon *et al.* (2005) reported a 50% reduction in N₂O emissions from soybean plots and almost complete suppression of CH₄ emissions from biochar amended acidic soils in the Eastern Colombian Plains. Yanai *et al.* (2007), however, reported an 85% reduction in N₂O emission from re-wetted soils containing 10% biochar, compared to soils without biochar. Biochar from municipal biowaste also caused a decrease in emissions of nitrous oxide in laboratory soil chambers (Yanai *et al.* 2007). Spokas *et al.* (2009) also found a significant reduction in N₂O emission in agricultural soils in Minnesota; while Sohi *et al.* (2010) found an emission suppression of

only 15%. Additions of 15 g biochar/kg of soil to a grass and 30 g/kg of soil to a soil cropped with soybeans completely suppressed methane emissions (Rondon *et al.* 2005).

Biochar and soil biota

Biochar has been described as a possible means to improve soil fertility as well as other ecosystem services and sequester carbon (C) to mitigate climate change (Lehmann *et al.*, 2006; Lehmann, 2007a; Laird, 2008; Sohi *et al.*, 2010). The observed effects on soil fertility have been explained mainly by a pH increase in acid soils (Van Zwieten *et al.*, 2010a) or improved nutrient retention through cation adsorption (Liang *et al.*, 2006). However, biochar has also been shown to change soil biological community composition and abundance (Pietikäinen *et al.*, 2000; Yin *et al.*, 2000; Kim *et al.*, 2007; O'Neill *et al.*, 2009; Liang *et al.*, 2010; Grossman *et al.*, 2010; Jin, 2010). Such changes may well have effects on nutrient cycles (Steiner *et al.*, 2008b) or soil structure (Rillig and Mummey, 2006) and, thereby, indirectly affect plant growth (Warnock *et al.*, 2007). Rhizosphere bacteria and fungi may also promote plant growth directly (Schwartz *et al.*, 2006; Compant *et al.*, 2010). Changes in microbial community composition or activity induced by biochar may not only affect nutrient cycles and plant growth, but also the cycling of soil organic matter (Wardle *et al.*, 2008; Kuzyakov *et al.*, 2009; Liang *et al.*, 2010). The material properties of biochar are very different from those of uncharred organic matter in soil (Schmidt and Noack, 2000), and are known to change over time due to weathering processes, interactions with soil mineral and organic matter and oxidation by microorganisms in soil (Lehmann *et al.*, 2005; Cheng *et al.*, 2008; Cheng and Lehmann, 2009; Nguyen *et al.*, 2010). However, the relationships between biochar chemical and physical properties and their effects on soil biota and potential concomitant effects on soil processes are poorly understood. The chemical stability of a large fraction of a given biochar material means that microorganisms will not be able to readily utilize the C as an energy source or the N and possibly other nutrients contained in the C structure. However, depending on the type of biochar, a fraction may be readily leached and therefore mineralizable (Lehmann *et al.*, 2009) and in some cases has been shown to stimulate microbial activity and increase abundance (Steiner *et al.*, 2008a).

Many soil microorganisms are specialists living in microhabitats that provide resources for their specific metabolic needs. For instance, aerobic microbes live at the surface of soil aggregates, while denitrifiers and semi-aquatic species dwell within the moist interior of soil peds (Sexstone *et al.*, 1985). Organic matter decomposition rates are higher at the surface of soil aggregates than in the core of aggregates due to higher influx of resources at the surface (organic matter, moisture, and O₂). This is evident from depleted C concentrations and C-to-N ratios, as well as the oxidation of lignin phenols and the accumulation of microbial polysaccharides at the aggregate surface relative to the aggregate core (Amelung and Zech, 1996). Similarly, the exterior surfaces of biochar particles in the soil are significantly more oxidized than the particle interior or core (Lehmann *et al.*, 2005; Liang *et al.*, 2006; Cheng *et al.*, 2008). This is due to sorption of organic matter on the biochar surface and the oxidation of the biochar C itself (Liang *et al.*, 2006), both biotically and abiotically mediated via reactions with O₂ (Cheng *et al.*, 2006, 2008). Similar to soil aggregates, the preferential oxidation of the biochar particle surface relative to the particle interior implies a limited diffusion of O₂ to the interior of biochar particles. Such differential redox conditions not only influence organic matter oxidation but also metal transformation.

Conclusion

Application of biochar to agricultural land for soil amelioration and agricultural productivity improvements is not a new phenomenon. A number of benefits have been identified within the

literature; biochar has been found to improve agriculturally significant soil parameters such as soil pH, cation exchange capacity and soil water holding capacity. Researchers have found the increase in these performance parameters has improved nitrogen use efficiency and therefore crop productivity in limited field trials. Further, biochar has the potential to reduce greenhouse gas emissions through carbon sequestration, as well as potentially decreasing methane and nitrous oxide emissions from the soil. However, the variable application rates, uncertain feedstock effects, and initial soil state provide a wide range of cost for marginally improved yield from biochar additions, which is often economically impracticable. Long-term field research focusing on an optimal combination of nutrient use, water use, carbon sequestration, avoided greenhouse gas emissions, and changes in soil quality and crop productivity is needed before large-scale biochar application to soils. The need for further clarity on optimizing biochar application to various crop yields is necessary if it is to gain widespread acceptance as a soil health manager.

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14. Water Saving Technology in Rice Production: Strategies for Mitigating Future Threats of Looming Water Crisis

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Introduction

Future conviction of food, nutritional and environmental security in India seems to be challenged by looming water crisis. There is an apprehension of declining water availability in agriculture, more so in rice during the days to come. Therefore, this dwindling natural resource need to be explored and utilized efficiently for sustainable rice production., as scenario of deficit water stress in rice cultivation will have a far reaching consequence on keeping the present momentum in rice production.

State of art

As per the World Bank estimates, the inverse relationship between population pressure with demand for fresh water in the future are mind boggling. Therefore, agriculture may likely to suffer from 10 -15% reduction in available water by 2025. Our concern on demand of food *vis-à-vis* supply of resources could envisage the uncomfortable condition in the years to come.

Strategic development

In future, three major challenges, viz., (1) How to save water, (2) How to increase water productivity and (3) How to deploy both blue, green and grey water resources for irrigating additional lands, are going to be the salient determinant in the future of sustainable rice production. Availability of blue water becomes scarce implying its efficient utilization in rice cultivation; while technology needs to be developed to explore and utilize the green and grey water more effectively.

Unlike requirement of 1500-4000 ha-mm irrigation water in conventionally grown rice, technologies have been developed to save water in rice production under irrigated condition without much compromising with grain yield. Three viable and vibrant technology options are available for efficient utilization of surface water; (1) system of aerobic rice cultivation, (2) system of rice intensification (SRI) and (3) system of alternate wetting & drying cycles of irrigation (AWD).

Results showed maximum amount of water saving could be possible in aerobic rice cultivation. Under the situation of limited irrigation facilities, particularly in favourable upland condition, this technology appears to be a boon to the farmers for sustaining rice productivity. Here, irrigation water is applied while soil becomes relatively dry pronouncing hair cracks on the surface. Concurrently, water requirement reduced to 800 to 1000 ha-mm. SRI technique is promising under irrigated medium land condition where water requirement could be restricted within 1200 to 1400 ha-mm by scheduling irrigation on moist surface soil only. Another technique under irrigated medium land condition is AWD cycles of irrigation management where requirement of irrigation water remains in between aerobic rice and SRI. Out of these three technologies, maximum water saving of 30 to 40% could be realized in aerobic rice cultivation; while it is more or less at par in other two techniques, AWD (15-30%) and SRI (20-25%) technique.

Table 2. Advantages of different water saving technologies in rice cultivation

<i>Technology Parameter</i>	<i>Conventional methods</i>	<i>Aerobic rice</i>	<i>AWD</i>	<i>SRI</i>
Irrigation Schedule	Continuous ponding of 5-10 cm water	On soil dry ness to hair cracks	On moist surface soil	On moist surface soil
Irrigation water requirement (ha-mm)	1500-4000	800-1000	1000-1200	1200-1400
Water saving (%)		30-40%	15-30%	20-25%

Conclusion

Agriculture in general and rice cultivation in particular, is passing through a critical phase of dwindling natural resources, needs to produce more rice with less inputs. India needs to sustain agricultural growth rate alleviating the threats of food insecurity. Therefore, target of '*More crops per drop*' through efficient utilization of irrigation water resources needs to be achieved for maintaining self sufficiency in rice production towards the food security front.

15. Agro-Techniques for Enhancing Resource Use Efficiency in Direct-Seeded Rice

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Introduction

Direct seeding of rice refers to the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. Direct seeding avoids three basic operations, namely, puddling (a process where soil is compacted to reduce water seepage), transplanting and standing water. There are three principal methods of direct seeding of rice (DSR): dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds on wet puddle soils) and water seeding (seeds sown into standing water; Wet-DSR is primarily done to manage the labor shortage, and is currently practiced in Malaysia, Thailand, Vietnam, the Philippines, and Sri Lanka. But, with the elevating shortages of water, the incentive to develop and adopt Dry-DSR has increased. Dry-DSR production is negligible in irrigated areas but is practiced traditionally in most Asian countries in rainfed upland ecosystems. Prior to the 1950s, direct seeding was most common, but was gradually replaced by puddle transplanting. In Asia, rice is commonly grown by transplanting one month-old seedlings into puddled and continuously flooded soil (land preparation with wet tillage). The advantages of the traditional system include increased nutrient availability (e.g. iron, zinc, phosphorus), weed suppression, in addition to these reduced water percolation losses, easy seedling establishment, and creating anaerobic conditions to enhance nutrient availability.

The traditional transplanting system (TPR), leads to high losses of water through puddling, surface evaporation and percolation (Farooq et al., 2011). Repeated puddling adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in subsurface layers, and forming hard-pans at shallow depths, all of which can negatively affect the following non-rice upland crop in rotation. According to Pandey and Velasco (2005), low wages and adequate availability of water favour transplanting, whereas high wages and low water availability favour DSR. Depending on water and labour scarcity, farmers are changing either their rice establishment methods only (from transplanting to direct seeding in puddle soil [Wet-DSR]) or both tillage and rice establishment methods (puddle transplanting to dry direct seeding in unpuddled soil [Dry-DSR]).

DSR is a major opportunity to change production practices to attain optimal plant density and high water productivity in water scarce areas. The adoption of a direct-seeded method for lowland rice culture would significantly decrease costs of rice production. In Southeast Asia, DSR is more often adopted in the dry season than in the wet season probably due to better water control; but dry-season rice accounts for less than one-quarter of rice production in this region (Farooq et al., 2011). At present, 23%, 26% and 28% of rice is direct-seeded globally, in South Asia and India, respectively (Rao et al., 2007). In Asia, dry seeding is extensively practiced in rainfed lowlands, uplands, and flood-prone areas, while wet seeding remains a common practice in irrigated areas. To date, no specific varieties have been developed for this DSR. Existing varieties used for TPR do not appear to be well-adapted for seedling growth in an initially oxygen-depleted microenvironment. As a result, farmers often resort to the costly practice of increasing the seeding rate for DSR by 2-3 times. New varieties suitable for DSR must be able to emerge and grow from a non-flooded soil (Farooq et al., 2011).

Direct seeding offers such advantages as faster and easier planting, reduced labor and less drudgery, earlier crop maturity by 7–10 d, more efficient water use and higher tolerance of water deficit, less methane emission, and often higher profit in areas with an assured water supply. Although labor and its associated costs may be reduced for crop establishment, other technologies are essential to overcome constraints imposed by direct seeding. For example, we should enhance the interaction of crop stand establishment, water management, and weed control in relation to crop lodging in both dry- and wet-seeded rice. Technology for land preparation, precision leveling, and prevention of crop lodging must be improved in wet direct-seeded rice. Similarly, management practices and control strategies are currently lacking for several pests (rats, snails, birds, etc.) that damage surface-sown seeds and for problem weeds that compete with rice seedlings. Greater understanding is required on the effect of planting or tiller density on weed pressure, pest damage, grain yield, grain quality, harvest index, and crop lodging at maturity to develop management strategies for high-density direct-sown rice in the tropics. Higher resistance to lodging is essential in rice varieties selected for intensive direct seeding to achieve high yields ($> 8 \text{ t ha}^{-1}$). Furthermore, varieties must be improved for early seedling vigor, weed competitiveness, tolerance of low oxygen level or submergence, and resistance to drought. We must find practical solutions to alleviate these constraints and to ensure optimum conditions for seeding. Only then will direct seeding become an attractive and sustainable alternative to traditional transplanting of rice.

Agro-techniques for enhancing resource- use efficiency in direct seeded rice

The production technology of DSR revolves around weed management, crop establishment and likely shifts in weed flora due to adoption of direct-seeded rice. In India rice producing states like Punjab, Haryana, U.P., Bihar, Terai of Uttaranchal, Orissa, Chhattisgarh and West Bengal also shifted towards DSR technique (Ladha et al., 2009). The most important prerequisites for a successful crop of direct drill seeded rice are (1) precise land leveling, (2) good crop establishment (CE), (3) precise water management, and (4) effective and efficient weed management (5) green house gas emission (Kumar and Ladha, 2011).

Precise land levelling

The extent of laser levelling in South Asia and China is currently extremely small, compared with 50–80% of the rice land in Australian rice-based systems. The average field slope in the IGP varies from 1 to 3° in the northwest (India and Pakistan) and from 3 to 5° in the eastern region (eastern India, Nepal, and Bangladesh). Due to a lack of uniform water distribution associated with unevenness of land, the problem of excess or no water causing large yield variability within a field is common and leads to poor establishment of DSR (Kumar and Ladha, 2011). Henceforth in 2001, laser assisted precision land levelling was introduced as an entry point for the success of alternative tillage and CE practices. It facilitates uniform and good CE, permits precise and uniform water control and good drainage, reduces the amount of irrigation water needed, increases cultivation area because of fewer bunds, improves input use efficiency (water, nutrients, and agrochemicals), and increases crop productivity (Jat et al., 2006). Laser land levelling results in saving of 20–25 per cent of irrigation water apart from several other benefits and DSR yield is correlated with precision of land levelling (Lantican et al., 1999). In Phillipines Lantican et al. (1999) estimated an average yield loss of 0.9 t ha^{-1} due to deficiency in land levelling, which results primarily from water stress in areas not levelled. In DSR technique water productivity was increased by 18.78% under laser levelled fields but the yield under DSR was less (2.96%) compared to TPR. In DSR technique grain yield and water productivity increased by 2.94% and 14.43% respectively, with laser levelling compared to transplanted rice (Jat et

al., 2006). Therefore, Laser land-levelling is a precursor technology and rather an entry point for successfulness of DSR through improved water and crop management.

Seed bed preparation

The method of seedbed preparation will depend on tillage method and will vary for conventional and conservation tillage systems. Evaluation of beds for rice and permanent beds in rice-wheat system systems commenced more recently. DSR crop is either sown on flat bed or on raised beds, but, for both, the seedbed should be free of weeds and precisely levelled at the time of sowing. For conventional till DSR, field should be pulverized to maintain good soil moisture and to maximize soil to seed contact. For zero tilled direct seeded rice (ZT-DSR), existing weeds should be killed by burning down herbicides such as paraquat (0.5 kg a.i. ha⁻¹ or glyphosate (1.0 kg a.i. ha⁻¹) (Kumar and Ladha, 2011). Potential agronomic advantages of beds include improved soil structure due to reduced compaction through controlled trafficking, and reduced water logging and timely machinery operations due to better surface drainage. Beds also provide the opportunity for mechanical weed control and improved fertilizer placement (Kumar and Ladha 2011). Raising crop on raised beds results in savings of 12–60% of irrigation water for direct-seeded and transplanted rice with comparable yields (Gupta et al., 2006). When grown on raised beds, a variety needs to be able to compensate for the loss in cropped area (caused by the relatively large row spacing between the beds) by producing more productive tillers.

Seeding time, seed rate and seeding depth

The published literatures show a widespread use of seed rates of up to 200 kg ha⁻¹ to grow a DSR crop. High seed rates are used mostly in areas where seed is broadcast with an aim to suppress weeds or when water-seeded. In the IGP, a seed rate of 20–25 kg ha⁻¹ has been found optimum for medium-fine-grain rice cultivars with a spacing of 20 cm between rows and 5 cm within rows (Gopal et al., 2010). High seed rates can result in large yield losses due to excessive vegetative growth before anthesis followed by a reduced rate of dry matter accumulation after anthesis and lower foliage N concentration at heading. These factors result in higher spikelet sterility and fewer grains per panicle. Moreover, dense plant populations at high seed rates can create favourable conditions for diseases and insects (and make plants more prone to lodging). Lower seed rate can be applied for high-tillering varieties and a higher seed rate for medium-tillering types.

Seeding depth is critical for all rice varieties but more so for semi-dwarf plant types because of their shorter mesocotyl length compared with conventional tall varieties. Placement of seeds too deep or shallow adversely affects the dynamics of seed germination due to weak coleoptiles and rapid drying of the soil surface in peak summers. Therefore, rice should not be drilled deeper than 2.5 cm to maximize uniform CE (Gopal et al., 2010).

Planting machinery

For accurate and precise seeding, rice should be drilled with a multi-crop planter fitted with inclined plate's seed metering systems and inverted T-type tynes to sow seeds at a depth of 1-1.5 inches to have good germination. Normal fluted roller-type seed-cum-fertilizer drills makes it difficult to maintain the seed rate and plant-to-plant spacing as accurate and precise due to continuous seeds fall and break them (Gopal et al., 2010; Gupta et al., 2006). With these precise seed-metering planters, we can establish crop with a lower seed rate and more precise plant-to-plant spacing (Gupta et al., 2006). DSR seeded with a planter or a seed cum fertilizer drill have many advantages over conventional puddled transplanting i.e. easier and timely planting, reduced labour burden at least 50%

(Pandey and Velasco, 1998). However, when loose crop residues are present on the soil surface, specialized machines are needed for drilling rice. Recently, different machines have been evaluated and refined to seed under loose residue, especially after combine harvest in South Asia as turbo happy seeder, rotary disc drill (Kumar and Ladha 2011; Gopal et al., 2010). Turbo seeder and PCR planter drilled the seed into a loose residue mulch load of up to 8–10 t ha⁻¹ (Gopal et al., 2010). Double disc coulters can drill seeds into a loose residue load of up to 3–4 t ha⁻¹. A limitation with this machine is that, being light weight (0.3 t).

Seed priming

One of the short term and the most pragmatic approaches to overcome the drought stress effects is seed priming. Seed priming tools have the potential to improve emergence and stand establishment under a wide range of field conditions. These techniques can also enhance rice performance in DSR culture (Farooq et al., 2011). It involves partial hydration to a point where germination-related metabolic processes begin but radical emergence does not occur. Primed seeds usually exhibit increased germination rate, uniform and faster seedlings growth, greater germination uniformity, greater growth, dry matter accumulation, yield, harvest index and sometimes greater total germination percentage (Farooq et al., 2011). Seed priming techniques, such as hydro priming, on-farm priming, osmo hardening, hardening and priming with growth promoters like growth regulators and vitamins have been successfully employed in DSR (Farooq et al., 2011). For primed seed, treatment with fungicide or insecticide should be done post-soaking to control seed borne diseases. Priming with imidacloprid resulted in increased plant height, root weight, dry matter production, root length, increased yield by 2.1 t ha⁻¹ compared with the control (non-primed), which was attributed to higher panicle numbers and more filled grains per panicle (Farooq et al., 2011). Priming rice seeds for 12 and 24 h improved crop establishment and subsequent growth (larger leaf area, taller plants, higher root and shoot dry weights measured 4 weeks after sowing) and also had significantly more tillers, panicles and grains per panicle in Ghana.

Water management and water productivity

Water management is critical in Wet-DSR, especially during the first 7–10 DAS. During this period, soil should be kept saturated but not flooded to facilitate root and seedling establishment (De Datta, 1986). However, the absence of standing water in the initial stages encourages the emergence of weeds that compete with rice seedlings. Precise water management, particularly during CE phase (first 7-10-days after sowing), is crucial in direct seeded rice. From sowing to emergence, the soil should be kept moist but not saturated to avoid seed rotting. After sowing in dry soil, applying a flush irrigation to wet the soil if it is unlikely to rain followed by saturating the field at the three-leaf stage is essential (Bouman et al., 2007).

Some management practices can be increase water productivity of DSR if followed properly:

- (i) Raised bed planting
- (ii) Mulching
- (iii) Bund management
- (iv) avoiding water stress at the following stages: tillering, panicle initiation, and grain filling
- (v) DSR with AWD

Nutrient management

Nutrient management is highly location-specific, no general recommendation is possible for all situations. Farmers in drought- and/or submergence-prone areas are reluctant to apply fertilizer to direct-seeded or transplanted rice crops because of the highly uncertain weather and yield. The combined use of locally available organic manures and fertilizers will maintain soil fertility and assure fairly high rice yields in rainfed areas. Researchers in India recommend 60 kg N, 13 kg P (30 kg P_2O_5), and 24 kg K (30 kg K_2O) ha^{-1} for medium-tall high-yielding varieties such as Savitri under transplanting or dry-seeding conditions (Samantaray et al., 1991). They also advise farmers to incorporate all the P and K and 50% of the N into the soil before seeding and to top dress the remaining 50% of the N at maximum tillering or panicle initiation (PI) if field water conditions permit. Topdressing of N on floodwater results in very high N losses in tropical climates. Subsoil banding of NPK fertilizers along with seed is highly efficient in promoting grain yield and nutrient use.

Land preparation and water management are the principal factors governing the nutrient dynamics in both DSR and TPR systems (Farooq et al., 2011). Since direct seeding follows aerobic cultivation of paddy usually results in different nutrient dynamics than the TPR because in DSR prepared land remains dry and aerobic throughout the season where in TPR land is prepared in standing water and soil is kept flooded during most of the season (Farooq et al., 2011). In direct seeding availability of several nutrients including N, P, S and micronutrients such as Zn and Fe, is likely to be a constraint. In addition, loss of N due to nitrification, denitrification, volatilization, and leaching is likely to be higher in Dry-DSR than in CT-TPR. Micronutrient deficiencies are of concern in DSR – imbalances of such nutrients (e.g. Zn, Fe, Mn, S and N) result from improper and imbalanced N fertiliser application. General recommendations for NPK fertilizers are similar to those in puddled transplanted rice, except that a slightly higher dose of N (22.5-30 kg ha^{-1}) is suggested in DSR (Kumar and Ladha, 2011) to compensate for the higher losses and lower availability of N from soil mineralization at the early stage as well as the longer duration of the crop in the main field in Dry-DSR. Split applications of N are necessary to maximize grain yield and to reduce N losses and increase N uptake. The remaining two-third dose of N should be applied in splits and topdressed in equal parts at active tillering and panicle initiation stage (Gopal et al., 2010). In addition, N can be managed using a leaf colour chart (LCC). Slow-release (SRF) or controlled-release N fertilizers (CRFs) offer the advantage of a “one-shot dose” of N and because of their delayed release pattern may better match crop N demand to reduce its losses and labour cost. Split application of K has also been suggested for direct seeding in medium-textured soil. In these soils, K can be split, with 50% as basal and 50% at early panicle initiation stage. In aerobic soils, Fe oxidation by root released oxygen reduces rhizosphere soil pH and limits release of Zn from highly insoluble fractions for availability to the rice plant. Basal application of zinc to the soil is found to be the best and to avoid its deficiency application of 25–50 kg ha^{-1} zinc sulfate is recommended. Under aerobic condition deficiency of Fe is more profound due to oxidation of available ferrous form to unavailable ferric form in soil. For correction of iron deficiency, at the time of sowing 0.5 kg of Librel Fe are drilled into the soil. It has been observed that foliar application is superior to soil application. Foliar-applied Fe is easily translocated acropetally and even retranslocated basipetally.

Effective and Efficient Management of Weeds: A major constraint

High weed infestation is the major bottleneck in DSR especially in dry field conditions. Adopting DSR may result in weed flora shifts toward more difficult-to-control and competitive grasses and sedges. More than 50 weed species infest direct-seeded rice, causing major losses to rice production worldwide (Rao et al., 2007). In DSR, weeds germinate simultaneously with rice, and there is no water layer to suppress weed growth. Estimated losses from weeds in rice are around 10% of total grain yield; however, can be in the range of 30 to 90%, reduces grain quality and enhances the cost of production (Rao et al., 2007). The DSR fields are more species-rich with greater diversity in weed flora than TPR. It favours variable flat sedge (*Cyperus difformis* L.) and water plant (*Sagittaria montevidensis* L.) in Australia and USA, and *Lindernia* spp. in Asia. In India, densities of barnyard grass, climbing dayflower (*Commelina diffusa* L.) and purple nut sedge (*Cyperus rotundus* L.) increased in DSR compared with TPR. It also favours sedges such as *Cyperus difformis*, *C. iria*, *C. rotundus*, and *F. Miliacea*. Weed growth reduced grain yield by up to 53 and 74%, respectively, and up to 68–100% for direct seeded Aus rice (cropping season in Bangladesh).

Weedy rice (*O. sativa f. spontanea*), also known as red rice, has emerged as a serious threat, it is highly competitive and causes severe rice yield losses ranging from 15% to 100%. Weedy rice also reduces milling quality if it gets mixed with rice seeds during harvesting. Therefore, a systematic, efficient and effective weed management depends on timing and method of land preparation, effectiveness of herbicides, relative to the dominant weed species and soil conditions at the time of application, effect of weather on weeds, and effect of combining herbicides and manual weed control (Rao et al., 2007). Adequate integrated weed management (IWM) strategies, including identification of new herbicides that are effective against a wide spectrum of weeds. FAO (1999) recommends an integrated approach that combines preventive, cultural, and chemical methods that is desirable for effective and sustainable weed control in Dry-DSR, moreover, weed surveillance may also prove beneficial in selecting suitable herbicides and weed management strategies in a region (Singh et al, 2009). However, cultural methods of weed control are preventive, since they enhance crop growth by precision agronomy, and in doing so maximise crop competition against weeds. One cultural technique as stale seed bed reduces weed emergence as well as the soil weed seedbank (Rao et al., 2007). Singh et al. (2009) reported 53% lower weed density in Dry-DSR after a stale seedbed than without this practice. Stale seedbed combined with herbicide (paraquat) and zero-till results in better weed control because of low seed dormancy of weeds and their inability to emerge from a depth greater than 1 cm (Chauhan and Johnson, 2010). Precise land leveling is effective in reducing the weed population up to 40%, the labour requirement for weeding by 75% (16 person-days ha), and weeding cost by 40%. Paired row planting pattern (15-30-15-cm row spacing) in DSR had a great influence on weeds as compared to normal row (23-cm row spacing) planting system (Chauhan and Johnson, 2010). Sesbania coculture technology can reduce the weed population by nearly half without any adverse effect on rice yield. Allelopathic plant extracts may also be beneficial in the weed management program. Allelopathic crops suppress obnoxious weeds when exploited in the field by crop rotation, cover or smother crops, intercropping, crop residues, mulching and allelopathic crop water extracts.

Green house gas emission (GHG's) management

Flooded rice culture with puddling and transplanting is considered one of the major sources of CH₄ emissions and accounts for 10-20% (50-100 Tg year⁻¹) of total global annual CH₄ emissions (Reiner and Milkha, 2000). Due individual or combined effects of various factors as soil

characteristics, climatic conditions, and management such as soil pH, redox potential, soil texture, soil salinity, temperature, rainfall, and water management amount of CH₄ emission varies between different crop establishment techniques. Methane emission starts at redox potential of soil below -150 mV and is stimulated at less than -200 mV. Methane emitted from paddy can be controlled by various management practices such as reducing the number of irrigations, multiple drainage system during the crop cycle, alternate wetting and drying, azolla application, semi-dry cultivation, Mycorrhiza and methanotrophs application. Studies comparing CH₄ emissions from different tillage and crop establishment (CE) methods but with similar water management (continuous flooding/mid-season drainage/intermittent irrigation) in rice revealed that, CH₄ emissions were lower in DSR than with CT-TPR (Tyagi et al., 2010). In Wet-DSR, the reduction in CH₄ increased from 16%-22% under continuous flooding to 82%-92% under mid-season drainage or intermittent irrigation compared with CT-TPR under continuous flooding. Due to aerobic environment and high moisture content under ZT-DSR results in nitrogen losses as N₂O gas and causing global warming. This trade off between CH₄ and N₂O is a major hurdle in reducing global warming risks so strategies must be devised to reduce emissions of both CH₄ and N₂O simultaneously. Developing water management practices in such a way that soil redox potential can be kept at intermediate range (-100 to +200 mV) to minimize emissions of both CH₄ and N₂O.

Management of crop lodging

Crop lodging at maturity is a serious problem with surface-seeded rice, especially under wet seeding including water seeding. Shallow root establishment and thin, long stems are the main factors responsible for lodging in surface-seeded high-density crops. In addition to high plant density, the rate and time of N application and level of floodwater and mid-season drainage of the field determine lodging severity. Crop lodging, if severe, makes harvesting by machines difficult. Grain losses are high and grain quality is poor in badly lodged crops even if they are harvested manually. Lodging caused by the bending of stems is common in TPR, whereas root lodging is severe in D-DSR (Kim et al., 1993). Kim et al. (1993) have observed that lodging resistant rice varieties possess thicker and deep-penetrating roots, bigger culms with thick walls, and erect stems and leaves that allow light penetration to the lower canopy. Cultural practices that could minimize lodging in D-DSR include using an appropriate seed rate, subsurface or anaerobic seeding, adjusting the rate and time of N application, and practicing midseason drainage. Midseason drainage can shorten the culm and reduce lodging in D-DSR.

Conclusion

Direct seeding could be an attractive alternative to transplanting of rice. It is expected to minimize labor input and reduce cultivation cost. The interaction is strong among land leveling, irrigation, weed management, and input-use efficiency. Location-specific synergistic combinations of technology options have to be identified and used to maximize economic returns to farmers and environmental benefits to the community. Further research is needed on managing N inputs during the post-PI stage to improve photosynthetic efficiency and grain production and to attain yields above 8 t ha⁻¹ in direct-seeded rice. The effect of plant density on the severity of weed problems and pest damage, grain yield, grain quality, harvest index, and lodging at maturity requires further study. Research on various factors affecting crop lodging is vital to improving the direct-seeding technology. A special rice breeding program should focus on developing specific rice varieties for direct seeding with early seedling vigor, drought and submergence tolerance, thick and deep-penetrating roots, and strong culms/stems to resist crop lodging at maturity.

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NOTES

16. Soil Quality and its Determination

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Introduction

Soil is a dynamic, living, natural body that is vital to the function of terrestrial ecosystems and represents a unique balance between physical, chemical and biological factors. The increased demographic pressure on our soil resources to meet the ever-growing needs of food and other basic necessities of life has led to their degradation. The degradation is evident in increased soil erosion, decline in soil fertility, water-logging, secondary salinization and contamination of soils with toxic elements etc. Collection of a data set from a system over time allows for a dynamic assessment change occurring over time in response to environmental interaction or management practice. A dynamic assessment is necessary for determining the direction and magnitude of this change (Fig. 1). With the increasing degradation of agricultural soils, there is a great need for sustaining the soil resource base and enhancing soil quality. The term "soil quality" has been coined to describe the combination of chemical, physical, and biological characteristics that enables soils to perform a wide range of functions. Karlen et al. (1997) proposed the following as vital soil functions:

- ✓ Sustaining biological activity, diversity, and productivity,
- ✓ Regulating and partitioning water and solute flow,
- ✓ Filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including agricultural, industrial and municipal by-products and atmospheric deposition,
- ✓ Storing and cycling nutrients and other elements within the Earth's biosphere, and
- ✓ Providing support of socioeconomic structures and protection for archaeological treasures associated with human habitation.

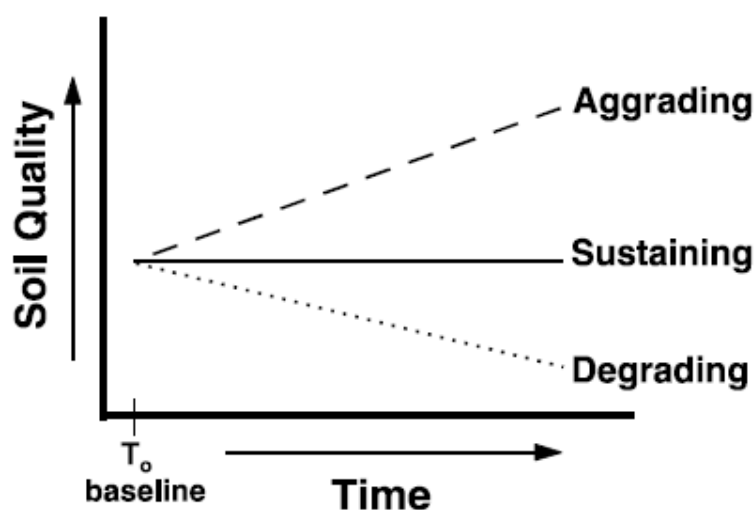


Fig. 1 Conceptual changes in temporal soil quality indicating degradation, maintenance, or improvement (Source: Seybold et al. 1998).

Soil quality is a measure of how well the soil does what we want it to do. And what do we want it to do? Support plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. The quality of a soil is an assessment of how it performs all of its functions now and how those functions are being preserved for future use. Over the years, soil quality has been defined by scientists as the “fitness for use” (Pierce and Larson, 1993), and by others as the “capacity of a soil to function” (Doran and Parkin, 1994; Karlen et al., 1997), while according to Arshad and Coen (1992) soil quality is “the sustaining capability of a soil to accept, store and recycle water, and energy for production of crops at optimum levels while preserving a healthy environment”. Karlen et al. (1992) defined soil quality as “the ability of the soil to serve as a natural medium for the growth of plants that sustain human and animal life”. Soil quality refers to its ability to sustain productivity and maintain environmental quality (Lal, 1994; NRC, 1993). “The capacity of a soil to function within boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health”, was the definition of soil quality put forth by Doran and Parkin (1994). Lal and Stewart (1995) described soil quality as the inherent attribute of soil and to characteristics and processes that determined the soil’s capacity to produce economic goods and services and regulate the environment. The soil quality definition given by Karlen et al. (1997) mentioned as: “The capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation”. It can be conceptualized as a three-legged stool, the function of which requires an integration of three major components - sustained biological productivity, environmental quality and plant and animal health. Soil quality traditionally has focused on, and has been equated with agricultural system productivity. Crop yield is an important indicator of system productivity that is, in part, dependent upon soil quality. Crop yield can serve as a bioassay for several interacting factors such as soil, water, air, disease, germplasm, and management. Crop yield alone, however, is an incomplete measure of system productivity. Soil quality may better represent system productivity and function.

Why does soil quality matter?

Soil quality is important for two reasons. First, using a soil improperly can damage it and the ecosystem, therefore we need to match our use and management of the land to the soil's capability. Second, we need to establish a baseline understanding about soil quality so that we can recognize changes as they develop. By using baselines to determine if soil quality is deteriorating, stable, or improving, we have a good indicator of the health of an ecosystem. The ultimate purpose of researching and assessing soil quality is to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms including people. In recent years, soil quality research has focused on the linkages among the following: management practices and systems; observable soil characteristics; and soil processes and performance of soil functions. Choosing the appropriate soil attributes to include in an index must include consideration of soil function and management goals that are site specific and user-oriented and must focus on sustainability rather than just crop yields. These indices would be useful in ascertaining the fragility of soil and for understanding how improved management might strengthen its resilience (Chaudhury et al., 2005). The testing of soil for routine analysis can only provide a snap shot on soil fertility which is not able to identify the production constraints because of deterioration of other soil properties. Therefore, assessing soil quality is advantageous for its holistic way to judge the management-induced changes. This capacity of the soil to function can be assessed by physical, chemical, and/or biological properties, which in this context

are known as soil quality indicators (Wander and Bollero, 1999). Perceptions of what constitutes a good soil vary. They depend on individual priorities with respect to soil function, intended land use, and interest of the observer (Doran and Parkin, 1994; Shukla et al., 2006). Individual soil properties may not provide an adequate measure of soil quality and integrated soil quality indicators based on a combination of soil properties can better reflect the status of soil quality than individual parameters. Soil quality changes with time can indicate whether the soil condition is sustainable or not (Arshad and Martin, 2002; Doran, 2002). Maintaining soil quality at a desirable level is a very complex issue due to climatic, soil, plant, and human factors and their interactions and it is especially challenging in lowland rice cropping systems because of puddling practices in soil preparation (Chaudhury et al., 2005). Our interest is mainly in detecting changes in soil quality resulting from a change in land use or management or in measuring the performance of a specific management system in terms of soil quality (Shahid et al., 2013). Soil Quality cannot be measured directly however; it can be inferred by measuring soil physiochemical and biological properties that serve as quality indicator (Brejda et al., 2000, Diack and Stott, 2001). Therefore an integrated 'soil quality index' based on the weighted contribution of individual soil property to maintain the soil quality may serve better indicator of soil quality for different land uses. Soil quality index which expresses the ability of a soil to perform ecosystem and social services would help with the interpretation of data from different soil measurements and show whether management and land use are having the desired effects on productivity, environmental protection, and health.

Soil quality is proving itself useful as an educational concept and as an assessment tool. Soil quality has been used to make students, policymakers, producers, and the public more aware of the essential processes soils perform. As an assessment tool, soil quality allows for a hands-on observation of soil processes and provides producers and managers with additional information to be used in making management decisions.

Soil quality indicators

Soils have chemical, biological, and physical properties that interact in a complex way to give a soil its quality or capacity to function (Karlen et al., 1997). Thus, soil health or quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as indicators. Indicators are measurable properties of plants and soil. The type of indicator chosen to evaluate soil quality depends on the soil function and the size of the area (i.e. field, farm, watershed, or region) in which the evaluation is made. Considering basic soil functions i.e., provision of sufficient amounts of water, and nutrients, provision of resistance and resilience to physical degradation, and sustaining plant growth under an appropriate utilization, numerous soil analyses might be required to fully characterize the soil/plant system. However, analyses can be time consuming and costly and are sometimes open to different interpretations, leading to a decision dilemma. The set of indicators used for assessing soil quality can vary from location to location depending on the kind of land (e.g., rangeland, wetland, agricultural land) or land use, soil function, and the soil forming factors. Thus, soil quality defined as functional capacity of soil, comprises of three predominant indicator groups viz., (i) Soil chemical quality and soil fertility indicators (ii) Soil physical quality indicators and (iii) Soil biological quality indicators (Table 1). Hence, soil quality is a function of all these three group of indicators. Soils may be fertile but may not be productive. Hence, while considering soil quality, it is important to give attention to all the three components.

Table 1. Soil quality indicators at different levels of soil management and planning

Physical indicators	Chemical indicators	Biological indicators
Field, Farm or Watershed indicators		
Passage of air	Base saturation percentage	Organic carbon
Structural stability	Cation exchange capacity	Microbial biomass carbon
Bulk density	Contaminant availability	C and N/Oxidizable carbon
Clay mineralogy	Contaminant concentration	Total biomass
Colour	Contaminant mobility	Bacterial
Consistence (dry, moist, wet)	Contaminant presence	Fungal
Depth of root limiting layer	Electrical conductivity	Potentially mineralizable N
Hydraulic conductivity	Exchangeable sodium percentage	Soil respiration
Oxygen diffusion rate	Nutrient cycling rates	Enzymes
Particle size distribution	pH	Dehydrogenase
Penetration resistance	Plant nutrient availability	Phosphatase
Pore conductivity	Plant nutrient content	Arlylsulfatase
Pore size distribution	Sodium adsorption ratio	Biomass C/total organic Respiration /biomass carbon/
Soil strength		Microbial community fingerprinting
Soil tilth		Substrate utilization
Structure type		Fatty acid analysis
Temperature		Nucleic acid analysis
Total porosity		
Water holding capacity		
Regional or National Indicators		
Desertification	Organic matter trends	Productivity (yield stability)
Vegetative cover	Acidification	Taxonomic diversity at the group level
Water erosion	Salinisation	Species richness diversity
Wind erosion	Changes in water quality	Keystone species and ecosystem engineers
Siltation of rivers and lakes	Changes in air quality	Biomass, density and abundance
Sediment load in rivers		

Source: Singer and Ewing (2000)

Determination of Soil Quality (Soil quality index)

Assessment of soil quality is a sensitive and dynamic way to document soils condition, its response to management, or its resistance to stress imposed by natural forces or human uses. It is

needed to identify production problem areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management, and to assist government agencies in formulating and evaluating sustainable agricultural and landuse policies. With the progressive development in the methodology of soil quality assessment, many tools of soil quality assessment viz., Soil Conditioning Index (SCI), Soil Management Assessment Framework (SMAF), the Agroecosystem Performance Assessment Tool (AEPAT) and the New Cornell “Soil Health Assessment” have been recently reported. Out of these, SMAF was developed as malleable tools for assessing soil response to management and is most widely used for the assessment of soil quality. The SMAF is an additive, non-linear indexing tool for assessing soil function (Andrews et al. 2004). The SMAF is intended for use by land managers and their advisors for use in assessing ongoing management practices. In determination of SQI using SMAF, four main steps were followed (Fig. 2): (i) formulation of appropriate goals for desired outcomes of soil functions, (ii) selection of a minimum data set (MDS) of indicators that best represent soil function, (iii) scoring the MDS indicators based on their performance of soil function and (iv) integration of the indicator scores into a comparative SQI.

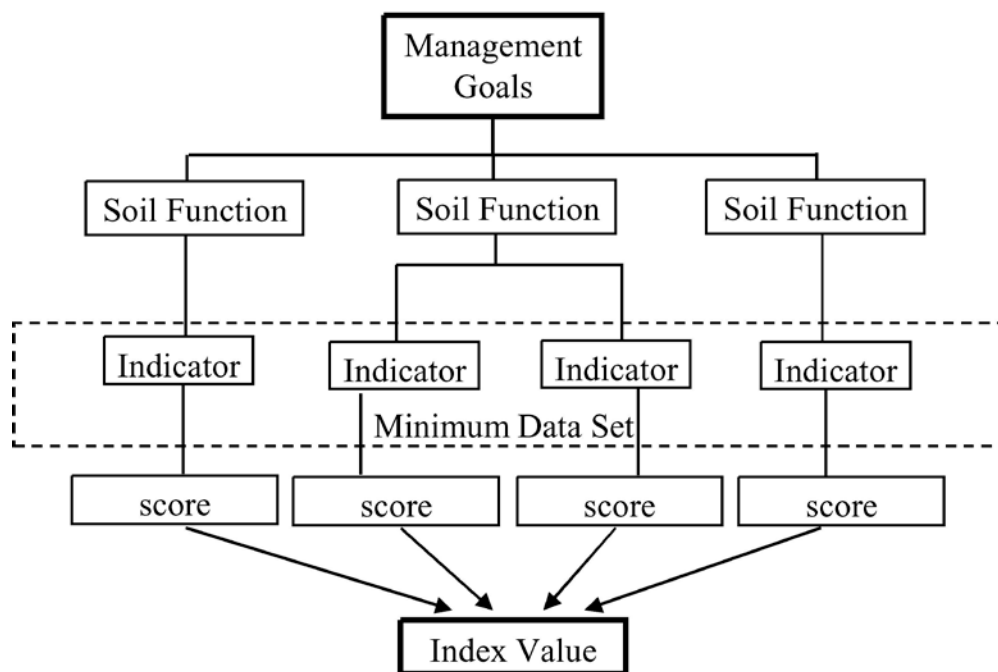


Fig. 2 A generalized framework for developing soil quality indices (Source: Karlen et al., 2001).

i) Formulation of appropriate goals for desired outcomes of soil functions

Soil quality indices and indicators should be selected according to the soil functions of interest and the defined management goals for the system. Management goals are often individualistic, primarily focused on on-farm effects, but can also be societal, including the broader environmental effects of farm management decisions such as soil erosion, agrochemical contamination of soil and water, or subsidy imbalance (from over-use of fossil fuels or agrochemicals). If achieving sustainability is the goal of agroecosystem management, a soil quality index will constitute one component within a nested agroecosystem sustainability hierarchy (Fig. 3).

Management goals may also differ by the interests and visions of different sections of people concerned with agriculture.

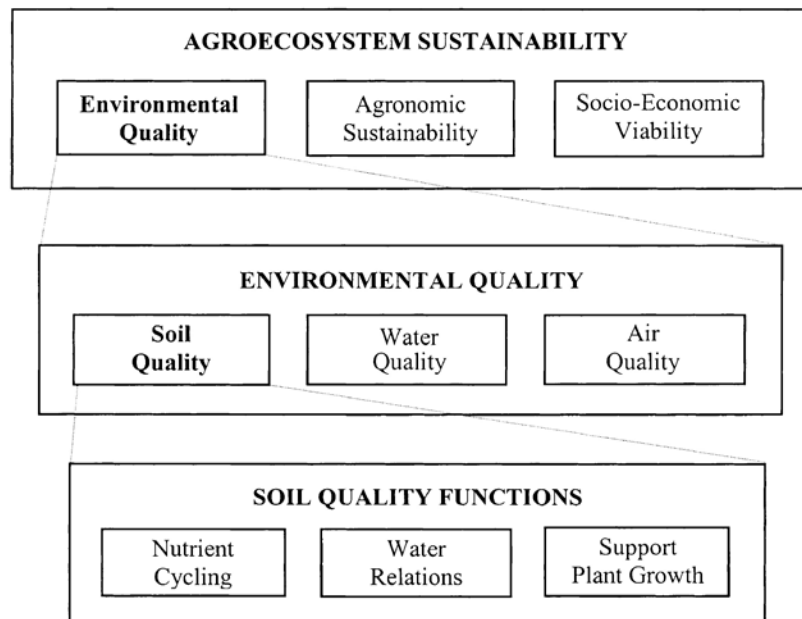


Fig. 3 Nested hierarchy of agroecosystem sustainability showing the relationship of soil quality to the larger agroecosystem. (Source: Andrews et al., 2002)

ii) Selection of a minimum data set (MDS) of indicators that best represent soil function

Once the system's management goals are identified, the next step for soil quality indexing is to choosing appropriate indicators for a minimum data set (MDS). It would be unrealistic to use all ecosystems or soil attributes as indicators, so a minimum data set (MDS) consisting of attributes encompassing chemical, physical and biological soil properties are selected for soil quality assessment. Nearly all of the physical, chemical, and biological attributes that comprise a minimum data set have established meanings and published procedures that predate the soil quality concept. A minimum dataset for assessing soil quality should have the following characteristics (Doran and Parkin, 1994):

- easy to measure
- detect changes in soil function
- integrate soil physical, chemical, and biological properties and processes
- accessible to many users and applicable to field conditions
- sensitive to variations in management and climate
- encompass ecosystem processes and relate to process-oriented modeling
- where possible, be components of existing soil data bases

Minimum data set components can be selected based on expert opinion (Karlen et al., 1996) and/or by using statistical methods. The physiological rhizosphere studies of Bachmann and Kinzel (1992) used principle component analysis (PCA), multiple correlation, factor analysis, cluster analysis and star plots to select characteristics for their diagnostic index. Bentham et al. (1992) used principal

component analysis and other statistical clustering techniques to choose variables best representing the progress of soil restoration efforts. The use of objective mathematical formulas reduces the possibilities for disciplinary biases that inhibit much would-be cross-disciplinary work (Doran and Parkin, 1996).

The expert opinion process functions best when a multidisciplinary team of scientists representing agronomy, ecology, economics, engineering, entomology, pathology, soil science, social science, or any other discipline deemed critical for the assessment being made can be assembled with landowners, land operators, and other interested stakeholders. Collectively, this group identifies the soil quality goals, critical functions, appropriate indicators, scoring methods, and priorities among each factor. The principal component analysis generally relies less on any individual scientist making selections of goals, functions, and indicators. It uses a statistical technique to identify the indicators that best represent variability in a large existing data set. This technique affords less opportunity for disciplinary bias but does require a robust data set. Mechanistically, the data set must have a sufficient number of observations and variables. Functionally, whatever is measured must have potential value as an indicator (i.e., some relationship to the critical soil functions). After the data are analyzed and mean comparisons are made, only those indicators showing statistically significant differences are included in the PCA. The data are then analyzed using PCA to prioritize and reduce the number of indicators or variables that need to be measured in subsequent samplings. PCs receiving high eigenvalues best represent variation in the systems. Therefore, only the PCs with eigenvalues ≥ 1 (Kaiser, 1960) are taken into consideration. Additionally, PCs that explain $\geq 5\%$ of the variability in the soils data (Wander and Bollero, 1999) were included when fewer than three PCs had eigenvalues ≥ 1 . Under a particular PC, each variable is given a weight or factor loading that represents the contribution of that variable to the composition of the PC. Only the highly weighted variables were retained from each PC for the MDS (Table 2). Highly weighted factor loadings were defined as having absolute values within 10% of the highest factor loading or ≥ 0.70 (absolute value, Shahid et al., 2013). When more than one factor was retained under a single PC, multivariate correlation coefficients were employed to determine if the variables could be considered redundant and, therefore, eliminated from the MDS (Andrews et al., 2002). Highly correlated variables were considered redundant and only one was considered for the MDS. If the highly weighted factors were not correlated (assumed to be a correlation coefficient < 0.60) then each was considered important, and thus, retained in the MDS. Among well correlated variables, the variable with the highest factor loading (absolute value) was chosen for the MDS. The PCA loading value of the selected variables under the respective PCs is used to provide “weighting factors” for the indicators included in the soil quality indices (Andrews et al., 2002). To check how well the MDS represented the management systems or goals, multiple regressions of both the EO selected and PCA-MDSs are performed using the indicators retained as independent variables and the end point measures (goals) as dependent variables. If any variable within the MDS did not contribute to the coefficient of determination from the multiple regressions, it was also ignored. After the MDS indicators were determined, results may be transformed using a linear or non-linear scoring method.

(iii) Scoring the MDS indicators based on their performance of soil function

After determining the variables for the MDS, every observation of each MDS indicator was transformed for inclusion in the SQI methods examined. Knowledge on the variations in soil quality indicators in similar type of soils under various distinct management systems is necessary to convert the raw data on soil parameters/soil quality indicators into unit less numerical scores. This will help us

to set the limits or thresholds for the soil quality indicators. Based on the range of each soil quality indicators and its measures and reported critical values, the limits/thresholds were fixed. As reported by Masto et al. (2007), the success and usefulness of a soil quality index mainly depends on setting the appropriate critical limits for individual soil properties. The optimum/critical values of soil quality could be obtained from the soils of undisturbed ecosystems (Warkentin 1996; Arshad and Martin 2002), where soil functioning is at its maximum potential to or in best managed systems or on critical values available in the literature. After finalizing the thresholds or limits the numerical score of each MDS variable is transformed using linear scoring or non-linear scoring functions.

Linear scoring function (LSF)

For ‘more is better’ indicators, each observation is divided by the highest observed value such that the highest observed value received a score of 1. For ‘less is better’ indicators, the lowest observed value (in the numerator) is divided by each observation (in the denominator) such that the lowest observed value receives a score of 1. For some indicators, observations are scored as ‘higher is better’ up to a threshold value and as ‘lower is better’ above the threshold (Lebig et al., 2001). The values of different variables can be transformed to a common range, between 0.1 to 1.0 with homothetic transformation (Velasquez et al., 2007):

$$y = 0.1 + \frac{(x - b)}{(a - b)} \times 0.9$$

where

y = value of the variable after transformation

x = the variable to transform

a = the maximum value of the variable

b = the minimum value of the variable

Non-linear scoring functions (NLSF)

For this method, indicators were transformed using non-linear scoring functions and the score (S) for each MDS variable is calculated using following equation (Bastida et al., 2006)

$$S = a / (1 + (x/x_0)^b)$$

Where

x = soil property value

a = maximum score (1.00) of the soil property

x_0 = baseline or value of each variable where the score equals 0.5 and equal the midpoints between threshold soil property values

b = value of the slope of the equation

Using this equation, three types of standardized scoring functions can be generated (1) ‘More is better’, (2) ‘Less is better’ and (3) ‘Optimum’ based on the critical and optimum levels of the variables related to the specific soil function (Glover et al., 2000). The equation defines a ‘More is better’ scoring curve for positive slopes, a ‘Less is better’ curve for negative slopes and ‘Optimum’ curve is defined by the combination of both (Fig. 4). Threshold values are soil property values where the score equals one (upper threshold) when the measured soil property is at most favorable level; or

equals zero (lower threshold) when the soil property is at an unacceptable level. Baseline values are soil property values where the scoring function equals 0.5 and equal the midpoints between threshold soil property values. Baselines are generally regarded as minimum target values. There are two base lines for ‘Optimum’ curves viz. lower base line and upper base line, which corresponds to 0.5 score of the growth and death curve, respectively (Andrews et al., 2002). Among the two methods, the non-linear scoring function reflects the system functions more accurately than the linear scoring function (Andrews et al., 2002).

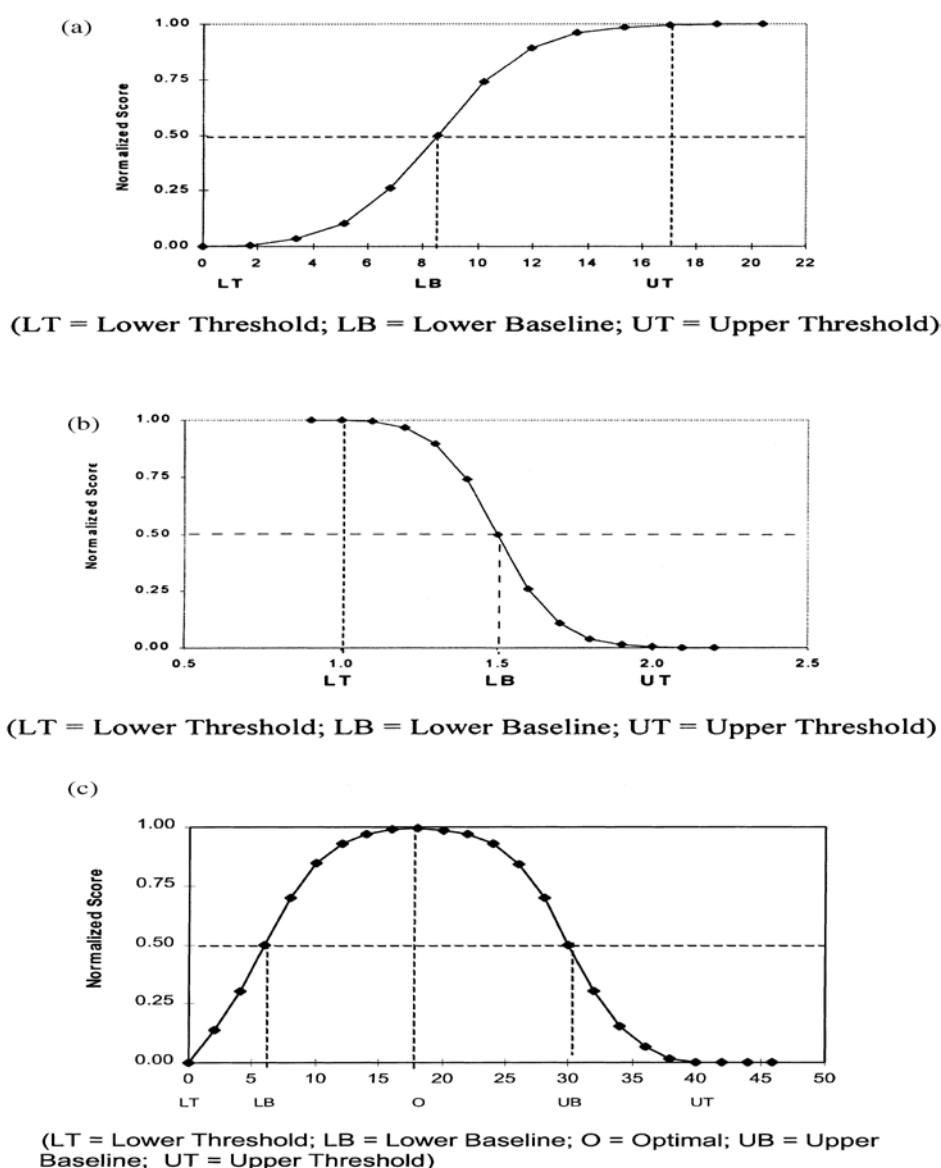


Fig. 4. (a) ‘More is better’ normalized scoring function (b) ‘Less is better’ normalized scoring function (c) ‘Optimum’ normalized scoring function

iv) Integration of the indicator scores into a comparative SQI

The last and final step will be integration of indicator scores into a comparative index of soil quality. Soil quality indicator values were normalized on a scale from 0 to 1. The following two soil quality indexing methods were compared:

1. Conceptual framework for analyzing soil quality
2. Principal component analysis based soil quality index

Conceptual framework

The Conceptual Framework model has been used to determine soil quality as described by Karlen et al. (1992) as follows:

$$\text{Soil quality index (SQI)}_P = qnc(wt) + qpss(wt) + qwr(wt) + qrr(wt) \quad (\text{for productivity goal})$$

$$\begin{aligned} \text{Soil quality index (SQI)}_{EP} \\ = qnc(wt) + qpss(wt) + qwr(wt) + qrr(wt) + qfb(wt) + qbdh(wt) \end{aligned} \quad (\text{for environmental protection goal})$$

where, qnc is the rating for the soil's ability to nutrient cycling, qpss to facilitate physical stability and support, qwr to water relations, qrr to resistance and resilience, qfb to filtering and buffering, qbdh to sustain biodiversity and habitat and (wt) is a numerical weighting for each soil function. Weights for all soil functions sum to 1.00. An ideal soil would fulfill all the functions considered important and under the proposed framework will receive a SQI of 1.00. As a soil fails to meet the ideal criteria, the SQI would fall, with zero being the lowest rating. Associated with each soil function are soil quality indicators that influence, to varying degrees, that particular function. As with soil functions, numerical weights assigned to selected soil quality indicators must sum 1.00 at each level.

Principal component analysis

Principal component analysis (PCA) is the method for reducing correlated measurement variables to a smaller set of statistically independent linear combinations having certain unique properties with regard to characterizing individual differences. Principal components (PCs) for a data set are defined as linear combinations of the variables that account for maximum variance within the set by describing vectors of closets fit to the n observations in p-dimensional space, subject to being orthogonal to one another (Dunteman, 1989). Each PC explained a certain amount of variation (%) in the total data set, this percentage provided the weight for variables chosen under a given PC. The final PCA based soil quality equation is as follows:

$$SQI = \sum_{i=1}^n W_i \times S_i \quad (\text{for both productivity and environmental protection goal})$$

Where

S = score for the subscripted variable

W = weighing factor derived from PCA

Here the assumption is that higher the index scores meant better soil quality or greater performance of soil function. Correlation of SQI thus developed is done with the management goals (e.g. crop yield).

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17. Soil Physical Properties as Affected by Rice Cultivation in Rice-Based Cropping Systems

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Abstract

Rice (*Oryza sativa* L.), a staple food for more than half of the world population, is commonly grown by transplanting seedlings into puddled soil (wet tillage) in most of the Asian countries. Upland crops are often planted after lowland rice to increase cropping intensity. However, lowland rice and upland crops have different soil physical requirements. Puddling a clay soil with high percolation rate benefits rice growth but reduces the yield of following dryland crops because of soil structural deterioration, shrinkage, drought stress, and impeded root growth. Puddling to decrease soil permeability is essential for lowland rice culture, but adversely affects upland crops following rice. The conflicting requirements of lowland rice and upland crops, changes in soil physical environment caused by puddling, effects of those changes on rice and upland crops, and the adverse effects of puddling are discussed. This conventional transplanted rice (TPR) production system is labour, water, and energy intensive and has become less profitable in the wake of increasing scarcity of these natural resources. These factors are leading farmers to adopt alternative rice cultivation methods such as direct seeding of rice (DSR). Some positive effects of DSR on soil physical properties are discussed. But transplanting would also continue as a popular method of rice cultivation especially in heavy rainfall and water logged conditions.

Introduction

Rice-based cropping systems accounts for more than half of the total acreage in South Asia, where rice is grown in sequence with rice or upland crops like wheat, maize or legumes. Rice based cropping systems occupy 13.5 million hectares in the Indo-Gangetic Plains (IGP) of South Asia (Gupta and Seth, 2007) which provides food security and livelihoods for millions. In 2007, the world rice harvested area was 159 Million hectare (Mha) out of which 142 Mha was in Asia and 44 Mha was in India. The world production of rice is 685 Million tonnes (MT) with an average productivity of 4309 kg ha⁻¹, out of which Asia contributing 622 MT with a productivity of 4386 kg ha⁻¹ and India contributed 148 MT, with an average productivity of 3370 kg ha⁻¹ rice paddy in 2007(FAOSTAT 2007).

The world population continues to grow steadily, while land and water resources are declining. Temperature increase, rising seas and changes in patterns of rainfall and its distribution under global climate changes might lead to substantial modifications in land and water resources for rice production as well as the productivity of rice crops grown in different parts of the world. During the green revolution era, rice productivity increased across monsoon Asia through a combination of new high-yielding varieties with increased input use, such as stable water supply from new irrigation systems, fertilizer, and biocide use (Hossain and Fischer, 1995). Now the productivity and sustainability of the rice production systems are threatened because of combination of factors such as inefficient use of inputs (fertilizer, water, labor); increasing scarcity of resources; changes in land use driven by a shortage of water and labor; socioeconomic changes (urbanization, labor migration, changing attitude of people to shun away from farm work). These factors causing yield to stagnate

over the past two decades. The challenges are to produce more food at less cost and to improve water productivity and increase nutrient use efficiency (Pingali, 1999).

Countries with a large population like China and India face the challenge of maintaining and increasing high yield levels in a scenario of increasing climatic variability. Over the last few decades the growth in agricultural production has come mainly from yield increase and to a lesser extent from area expansion. The agricultural land available per capita is expected to decline further (FAO, 2002). Furthermore, in high intensity agricultural production areas, yield increase seems to have reached a ceiling despite higher input use. Crop yields even decline in some cases, for example in the grain-producing areas of Punjab in India (Aulakh, 2005). Water is one of the most precious natural resources for agricultural production and agriculture accounts for 70 percent of water use (FAO, 2002). In the Indian state of Punjab, characterized by intensive irrigated agriculture, the groundwater table is falling at a rate of 0.7 m per year (Aulakh, 2005). Agriculture contributes to the problem by wasting water and by sealing and compacting the soils so that excess water cannot infiltrate and recharge the aquifer; one of the causes of the growing number of flood catastrophes (DBU, 2002).

Reduced recycling of crop residue, minimal and unbalanced fertilizer addition, limited options for crop rotation and the regular intensive tillage are some of the factors responsible for the soil degradation over time. Tillage primarily helps in weed management and to create a seed bed with a fine soil tilth suitable for germination and seedling establishment. Tillage also helps in mineralization of nutrients, incorporation of fertilizers, crop residues and soil amendments, temporary alleviation of compaction, and management of some soil-borne diseases and insects (Hobbs et al., 2008; Kassam et al., 2009). However, regular tillage breaks down soil organic matter through mineralization, more so in warmer climates (Kirschbaum, 1995), thus contributing to deteriorating soil physical, chemical and biological properties (Wall, 2007). Tillage also adversely affects soil structure, with consequences for water infiltration and soil erosion through runoff, and create hardpans below the plough layer (Thierfelder and Wall, 2009). Soil structure is strongly correlated with the organic matter content and the soil life. Organic matter stabilizes soil aggregates, provides feed to soil life and acts as a sponge for soil water. With intensive tillage-based agriculture, the organic matter of soil is steadily decreasing, leading to a decline in productivity (Shaxon and Barber, 2003).

Though significant strides have been made for total food grain production but evidence from long-term experiments shows that crop yields are stagnating and sometimes declining (Ladha *et al.*, 2003). Soil quality is governed primarily by the tillage practices used to fulfill the contrasting soil physical and hydrological requirements of the rice and subsequent crop (Mohanty *et al.*, 2007). Current crop cultivation practices in these systems degrade the soil and water resources thereby threatening the sustainability of the system (Kumar and Yadav, 2001; Gupta *et al.*, 2003). Agricultural technologies that can save resources, reduce production costs and improve production while sustaining environmental quality are therefore becoming increasingly important (Gupta *et al.*, 2002; Hobbs and Gupta, 2003). Hence it is essential that improved soil and water management methods be developed and adopted for rice lands, both to increase food production and to avoid soil erosion and degradation.

Soil properties and tillage affecting rice-based cropping systems

The need for more food has necessitated agricultural diversification on the rice soils of South and Southeast Asia. The dryland crops usually grown on rice soils in double or multiple-cropping systems are vegetables and pulses such as mungbean, cotton, tobacco, peanut, and mustard. Cropping intensity of rice-based systems can be increased by growing more rice crops or by planting upland crops before or after rice. Rice usually is grown in wet season when water is plentiful. Pre and post monsoon periods may be relatively dry and favor upland crops. Some rice-based cropping systems are

- *rice – rice – fallow,*
- *rice – cereal (maize, wheat, sorghum, etc.),*
- *rice – pulse (mung, black gram, green gram, soybean, cowpea, etc.),*
- *rice – oilseed (mustard, groundnut, etc.).*

Cropping sequences that include both lowland and upland crops require special management for both the situations. Moreover, soils react differently to management, depending on soil characteristics. When crops within a sequence have dissimilar soil physical requirements, an understanding of the soil properties is very much essential for selecting suitable management practices.

Rice can be established by four principal methods: Dry direct seeded rice (Dry-DSR), Wet direct seeded rice (Wet-DSR), water seeding, and transplanting. These methods differ from others either in land preparation (tillage) or crop establishment methods or in both (Kumar and Ladha, 2013). Dry, wet, and water seeding, in which seeds are sown directly in the main field instead of transplanting rice seedlings, are commonly referred to as direct seeding. Direct seeding is the oldest method of rice establishment which was most common prior to the 1950s, but was gradually replaced by transplanting in puddle soil (Pandey and Velasco, 2005; Rao et al., 2007).

Rice is the only cereal that germinates and thrives in water. To retain impounded surface water, soil must have low permeability, whether naturally so or as a product of management. Rice roots have a cortical structure similar to that of many water plants, and lowland rices develop larger root systems in dense, submerged, puddled soils than in upland soils. Upland crops, develop better root systems in dry soils. They need a well aerated seed zone and rooting medium with oxygen in water-free soil pores for root respiration. In well-drained, loamy sand and sandy loam soils without restricting layers, wheat (Jalota et al., 1980), mustard, and barley roots can grow more than 180 cm deep. Upland crops do not grow well on continually submerged soils (Chaudhary et al., 1974.), nor on soils with dense layers at shallow depth. Because water comes to them intermittently, they depend on water stored in the root zone for survival between wettings. Tillage of heavy-textured soils for dryland crops must facilitate seedling emergence and increase water-holding capacity. Additionally, soil management must ensure adequate crop stand by improving seedling emergence in direct sown rice, and facilitate rice transplanting. Soil structure also must ensure an economic yield from a following dryland crop. Tillage type and intensity depend on the antecedent soil physical conditions.

Requirement of soil tillage for rice

Usually, both dry and wet tillage are necessary to prepare soil for rice. Tillage changes soil porosity and pore-size distribution and hence permeability and percolation, and water retention capacity of the surface layer. In most Asian countries, wetland tillage for rice i.e. puddling is practiced. Water seeding is widely practiced in the United States, primarily to manage weeds such as weedy rice, which are normally difficult to control (Hill et al., 1991). Wet-DSR is primarily done to manage the labor shortage, and is currently practiced in Malaysia, Thailand, Vietnam, the Philippines, and Sri Lanka (Pandey and Velasco, 2002; Weerakoon et al., 2011).

Puddling is the most important soil management practice. It reduces water losses through percolation, which limits leaching of plant nutrients, and preserves aquatic conditions that favor lowland rice growth (De Datta. et al., 1974). Puddling destroys soil structure, decreases large pores, and increases small pores in the surface layer. Increased microporosity and decreased macroporosity lower permeability and increase soil water retention at low tensions. Puddling markedly increases soil–water retention in soils dominated by 2:1 swelling clays. The effect is less in soils dominated by kaolinite clays.

For upland crops following rice, tillage provides a seedbed of fine tilth to ensure adequate seed–soil contact, especially when the seed zone is dry. Sometimes it is necessary to compact the soil with a roller to establish better seed–soil contact. Deep tillage also breaks up natural or induced restricting layers and stimulates rooting for optimum growth of upland crops.

Puddling

Puddling, in general, refers to the destruction of soil aggregates into ultimate soil particles at a moisture content near saturation. Buehrer and Rose (1943) defined puddling as "the destruction of the aggregated condition of the soil by mechanical manipulation within a narrow range of moisture contents above and below field capacity (0.03 MPa), so that soil aggregates lose their identity and the soil is converted into a structurally more or less homogeneous mass of ultimate particles." Puddling, although a capital and energy-intensive process, is practiced to achieve certain objectives such as weed control, ease of transplanting, and reduction in percolation losses of water and nutrients. Puddling changes soil into a homogenous suspension of primary particles.

The ease and degree of puddling depend on soil wetness, soil type, nature of the implement used, and cultural practices. Maximum puddling occurs at moisture contents between field capacity and saturation (Koenigs, 1963). At this moisture cohesion within soil aggregates is minimal, which helps increase the number of shear planes in soil. The process is more thorough in soils with 2:1 clays than in coarse-textured soils with low-activity clays. Swell-shrink characteristics are important in puddling, and some soils therefore puddle more effectively than others. Puddling a clay soil increases pore volume, at least temporarily, but the volume of interaggregate or transmission pores substantially diminishes. In contrast, the volume of storage pores increases. Effective puddling drastically reduces a soil's permeability as compared to its aggregated state. Hydraulic conductivity of the plow pan is lower because the transmission pores have been changed to capillary pores. Puddling has little or no effect on coarse-textured soils, or on soils that are easily dispersed, such as fine-textured soils with high exchangeable sodium percentage (ESP), or sodic soils. To save time and expensive inputs, it is important to identify soils that can be manipulated by wet tillage from those that cannot or should not. Long-term effects of puddling Soils that are repeatedly puddled over many years undergo drastic structural changes. These changes differ with soil texture and mineralogy. When puddled soils dry,

they shrink and develop weak structures with smaller proportions of water-stable aggregates. When a puddled soil dries, water retention capacity decreases more than for an aggregated soil. During prolonged rainless periods under rainfed conditions, a rice crop in puddled soil may therefore experience more drought stress than in an aggregated soil.

Effects of puddling on soil physical properties

Soil Structure: Puddling causes the destruction of soil aggregates and peds into plastic mud. Wetting of initially dry soil causes uneven swelling in aggregates and explosion caused by entrapped air. The result is the slaking of aggregates. The effect of puddling on surface soil structure depends on soil texture and aggregate stability. Aggregate stability is determined by the amount and type of clay fraction; organic matter and hydrous oxides, which may form interparticle bonds; and the electrolyte concentration of the soil solution. Flooding may weaken interparticle bonding by increasing the solubility of iron and manganese oxides and decomposition of organic matter (Kawaguchi and Kita, 1957), thereby dispersing soil aggregates, depending upon the soil type. Chaudhary and Ghildyal (1969) reported a drop in mean weight diameter of aggregates from 1.70 mm to 0.36 mm due to puddling.

Soil Stratification: Stratification after puddling is common, especially in medium-textured soils. The sand fraction settles first from the muddy water and gradually is covered by finer silt and clay. The thickness of the layers depends on the original texture.

Development of a traffic pan: A dense layer of reduced permeability may develop over several years if soil is not loosened by tillage and ultimately transmission, retention, and recharge will change. A traffic pan is important to preserve surface water in rainfed and irrigated rice on permeable soils without a natural or induced high groundwater table. Traffic pan development and soil compaction depend on soil texture, structure, and swelling and shrinkage characteristics. Fine loamy soils favor compaction (16). Soils with high clay and sodium contents do not.

Permeability: Traffic pans in puddled soils have been reported to have very low hydraulic conductivity. Moreover, it may be the puddled layer, not the traffic pan, that reduces permeability. The magnitude of the decline in permeability depends on soil texture and structure, clay mineralogy, organic matter content, etc. In moderately permeable, freely drained soils planted to lowland rice, percolation diminished to 20% of the initial rate in 4 yr, stabilizing at about 12 mm/d. In more permeable soils, it took 6 yr of rice cultivation to reach an equilibrium rate of 20 mm/d.

Because puddled soil cracks when it dries, thus accelerating percolation losses, drying should be avoided during rice growth, unless specifically needed to improve subsoil drainage when water supply is plentiful.

Bulk Density and Soil Strength: The change in bulk density caused by puddling depends on the aggregation status of the soil before puddling. If a parallel-oriented, closely packed structure is produced from a well-aggregated open structure, bulk density increases and vice versa. Puddling of a well-aggregated porous soil results in a massive structure of increased bulk density (Ghildyal, 1982). A dried puddled soil is very compact and hard and develops broad and deep cracks, depending on the nature and amount of clays. The main flocculating and cementing agents in puddled soils are active Fe, Mn, and Al and organic complexes (Saito, 1985). Settling is faster in sandy soils or in soils with kaolinitic mineralogy (Moormann and van Breemen, 1978).

Soil strength is a measure of resistance that must be overcome to cause a deformation in soil. The resistance is to both volumetric compression and linear deformation and depends on moisture content, texture, type and amount of clay, arrangement of particles in the soil matrix, and ionic species and concentrations. Soil strength decreases with increase in moisture content and increases with bulk density (Kisu, 1978). Soil strength in the puddled layer may be near zero because of high moisture content and loosely arranged soil particles. With greater bulk density and soil strength, root length density is reduced.

Soil Porosity: Change in porosity by puddling depends on the change in the orientation of soil particles in puddled layer. If a parallel oriented structure is produced on puddling from an initially open-gel structure, total porosity will decrease, and vice versa. Pore-size distributions and rigidity of the pore system are as important for growth and development of lowland rice roots as for upland crops. Under submerged conditions rice roots penetrated extensively in soils with large total porosity and a high proportion of pores > 150 μm diameter. Puddling of soil, therefore, improves root growth of rice by decreasing the rigidity of pores and soil resistance to penetration. Changes in pore-size distribution due to puddling strongly influence other soil physical processes, such as gaseous exchange, water retention and transmission, and evaporation losses from soils

Water Retention and Transmission: At lower water potentials, water retention in puddled soils always exceeds that in nonpuddled soils depending on soil texture and initial aggregation (Yun-sheng, 1983). Drying brings soil moisture characteristics of puddled soils close to those of nonpuddled ones (Taylor, 1972); moreover, resaturation does not restore to a dried puddled soil its original high water-retention capacity. This implies that in rain-fed conditions a rice crop may experience more drought stress during prolonged rainless periods in puddled than in aggregated soil. Evaporation losses from puddled soils are low because of their increased microporosity. In puddled soils, because of high water-retention capacity, more energy is needed to evaporate the same quantity of water compared to non puddle soils. Higher unsaturated hydraulic conductivity of puddled soils (because of large microporosity) may also help in keeping the surface soil moist longer by transporting more profile water upward to the soil surface. Consequently, it may take weeks to months to dry a puddled soil as compared to a well-structured soil. Rice grown on a puddled soil may therefore be less affected by mild drought than rice on a granulated soil (De Datta and Kerim, 1974).

Effect of puddling on growth of upland crop after rice

Although puddling favors rice growth, it adversely affects growth of upland crops following rice because it changes seedbed tilth and modified soil–water and soil–plant relations.

Structural characteristics and soil tilth after tillage of a puddled soil: Many soils that have been planted to rice have enough water for a dryland crop after rice. However, their seedbed structure usually is unsuitable, and dryland crops after rice often have low yields. Similarly, seedbeds may be difficult to establish for direct-seeded rice at the onset of monsoon. Direct-seeding is becoming more widespread because short-duration rices now permit the growing of two rice crops in wet season. Soil structure must be manipulated to allow easy crop establishment, rapid early growth to compete with weeds, and sufficient available water despite erratic early rains.

Plowing soils previously puddled for rice breaks soil into hard, medium-to-large clods that provide poor seedbed tilth and seed–soil contact for upland crops. Large clods permit greater water loss from the surface layers and may cause seed-zone moisture to fall below the level needed for seed germination. Under such conditions, it may be impossible to grow an upland, rainfed crop after rice.

Proper soil moisture and tillage are necessary to achieve a desired tilth. Fine-textured soils, especially those with 2:1 expanding clay minerals, are much more difficult to restructure after puddling than coarse soils. Moreover, turnaround time between rice harvest and upland-crop seed-planting may be long if the puddled soil is slow to dry to a cultivable wetness. Such delay may be disadvantageous for the cropping sequence and its productivity.

Soil-plant relations: Root system development is adversely affected by dense soil layers at shallow depth. Water absorption and root growth are restricted when soil is even mildly compacted. Root elongation rate is inversely related to soil strength. Consequently, root development is retarded by traffic pans.

Regeneration of Soil Structure for reducing the effect of puddling

To successfully grow upland crops after rice, it usually is necessary to restructure the soil. Areas where an upland crop follows lowland rice, regeneration of soil structure after rice crop is very much relevant. Soil texture and organic matter content determine if that can be done. The speed of recovery of soil structure depends on soil texture, clay mineralogy, organic matter, and environmental conditions. Regeneration is faster in kaolinitic clay soils rich in organic matter and iron oxides than in soils dominated by montmorillonitic clays and poor organic matter. Regeneration can be speeded up by adopting suitable tillage techniques at appropriate moisture contents and proper organic matter management. Tillage is difficult in clay soils because they are hard when dry and sticky when wet. Texture Medium- to slightly fine-textured soils favor upland crops because they till well, have high water-holding capacity, good drainage, and good nutrient supplying capacity. Similar or slightly heavier soils such as fine loam, fine silt, and fine clay soils favor rice growth. Soils with 25–50% clay in the topsoil and a similar or somewhat higher clay percentage in the subsoil produce the highest rice yields. Coarse-textured soils do not favor rice because they have high percolation rates, poor water economy, and high soluble nutrient losses. They also are not well suited to upland crops because of low cation exchange capacity, nutrient content, and water-holding capacity. Puddling, in general, has been found to decrease the soil moisture range over which an optimum soil tilth can be obtained. However, lowland soils dry slowly, often taking weeks to months to reach a workable moisture content. This increases the turnaround time between two crops (Morris, 1982). Upon drying, puddled soils become impenetrable to roots because of increased mechanical impedance (Syarifuddin and Zandstra, 1978). With excess moisture, it may be worthwhile to try zero or minimum tillage for upland crops after lowland rice, with proper crop selection (Zandstra, 1982). If a crop can be grown satisfactorily by reduced tillage, it will shorten the turnaround time and also alleviate problems in creating an adequate seedbed. Inclusion of legumes such as chickpeas (*Cicer arietinum* L.), in rotation with lowland rice improved the structure of lowland soil.

Organic matter content: In addition to supplying nutrients, organic matter promotes soil aggregation. Under submergence, however, it helps create a reduced zone that may favor rice growth, and generally increases water holding capacity of mineral soils. Moormann and Van Breemen (1978) reported that high organic matter content reduced drought stress on sandy or coarse loam pluvial rice lands with dominantly kaolinitic clays. Fine-textured soils, especially those with montmorillonitic clay, break into large, hard clods that make a poor seedbed for upland crops after rice. Moreover, the high bulk density of such soils affects subsequent growth and yield of the upland crops. Organic matter content is especially important in such soils. Restoring good tilth after a lowland rice crop is more difficult in soils low in organic carbon (<0.6%) than in humic soils with similar texture and clay mineralogy (Moormann and Van Breemen, 1978).

Drying and Wetting effect on soil aggregation

Repeated cycles of drying and wetting play a major role in aggregation through shrinking and swelling that lead to formation of aggregates. Swelling or rewetting leads to reorientation of particles. Shrinking or drying leads to formation of cracks and increase in formation of link bonds through cementation. The mechanisms involved, especially the opposing forces, are not clearly understood. Non-uniform drying can lead to unequal strains throughout the soil mass. Consequently, large clods can break down into small aggregates by drying. Similar to rapid drying, rapid wetting also breaks large clods into aggregates because of the effect of entrapped air. That is why slow wetting, wetting by capillarity or wetting in vacuum is suggested for minimizing risks of soil slaking or rapid dispersion (Yoder, 1936). There is no slaking of aggregates if air in the soil is replaced by CO₂. Other causes of slaking by rapid wetting include differential swelling, and swelling of the oriented clay coatings or streaks. However, the relative effectiveness of wetting and drying depends on the texture and cohesive properties of the soil (Grant, 1965). In heavy textured soils, desiccation cracks lead to formation of ped faces. Rewetting of the shrunken soil causes swelling and development of shearing forces between the wet/dry boundary layer. Repeated shrinkage and swelling leads to formation of prismatic, blocky, parallelepiped, or platy peds in subsurface layers of heavy-textured soils.

Shifting of Puddled Transplanting to Direct Seeding of Rice

Following points may be attributed for shifting of transplanting of rice to direct seeded rice

Water scarcity: Rice consumes about 50% of total irrigation water used in Asia (Barker et al., 1998) and 34–43% of the world's irrigation water (Bouman et al., 2007). On average, 2500 L of water are applied, ranging from 800 to more than 5000 L, to produce 1 kg of rough rice (Bouman, 2009). The seasonal water input to rice fields is the combination of water used in land preparation and to compensate for evaporation, transpiration, seepage, and percolation losses during crop growth. Most of the water applied during crop growth is not used directly for transpiration, and is therefore considered lost from fields. Tuong and Bouman (2003) estimated seasonal water input for typical puddled transplanted rice to vary from 660 to 5280 mm depending on growing season, climatic conditions, soil type, and hydrological conditions, with average of 1000–2000 mm in most cases (Tuong, 1999). The higher water application in rice is mostly due to water requirements for puddling and losses associated with continuous flooding such as seepage and deep percolation losses to groundwater (Hafeez et al., 2007). Seepage and percolation losses vary from 25% to 85% of total water input depending on soil type and water table (Choudhury et al., 2007; Dong et al., 2004). In the major rice-growing Asian countries, per capita water availability decreased by 34–76% between 1950 and 2005 and is likely to decline by 18–88% by 2050 (Gardner-Outlaw and Engelman, 1997). Another evidence of growing water scarcity is the depleting groundwater resources, especially in South Asia and North China (Shah et al., 2007), threatening the most intensive irrigated rice–wheat growing areas. Groundwater tables have fallen in the major rice-growing countries. In the Indian states of Punjab, Haryana, Gujarat, Tamil Nadu, Rajasthan, Maharashtra, and Karnataka, it is falling at 0.5–2 m per year (Singh and Singh, 2002; Tuong and Bouman, 2003). Increasing water scarcity has threatened the productivity and sustainability of the irrigated rice system in Asia (Tuong et al., 2004). About 13 million ha of Asia's irrigated wet-season rice and 2 million ha of irrigated dry-season rice may experience physical water scarcity by 2025 (Tuong and Bouman, 2003).

Inefficient rice production technologies currently adopted by a majority of farmers globally warrants the exploration of alternative rice production methods, which inherently require less water and are more efficient in water use. DSR provides some opportunities for saving water. Both Dry- and

Wet-DSR are more water efficient and have an advantage over conventional transplanted rice (Dawe, 2005; Humphreys et al., 2005).

The labor shortage and increasing labor wages: Conventional TPR is highly labor intensive. Both land preparation (puddling) and CE methods (transplanting) of CT-TPR require a large amount of labor. Rapid economic growth in Asia has increased the demand for labor in nonagricultural sectors, resulting in reduced labor availability for agriculture (Dawe, 2005). Moreover, government policies such as The Mahatma Gandhi National Rural Employment Guarantee Act, introduced by the Indian government in 2005 (GOI, 2011), promising 100 days of paid work in people's home village, is creating a labor scarcity in the cereal bowl of northwest India, which is dependent on millions of migrant laborers from eastern Uttar Pradesh and Bihar for rice transplanting. Because of high labor demand at the time of transplanting, increasing labor scarcity and rising wage rates are forcing farmers to opt for a shift in method of rice establishment from transplanting, which requires 25–50 person-days ha⁻¹, to direct seeding, which in comparison needs about 5 person-days ha⁻¹ (Balasubramanian and Hill, 2002; Dawe, 2005).

Adverse effects of puddling on soil physical properties and the succeeding non-rice crop: Growth and yield of the dryland crops are influenced by soil mechanical properties, soil temperature, and moisture regimes after rice. Although puddling is known to be beneficial for growing rice, it can adversely affect the growth and yield of subsequent upland crops because of its adverse effects on soil physical properties, which includes poor soil structure, suboptimal permeability in the subsurface layer, and soil compaction (Gathala et al., 2011; Kumar et al., 2008). It is therefore important to identify alternatives to puddling (e.g., Dry-DSR), especially in those regions where water is becoming scarce and an upland crop is grown after rice. On average, wheat yields were 9% higher when wheat was grown after Dry-DSR than when grown after CT-TPR. Of 35 studies, in 28 cases, puddling had adverse effects on succeeding wheat productivity (Kumar et al. (2008).) The main reason reported for the lower grain yield of wheat grown after CT-TPR was poor root development in a suboptimal soil physical environment resulting from puddling during the previous rice crop (Aggarwal et al., 1995; Ishaq et al., 2001). Poor establishment and yields have also been found in other upland crops grown after rice, including chickpea and Indian mustard in India (Gangwar et al., 2008).

The process of puddling provides many benefits to rice but adversely affects the growth and yield of the subsequent upland crop (i.e., wheat) because of its adverse effects, especially on soil physical properties. Dryland crops grow badly on poorly structured, puddled soils. This requires an alternative tillage method that provides optimal yield of all the crops in a rotation with maximal efficiency of resource use such as labor and water.

Direct-Seeded Rice: Dry direct seeding In Dry-DSR, rice is established using several different methods, including (1) broadcasting of dry seeds on unpuddled soil after either zero tillage (ZTdry-BCR) or conventional tillage (CT-dry-BCR), (2) dibbled method in a well-prepared field (CT-dry-dibbledR), and (3) drilling of seeds in rows after conventional tillage (CT-dry-DSR), reduced tillage using a power-tiller-operated seeder (PTOS) [RT (PTOS)-dry-DSR], zero tillage (ZTdry-DSR), or raised beds (Bed-dry-DSR) (Kumar and Ladha, 2011).

Wet direct seeding: In contrast to Dry-DSR, Wet-DSR involves sowing of pregerminated seeds with a radicle varying in size from 1 to 3 mm on or into puddle soil. When pregerminated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic and this is known as aerobic Wet-DSR. When pregerminated seeds are sown/drilled into puddled soil, the seed environment is mostly anaerobic and this is known as anaerobic Wet-DSR. In both aerobic and anaerobic Wet-DSR,

seeds are either broadcast [CT-wet-BCR (surface)] or sown in-line using a drum seeder [CT-wet-DrumR (surface)] (Rashid et al., 2009) or an anaerobic seeder [CT-wet-DSR (subsurface)] with a furrow opener and closer (Balasubramanian and Hill, 2002).

Water seeding: In this method, pregerminated seeds (24-h soaking and 24-h incubation) are broadcast in standing water on puddled (Wet-water seeding) or unpuddled soil (Dry water seeding). Normally, seeds, because of their relatively heavy weight, sink in standing water, allowing good anchorage. The rice varieties that are used possess good tolerance of a low level of dissolved oxygen, low light, and other stress environments (Balasubramanian and Hill, 2002). Water seeding has gained popularity in areas where red rice or weedy rice is becoming a severe problem (Azmi and Johnson, 2009).

Areas where direct seeding may be preferred

Crop establishment, though using direct sowing, can vary from broadcasting manually or mechanically (aeroplane or power sprayer) to line sowing using either a drill or a drum seeder, or manually by the dibble method in puddled or unpuddled soil. In areas where labor scarcity has been serious but water is relatively more readily available, farmers shifted to Wet-DSR without making a change in tillage. However, in areas where both labor and water are emerging as major constraints, farmers are interested in Dry- DSR with zero or reduced tillage.

Both Dry- and Wet-DSR have the potential to reduce water and labor use compared with CT-PR. Tabbal et al. (2002) in their on-farm studies in the Philippines observed on average 67–104 mm (11–18%) of savings in irrigation water in Wet-DSR compared with CT-TPR when irrigation application criteria was same for both establishment methods. Cabangon et al. (2002) in the Muda region of Malaysia found that irrigation water application in Dry-DSR was about 200 mm (40%) less than that in CTPR. Similarly, 10–50% savings in water have been claimed with Dry-DSR compared with CT-TPR from India when irrigation application criteria after crop establishment (CE) were either the appearance of hairline cracks or tensiometer-based (-20 kPa at 20-cm depth) (Sudhir-Yadav et al., 2011a,b). Similar to saving in water, DSR can reduce total labor requirements from 11% to 66% depending on season, location, and type of DSR compared with CT-TPR (Rashid et al., 2009). Labor requirements for CE decrease by more than 75% with direct seeding compared with transplanting (Dawe, 2005).

Following points may be kept in consideration while deciding for suitability of tillage systems for rice based cropping systems.

1. On soils with predominantly high-activity clays, on soils that are easily dispersed when submerged, and on soils with naturally low permeability, with adequate weed control, rice grows successfully without puddling. Under these conditions, eliminating puddling would improve growth and yield of following dryland crops.
2. In unpuddled coarse-textured fields with predominantly low activity clays, yield is reduced because of high percolation and nutrient leaching, Because effective puddling is impossible in poorly structured soils, they respond better to soil compaction than to wet or dry plowing.
3. In rice-wheat cropping system, use of green manure, farmyard manure and crop residues restore the damaged soil structure (due to puddling in rice) by increasing its organic carbon content, size and stability of aggregates, water retention and infiltration; and decreasing bulk density, dispersion ratio and soil strength. The beneficial effects confines to 10 cm with green

manure, farmyard manure individually and to 15 cm in combination with crop residues. Incorporation of residues of the both crops together with green manure is most effective to maintain the structure of the plough layer soil in rice–wheat cropping system (Singh *et. al.*, 2007).

Summary

Rice is cultivated in wet season and there has been a congruent decline in yields of the following upland crop in dry season. Puddling destroys soil aggregates, triggering changes in soil physical properties. Studies are needed to determine effective and efficient methods for restructuring puddled soils for nonrice crops. The effect of tillage systems and their consequences on soil physical properties including soil aggregation, bulk density, soil strength, pore-size distributions, water retention and transmission, and the formation of subsurface hardpans in relation to crop production in rice-based cropping systems have been discussed. Bulk density may increase or decrease depending on the structural status of the soil before puddling. Soil strength decreases with puddling. Puddling eliminates water-transmission pores and increases storage and residual pores. Hydraulic conductivity, percolation rate, and evaporation loss are minimized upon puddling. Many rainfed ricelands are planted with dryland crops after rice. Crop establishment and management to ensure optimum use of residual soil water are critical. Understanding the relevant soil physical conditions could help increase agricultural production. Dryland crops grown on puddled soils may, however, suffer from poor soil structure and drought stress because of soil shrinkage and root growth impedance below the plow pan. Direct seeding could be an attractive alternative to transplanting of rice. It is expected to minimize labor input and reduce cultivation cost. Location-specific synergistic combinations of technology options have to be identified and used to maximize economic returns to farmers and environmental benefits to the community. Available evidence indicates that a shift to direct seeding has had a favorable impact on farmer income because it has helped reduce the cost of labor. Where farmers have been able to grow more than one rice crop as a result of direct seeding, the benefits have been even more pronounced. Although direct seeding is likely to be more widely adopted in the future, transplanting will probably continue to be used, especially in poorly drained rainfed areas. As labor costs rise, farmers would seek labor-saving methods for establishing rice in these poorly drained areas. Without these labor-saving transplanting methods (or heavy investments in drainage), these areas may stop producing rice as labor costs keep rising. Mechanical transplanting could play an important role in these environments. Research to develop cost-efficient mechanical transplanters that would be more suitable to the farming conditions of South and Southeast Asia need to be developed and popularized among farmers.

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18. C3 and C4 Plants to Tackle Climate Change

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Introduction

The world's human population is predicted to reach over 9.3 billion by the year 2050 (U.S. Census Bureau 2014) and shifts in diets toward animal products, oils, and other resource intensive foodstuffs are placing ever more pressure on agricultural systems to increase production (Kastner et al. 2012). At the same time, degraded soils as well as water, arable land, and other resource limitations challenge production and climate change represents an increasingly serious threat (Lobell et al. 2008). This widening mismatch between demand and supply is causing grave concern for future food security. By 2050, much of the world will experience a growing season that will likely have higher temperatures than the hottest growing seasons of recent times and this increase in temperatures will probably be accompanied by more variable rainfall (Battisti and Naylor 2009). Crops will be impacted in various ways. For example, rice flowers show increased sterility at higher temperatures. Maize is also very sensitive to drought at the time of flowering. Wheat senescence starts earlier and is faster under warmer conditions (Lobell et al. 2012). Adding up these and other effects, models show possible yield losses of 6-10% per 1°C of warming in the average temperature of the growing season (Guarino and Lobell 2011). This means the world could see significant production losses in the future. Taking more land under cultivation to increase food production is not an option in most parts of the world without serious impacts on wild biodiversity and the provision of ecosystem services. Increasing agricultural yields in a framework of sustainable intensification is therefore an important solution (Garnett et al. 2013). Significant headway can be made by improving agricultural practices and creating more favorable policy environments for example to avoid food wastage but such measures can only provide a partial solution. It is estimated that we must double world food production by 2050 to meet increasing demand, but the once rapid growth seen in the “green revolution” has stalled, and even past advances are threatened by climate change (Battisti and Naylor, 2009, Wheeler and Braun, 2013 and Lobell et al. 2013). Much of past yield improvement has focused on increases in the harvest index and resistance to pests. However, all else being equal, the quantity of photosynthesis places an upper limit on the supply of food and fuels from our agricultural systems. Ironically, we currently have very limited ability to assess photosynthesis of the breadbaskets of the world. Agricultural production inventories provide important information about crop productivity and yields (Hicke et al., 2004, Monfreda, et al., 2008 and Ramankutty et al., 2008) but these are difficult to compare between regions and lag actual production. Carbon cycle models, based on either process-oriented biogeochemistry understand the controls and variations of global gross primary production (GPP, equivalent to ecosystem gross photosynthesis) (Beer et al., 2010) and to investigate the climate impact on crop yields (Ciais et al. (2005). However, uncertainty associated with inaccurate input data and much simplified process descriptions based on the plant functional type concept severely challenge the application of these models to agricultural systems.

It will be crucial to adapt agriculture to the increasingly challenging environmental conditions by breeding new crop varieties. The list of possible plant traits that could be used is long, including everything enhanced photosynthesis and grain filling.

Climate change & food security

Climate change is expected to have generally negative effects on developing-country agriculture, with concomitant implications for food security. Projections indicate that the impacts will increase over time, with socioeconomic development and trade much more important drivers of food security in the short run, but with climate change playing an increasingly important role after 2030. In the intervening years, however, climate shocks such as drought, flooding, and extreme temperatures are expected to increase in frequency and intensity, and that is already occurring (IPCC 2012). In the absence of measures to reduce the vulnerability to, and impacts of, such extreme events, they can be expected to generate significant and negative impacts on food security (FAO 2010; Foresight 2011). At present, some 70 percent of the food-insecure people in the world are rural and directly or indirectly dependent on agriculture for income as well as food (IFAD 2011). Rural poverty and hunger are concentrated in two locations: South Asia, with the greatest number of poor rural people, and Africa south of the Sahara (SSA), with the highest incidence of rural poverty. Those two areas are also where the bulk of future population growth is expected to occur. Some countries, mostly in SSA, could see population increases of 200 percent or more to the middle of this century, representing a substantial growth in absolute numbers (Nelson and van der Mensbrugghe 2013). Such areas of growing populations, highly dependent on agriculture and with high rates of food insecurity, are also where climate change is expected to have the worst effects. Ericksen et al. (2011) indicate considerable overlap between areas of high poverty and food insecurity and “climate change hotspots,” partly due to projected impacts of climate change but also because poverty reduces coping capacity. Reducing poverty and food insecurity in agriculture-dependent populations is thus also a key means of reducing vulnerability to climate change, increasing the urgency of addressing the challenge. How to accomplish that goal? Research has shown that gross domestic product growth originating in agriculture is almost three times more effective in reducing poverty than growth in other sectors of the economy due not only to the direct poverty reduction effect but also to its potentially strong growth linkage effects on the rest of the economy (FAO 2012b; De Janvry and Sadoulet 2010). Thus, the next 20 years are a critical window of time for accelerating the rate of agricultural growth in least-developed countries to achieve food security and development for agriculture-dependent populations.

Achieving sustainable food security in a world with a growing population, changing diets and a changing climate is a major challenge. More food is needed in the future but climate change means less food production potential and poor people will be hit the hardest. Climate-related crop failures, fishery collapses and livestock deaths already cause economic losses and undermine food security, and these are likely to become more severe as global warming continues.

Climate change and Agricultural production system

Climate change may affect agricultural and natural systems in many ways. In general, higher average temperatures will accelerate the growth and development of plants. As for livestock, most species have comfort zones between 10 and 30 degrees Celsius (°C), and at temperatures above that, animals reduce their feed intake 3 to 5 percent per additional degree of temperature. Rising temperatures are not uniformly bad: they will lead to improved crop productivity in parts of the tropical highlands, for example, where cool temperatures are currently constraining crop growth. Average temperature effects are important, but there are other temperature effects too. Increased night-time temperatures have negative effects on rice yields, for example, by up to 10 percent for each 1 °C increase in minimum temperature in the dry season. Increases in maximum temperatures can lead to severe yield reductions and reproductive failure in many crops. In maize, for example, each

degree day spent above 30 °C can reduce yield by 1.7 percent under drought conditions. Climate change is already affecting rainfall amounts, distribution, and intensity in many places. This has direct effects on the timing and duration of crop growing seasons, with concomitant impacts on plant growth. Rainfall variability is expected to increase in the future, and floods and droughts will become more common. Changes in temperature and rainfall regime may have considerable impacts on agricultural productivity and on the ecosystem provisioning services provided by forests and agroforestry systems on which many people depend. There is little information currently available on the impacts of climate change on biodiversity and subsequent effects on productivity in either forestry or agroforestry systems.

Climatic shifts in the last few decades have already been linked to changes in the large-scale hydrological cycle. Globally, the negative effects of climate change on freshwater systems are expected to outweigh the benefits of overall increases in global precipitation due to a warming planet.

The atmospheric concentration of carbon dioxide (CO₂) has risen from a preindustrial 280 parts per million to approximately 400 parts per million, and was rising by about 2 parts per million per year during the last decade. Many studies show a beneficial effect (CO₂ fertilization) on some crops (those that utilize a C₃ photosynthetic pathway) but limited if any effect on other plants such as maize and sorghum that utilize a C₄ photosynthetic pathway. There is some uncertainty associated with the impact of increased CO₂ concentrations on plant growth under typical field conditions, and in some crops such as rice, the effects are not yet fully understood. Whereas increased CO₂ has a beneficial effect on wheat growth and development, for example, it may also decrease the protein concentration in the grain. In some crops such as bean, genetic differences in plant response to CO₂ have been found, and these could be exploited through breeding. Increased CO₂ concentrations lead directly to ocean acidification, which (together with sea-level rise and warming temperatures) is already having considerable detrimental impacts on coral reefs and the communities that depend on them for their food security.

Many of the impacts of climate change on agriculture will be mediated through water. The global demand for water withdrawals by agriculture are projected to increase by 11 percent to 2050 (Bruinsma 2009), and climate change adds serious challenges to the water security problem.

The impacts of changes in climate and climate variability on agricultural production will have substantial effects on smallholder and subsistence farmers, pastoralists, and fisher folk in many parts of the tropics and subtropics. Crop yields in SSA are likely to be particularly adversely affected, and the resulting reduced food security potentially will increase the risk of hunger and under nutrition (HLPE 2012).

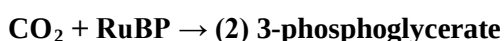
Photosynthesis

Photosynthesis is a process used by plants and other organisms to convert light energy, normally from the Sun, into chemical energy that can be later released to fuel the organisms' activities. This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesized from carbon dioxide and water hence the name photosynthesis. In most cases, oxygen is also released as a waste product. Most plants, most algae, and cyanobacteria perform photosynthesis, and such organisms are called photoautotrophs. Photosynthesis maintains atmospheric oxygen levels and supplies all of the organic compounds and most of the energy necessary for life on Earth. There are 3 basic types of photosynthesis: C₃, C₄, and CAM. Each has advantages and disadvantages for

plants living in different habitats. All 3 forms of photosynthesis are based on two pathways. The first are the light reactions, where energy from the sun is absorbed by the chlorophyll of the plant, and the energy is transferred to hydrogen ions which are split off from water (Oxygen is produced at this point). The second pathway is the "dark reactions" - better known as carbon fixation or the Calvin Cycle. Here, carbon dioxide is taken from the air and combined to make sugars. The energy absorbed in the light reactions is used to drive this process, with the end result being sugar molecules with energy stored in the carbon-carbon bonds of the sugar. The 3 types of photosynthesis differ in details of how these processes are carried out (Fig.1).

C3 Photosynthesis

C₃ carbon fixation is one of three metabolic pathways for carbon fixation in photosynthesis, along with C₄ and CAM. This process converts carbon dioxide and ribulose biphosphate (RuBP, a 5-carbon sugar) into 3-phosphoglycerate through the following reaction:



This reaction occurs in all plants as the first step of the Calvin–Benson cycle. In C₄ plants, carbon dioxide is drawn out of malate and into this reaction rather than directly from the air. Plants that survive solely on C₃ fixation (C₃ plants) tend to thrive in areas where sunlight intensity is moderate, temperatures are moderate, carbon dioxide concentrations are around 200 ppm or higher, and ground water is plentiful. The C₃ plants, originating during Mesozoic and Paleozoic eras, predate the C₄ plants and still represent approximately 95% of Earth's plant biomass. C₃ plants lose 97% of the water taken up through their roots to transpiration. Examples include rice and barley. C₃ plants cannot grow in hot areas because Ribulose-1,5-bisphosphate carboxylase/ oxygenase incorporates more oxygen into RuBP as temperatures increase. This leads to photorespiration, which leads to a net loss of carbon and nitrogen from the plant and can, therefore, limit growth. In dry areas, C₃ plants shut their stomata to reduce water loss, but this stops CO₂ from entering the leaves and, therefore, reduces the concentration of CO₂ in the leaves. This lowers the CO₂:O₂ ratio and therefore increases photorespiration.

.C4 Photosynthesis

The C₄ photosynthesis is an adaptation of the C₃ pathway that overcomes the limitation of the photorespiration, improving photosynthetic efficiency and minimizing the water loss in hot, dry environments (Edwards & Walker, 1983). Generally, C₄ species originate from warmer climates than C₃ species. Most C₄ plants are native to the tropics and warm temperate zones with high light intensity and high temperature. Under these conditions, C₄ plants exhibit higher photosynthetic and growth rates due to gains in the water, carbon and nitrogen efficiency uses. Some of the world's most productive crops and pasture, such as maize (*Zea mays*), sugar cane (*Saccharum officinarum*), sorghum (*Sorghum bicolor*), amaranth, paspalums (*Paspalum notatum* and *P. urvillei*), bermudagrass (*Cynodon dactylon*), blue grama (*Bouteloua gracilis*) and rhodes grass (*Chloris gayana*) are C₄ plants. In addition, the most troublesome weeds like nutgrass, crabgrass and barnyard, are also C₄ species. Although C₄ plants represent only a small portion of the world's plant species, accounting for only 3 % of the vascular plants, they contribute about 20% to the global primary productivity because of highly productive C₄-grass-lands

C₄ photosynthesis differs in 2 key ways. First, instead of RuBP carboxylase, a different enzyme, PEP carboxylase, is used to grab CO₂. The PEP carboxylase is less likely to bind to oxygen, thus photorespiration is less likely to occur, a decided advantage under hot, dry conditions where

water may be scarce and the stomata remain closed for long periods, trapping oxygen in the plant. A second difference is that not all of the photosynthetic reactions take place in the same cells. Carbon is taken up in the mesophyll cells of the leaf (by PEP carboxylase), added to other carbons to form a 4-carbon chemical (hence the name C_4) called oxaloacetate, and the oxaloacetate is pumped into adjacent bundle sheath cells where the rest of the Calvin Cycle takes place. And this two cell compartmentation is known as Kranz anatomy.

Single cell C_4 Photosynthesis

The fundamental paradigm underpinning the efficiency of C_4 photosynthesis in terrestrial plants is the 'division of labour' between the initial fixation of CO_2 into C_4 acids, and their subsequent utilization to generate high concentrations of CO_2 for ultimate fixation by Rubisco. The basic model for C_4 plants with classical kranz anatomy consists of two photosynthetic cycles (C_3 and C_4) operating across two photosynthetic cell types (mesophyll and bundle sheath), with strict cell and organelle specific localisation of key enzymes and with sufficient resistance to CO_2 back diffusion. Indeed, the discovery of the kranz anatomy by Haberlandt preceded that of C_4 biochemistry by a century. The prevailing consensus has been that efficient C_4 photosynthesis necessitates the collaboration of two cell types. Recently, this notion has been challenged by the discovery of non-kranz or single-cell C_4 photosynthesis in shrubs (*Borszczowia aralocaspica* and *Bienertia cycloptera*; Chenopodiaceae family) found in the salt deserts of Central Asia (Voznesenskaya et al. 2002, 2003). These plants show CO_2 and O_2 responses typical of C_4 photosynthesis but lack the kranz anatomy. They perform C_4 photosynthesis through the spatial localisation of dimorphic chloroplasts (as well as other organelles and photosynthetic enzymes) in distinct positions within a single chlorenchyma cell. Yet, the details of the partitioning differ between the two species (Edwards et al. 2004). Thus, single-cell C_4 plants have efficient photosynthesis which is not inhibited by O_2 , and their carbon isotope values are similar to kranz-type C_4 plants. Although, single-cell C_4 photosynthesis breaks away from the classical kranz anatomy, it remains within the general 'division of labour' paradigm.

CAM photosynthesis

The final form of photosynthesis is CAM photosynthesis or Crassulacean-Acid metabolism. This type of photosynthesis is most common in desert plants where water is at a premium. In CAM photosynthesis, CO_2 is taken up only at night and is stored in vacuoles. This causes a buildup of oxaloacetate (acidic) which we just met in C_4 photosynthesis in those vacuoles. The effect is to partition the initial uptake of CO_2 and the rest of the Calvin Cycle over time (as opposed to the partition of these reactions in space that occurs in C_4 photosynthesis). The stomata are open only at night, when it is relatively cool and humid; they stay closed during the hot, dry day. In the morning, sunlight driving the light reactions allows the stored carbon to be combined into sugars. The stored carbon may run out fairly quickly, however, meaning that photosynthesis only proceeds for part of the day, and that means little production of sugars. Thus desert plants can survive the dry conditions, but at the cost of rapid growth. Desert plants are often very slow to grow, and this is one of the reasons they invest so much energy in defensive structures (spines) and chemicals - they can't afford to lose such hard-earned biomass.

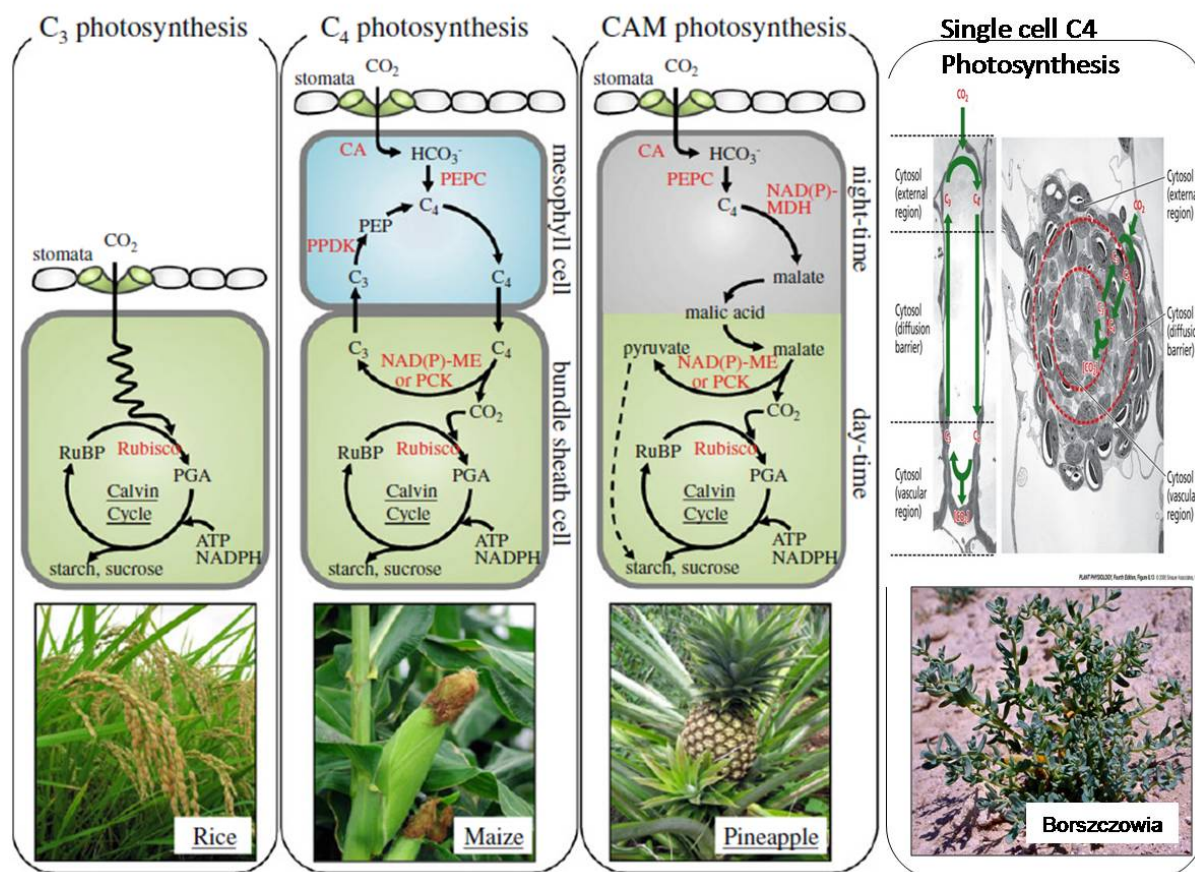


Fig. 1 Basic difference between C₃, C₄, CAM and single cell C₄ photosynthesis system

C₃ vs C₄ species

C₄ species have evolved in a high CO₂ environment. This increases both their nitrogen and water use efficiency compared to C₃ species. C₄ plants have greater rates of CO₂ assimilation than C₃ species for a given leaf nitrogen when both parameters are expressed either on a mass or an area basis (Ghannoum et al., 2011). Although the range in leaf nitrogen content per unit areas is less in C₄ compared to C₃ plants, the range in leaf nitrogen concentration per unit dry mass is similar for both C₄ and C₃ species. Even though leaf nitrogen is invested into photosynthetic components into the same fraction in both C₃ and C₄ species, C₄ plants allocate less nitrogen to Rubisco protein and more to other soluble protein and thylakoids components. In C₃ plants, the photosynthetic enzyme Rubisco accounts for up to 30% of the leaf nitrogen content (Lawlor et al., 1989), but accounts for only 4–21% of leaf nitrogen in C₄ species (Evans & von Caemmerer, 2000). The lower nitrogen requirement of C₄ plants results from their CO₂-concentrating mechanism, which raises the bundle sheath CO₂ concentration, saturating Rubisco in normal air and almost eliminating photorespiration. Without this mechanism, Rubisco in the C₃ photosynthetic pathway operates at only 25% of its capacity (Sage et al., 1987) and loses ca. 25% of fixed carbon to photorespiration (Ludwig & Canvin, 1971). To attain comparable photosynthetic rates to those in C₄ plants, C₃ leaves must therefore invest more heavily in Rubisco and have a greater nitrogen requirement. Because the Rubisco specificity for CO₂ decreases with increasing temperature (Long, 1991), this difference between the C₃ and C₄ photosynthetic nitrogen-use efficiency is greatest at high temperatures (Long, 1999). The high photosynthetic nitrogen-use efficiency of C₄ plants is partially offset by the nitrogen requirement for CO₂-concentrating mechanism enzymes, but the high maximum catalytic rate of PEP-carboxylase

means that these account for only ca. 5% of leaf nitrogen (Long, 1999). Improved leaf and plant water use efficiency in C4 plants is due to both higher photosynthetic rates per unit leaf area and lower stomatal conductance, with the greater CO₂ assimilation contributing to a major extent (Ghannoum et al., 2011). The advantages of greater nitrogen use efficiency and water use efficiency of C4 relative to C3 photosynthesis are fully realized at high light and temperature, where oxygenase reaction of Rubisco is greatly increased. It is worth noting, although in C4 plants energy loss due to photorespiration is eliminated, and additional energy is required to operate the C4 cycle (2 ATPs per CO₂ assimilated). In dim light, when photosynthesis is linearly dependent on the radiative flux, the rate of CO₂ assimilation depends entirely on the energy requirements of carbon assimilation (Long, 1999). The additional ATP required for assimilation of one CO₂ in C4 photosynthesis, compared with C3 photosynthesis, increases the energy requirement in C4 plants (Hatch, 1987). However, when the temperature of a C3 leaf exceeds ca. 25 °C, the amount of light energy diverted into photorespiratory metabolism in C3 photosynthesis exceeds the additional energy required for CO₂ assimilation in C4 photosynthesis (Hatch, 1992; Long, 1999). This is the reason why at temperatures below ca. 25–28 °C, C4 photosynthesis is less efficient than C3 photosynthesis under light-limiting conditions. It is interesting to note, that while global distribution of C4 grasses is positively correlated with growing season temperature, the geographic distribution of the different C4 subtypes is strongly correlated with rainfall (Ghannoum et al., 2011). On the contrary, C4 plants are rare to absent in cold environments. Although there are examples of plants with C4 metabolisms that show cold adaptation, they still require warm periods during the day in order to exist in cold habitats (Sage et al., 2011). In consequence, C4 species are poorly competitive against C3 plants in cold climates (Sage & McKown, 2006; Sage & Pearce, 2000). The mechanisms explaining the lower performance of C4 plants under cold conditions have not been clarified (Sage et al., 2011). Among early plausible explanations were the low quantum yield of the C4 relative to the C3 pathway (Ehleringer et al., 1997), and enzyme lability in the C4 cycle, most notably around PEP metabolism (PEPcarboxylase and pyruvate orthophosphate dikinase) (Matsuba et al., 1997). Both hypothesis are insufficient since maximum quantum yield differences do not relate to conditions under which the vast majority of daily carbon is assimilated and there cold-adapted C4 species that have cold stabled forms of PEP-carboxylase and pyruvate orthophosphate dikinase, and synthesize sufficient quantity to overcome any short term limitation (Sage et al., 2011). The current hypothesis is that C4 photosynthesis is limited by Rubisco capacity at low temperatures. Even in cold-tolerant C4 species, Rubisco capacity becomes limiting at low temperature and imposes a ceiling on photosynthetic rate below 20 °C (Kubien et al., 2003).

Photosynthesis & climate change

Global climate change is resulting in increases in the daily, seasonal, and annual mean temperatures experienced by plants. Moreover, climate change will increase the intensity, frequency, and duration of abnormally low and high temperatures (Tebaldi et al. 2006; Christensen et al. 2007). Temperature limits plant growth and is also a major determining factor in the distribution of plants across different environments (Mittler 2006). Since plants cannot move from unfavorable to favorable temperature conditions, the ability to withstand and/or acclimate to environmental temperature and carbon dioxide variation is essential for plant survival. Since photosynthesis has long been recognized as one of the most temperature and carbon dioxide sensitive processes in plants, understanding the physiological processes that underlie the temperature and CO₂ response of photosynthesis and its acclimation is important to both agriculture and the environment. The temperature response of photosynthesis can be described with a parabolic curve having an optimum temperature, and thus photosynthesis is inhibited at both low and high temperatures (Berry and Bjořrkman 1980). Most

plants show considerable capacity to adjust their photosynthetic characteristics to their growth temperatures. The most typical phenomenon is a shift in the optimum temperature of photosynthesis as the growth temperature changes or with seasonal temperature shifts, which allows the plant to increase photosynthetic efficiency at their new growth temperature (Yamori et al. 2010b).

Photosynthesis is intimately tied to climatic conditions, both directly and indirectly. While light absorption is independent of temperature, the subsequent steps in converting light into chemical energy respond to temperature in complex ways. In C₃ plants, the uptake of CO₂ by Rubisco is the first step in photosynthetic CO₂ assimilation, and Rubisco is not saturated with CO₂ at normal intercellular CO₂ concentrations. Both CO₂ and O₂ also compete for access to the active sites on Rubisco, with increasing CO₂ favouring carboxylations at the expense of oxygenations, so that an increasing proportion of reducing and phosphorylation potentials can be channelled towards CO₂ fixation. Indirect effects of climate change may ultimately be even more important. Plants require an aqueous medium in their cells, and photosynthetic function is impaired when plant water status falls below critical values. Plants could maintain an aqueous internal environment by closing their stomata and minimizing water loss by fully surrounding their leaves by a cuticular epidermis that allows only minor rates of water loss. However, stomatal closure would also prevent the diffusive entry of CO₂ into photosynthesising cells. On-going water loss is therefore an inevitable cost of the need to maintain an open diffusion path for CO₂ to enter photosynthesising leaves. Plants photosynthesise in order to produce carbon for growth. To grow new tissues, plants also need inorganic nutrients from the soil, such as nitrogen and phosphorus, and plant responses to climatic changes can be modified by the availability of these nutrients. Nutrient availability itself can also be affected by environmental factors, especially temperature, because the rate of soil nutrient mineralisation strongly depends on temperature. For a detailed assessment of the overall effects of a changing climate on photosynthesis, it is necessary to investigate the response to the simultaneous changes in several climatic variables, such as temperature, water availability, and CO₂ concentration. Photosynthesis responds to all aspects of the climate. The inherent ability for temperature acclimation of photosynthesis can thus be expected to be different among plants utilizing differing photosynthetic pathways [e.g., among C₃, C₄, and crassulacean acid metabolism (CAM) plants].

C₄ plants are often associated with relatively arid regions with high temperatures, such that C₄ plants may have a greater ability for photosynthetic acclimation to high temperature than C₃ plants (e.g., Oberhuber and Edwards 1993; Kubien and Sage 2004; Osborne et al. 2008). Interestingly, even within C₃ plants, interspecific differences in temperature acclimation of photosynthesis have been observed. For example, the inherent ability for temperature acclimation of photosynthesis appears to differ between temperate evergreen species and tropical evergreen species (Cunningham and Read 2002), between cold sensitive species and cold tolerant species (Yamori et al. 2010b), and even among ecotypes of the same species, depending on their original habitats (Slatyer 1977). However, Campbell et al. (2007) found no difference in the level of temperature acclimation of photosynthesis among grasses, forbs, and woody plants. Thus, there is a discrepancy between studies in the inherent ability for photosynthetic temperature acclimation between groups, and we need to understand this phenomenon to predict how changing temperatures will alter plant photosynthetic responses.

It is now possible to analyze what process limits photosynthesis at various environmental conditions, based on well-tested models of photosynthesis (von Caemmerer 2000). Moreover, developments of molecular biology and transgenic technology have provided a set of powerful tools to identify and then modify the limitations imposed on photosynthesis by the environment. Thus, we then consider the underlying physiological and biochemical mechanisms for temperature acclimation

of photosynthesis and discuss what process would be the limiting step of photosynthetic rate at various temperatures. Less research on photosynthetic temperature responses has been done on CAM plants than C3 and C4 plants and differences in the temperature response of photosynthesis between day and night have not been clarified in CAM plants with diurnal photosynthetic patterns, although day and night temperatures vary considerably in deserts where many CAM plants are found.

Adaptation of C3 and C4 species to climate change

Climate change affects plants in many different ways. Increasing CO₂ concentration can increase photosynthetic rates. This is especially pronounced for C3 plants, at high temperatures and under water-limited conditions. Increasing temperature also affects photosynthesis, but plants have a considerable ability to adapt to their growth conditions and can function even at extremely high temperatures, provided adequate water is available. Temperature optima differ between species and growth conditions, and are higher in elevated atmospheric CO₂. With increasing temperature, vapour pressure deficits of the air may increase, with a concomitant increase in the transpiration rate from plant canopies. However, if stomata close in response to increasing CO₂ concentration, or if there is a reduction in the diurnal temperature range, then transpiration rates may even decrease. Soil organic matter decomposition rates are likely to be stimulated by higher temperatures, so that nutrients can be more readily mineralised and made available to plants. This is likely to increase photosynthetic carbon gain in nutrient-limited systems. All the factors listed above interact strongly so that, for different combinations of increases in temperature and CO₂ concentration, and for systems in different climatic regions and primarily affected by water or nutrient limitations, photosynthesis must be expected to respond differently to the same climatic changes.

It is well-established that the physiological advantages, conferred by the higher photosynthetic efficiency of C4, relative to C3, photosynthesis under high light and temperature, are crucial for the ecological dominance of C4 plants in open, hot and arid environments (Osmond et al., 1982; Long, 1999). In particular, the presence of a CO₂ concentrating mechanism in C4 leaves endows them with higher WUE than their C3 counterparts when compared under standard conditions (Osmond et al., 1982; Long, 1999). However, it remains questionable whether the higher WUE of C4, compared with C3, plants leads to greater tolerance to water stress. Although the C4 CO₂-concentrating mechanism offers C4 photosynthesis a greater buffering capacity against CO₂ shortages brought about by partial stomatal closure under water stress, the biochemistry of C4 photosynthesis is as or even more sensitive than that of C3 photosynthesis. The reasons are not clear. However, a greater sensitivity of the C3, relative to the C4, cycle emerges as a probable site of metabolic limitation under water stress.

Conclusion and future work

The earth's climate is predicted to be warm by an average of 1.1–6.4 °C during the next century as a result of the increased greenhouse gases in the atmosphere. High leaf temperatures can reduce plant growth and limit crop yields, with estimates of up to a 17 % decrease in yield per 1.0 °C increase in average growing season temperature (Lobell and Asner 2003). It has been argued that a new “green revolution” is needed in world agriculture to increase crop yields for food demands (Fischer and Edmeades 2010), and enhancing photosynthesis is a promising approach for increasing crop yield. However, to reach this goal, we must understand what process limits photosynthesis under a range of growth conditions, and how well photosynthesis can acclimate to predicted changes in temperature. There was a clear difference in the ability to acclimate photosynthesis to increases in growth temperature between species from differing photosynthetic pathways. C4 species had higher optimum temperatures of photosynthesis, but a reduced ability to acclimate the temperature optimum of photosynthesis to growth temperature, than C3 species, while C3 species tended to maintain the

same photosynthetic rate at their growth condition across a range of growth temperatures than C4 species. It was also found that, within C3 species, evergreen woody plants and perennial herbaceous plants showed greater temperature homeostasis of photosynthesis than deciduous woody plants and annual herbaceous plants. In addition, It was also claimed that CAM plants, the temperature response of CO₂ fixation at night was much different from that of chloroplast electron transport in the day, and that both CO₂ fixation rates and electron transport rates acclimated to shifts in growth temperatures. This could be considered to be an adaptive response since CAM plants from desert environments can experience a drastic alteration in day and night temperatures during a 24-h period. Advances in plant transformation technology now make it possible to manipulate photosynthesis by overexpressing particular genes for alleviating bottleneck steps of photosynthesis. Thus, understanding the mechanisms of temperature acclimation of photosynthesis via comparisons of species differences and/or changes in growth temperature is of immense importance for identifying a biomolecular target for enhancing leaf photosynthesis. What would be a useful biomolecular target for enhancing leaf photosynthesis? There is no single answer, since the limiting step of photosynthesis differs depending on plants species, and also differs depending on growth and measurement temperatures even in a single plant species (Yamori et al. 2010b). Therefore, the impact on the control of carbon fixation by manipulation of one enzyme would differ depending on the plant species and growth conditions. More attention should be paid to studying differences in the photosynthetic limiting step depending on species and growth conditions, as this might provide opportunities for achieving faster improvements in crop production.

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19. Eddy Covariance Systems: Advanced Technology for GHGs Flux Measurement

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Introduction

Eddy Covariance is a micrometeorological technique to measure vertical turbulent flux of water, carbon dioxide, heat, methane, ozone, nitrate and volatile organic components in the atmospheric boundary layer. The eddy covariance (also known eddy flux) technique provides a direct measure of the turbulent flux of a scalar across horizontal wind streamlines (Paw et al. 2000). It is a statistical method used in meteorology and other applications that analyzes high-frequency wind and scalar atmospheric data series, and yields values of fluxes of these properties.

Purpose and application of Eddy-Covariance Fluxes

Long-term measurements of CO₂ flux have been carried out in various ecosystems in the world, especially in forest ecosystems as they are believed to be the most influential terrestrial ecosystems in the global CO₂ budget (Saigusa et al., 2002; Carrara et al., 2003). On the other hand, non-forest ecosystems viz. grasslands, wetlands and agricultural fields have also been observed because they contribute to regional and global CO₂ budgets (Saito et al., 2005; Tsai et al., 2006). The EC technique is widely employed as the standard micrometeorological method to monitor fluxes of CO₂, water vapour and heat, which are bases to determine CO₂ and heat balances of land surfaces (Fig. 1) (Aubinet et al., 2000). The EC technique has become the most important method for measuring trace gas exchange between terrestrial ecosystems and the atmosphere (Baldocchi, 2003; Smith et al., 2010). The direct, continuous measurement of carbon, water and energy fluxes between vegetated canopies or biosphere and the atmosphere can be obtained with minimal disturbance to the vegetation using this sophisticated research tool. It can represent a large area of land at the ecosystem than the typical plot area (Papale et al., 2006; Desai et al., 2008; Lalrammawia et al., 2010) for a short period or even for several years. It has become the backbone for bottom up estimates of continental carbon balance from hourly to inter annual time scales (Papale and Valentini, 2002; Reichstein et al., 2005).

The EC technique is based on high frequency (10-20 Hz) measurements of wind speed and direction as well as CO₂ and H₂O concentrations at a point over the canopy using a three-axis sonic anemometer and a fast response infrared gas analyzer (Aubinet et al., 2003). Assuming perfect turbulent mixing, these measurements are typically integrated over periods of half an hour building the basis to calculate carbon and water balances from daily to annual time scales (Papale et al., 2006). Apart from three-axis sonic anemometer and fast response infra-red gas analyzer several other sensors are attached to the EC unit for measurement of some auxiliary parameters namely, relative humidity, air temperature, incoming radiation, net radiation, photosynthetic photon flux density, photosynthetically active radiation, precipitation, soil temperature, soil moisture, soil heat flux etc. EC flux towers are currently operational worldwide covering different climate conditions; land use and land cover (Baldocchi et al., 2001).

In Asia, EC flux measurements were conducted in Japan (Miyata et al., 2000; Miyata et al., 2005; Saito et al., 2005), Korea (Moon et al., 2003), India (Bhattacharyya et al., 2013); Bangladesh (Hossen et al., 2007; Hossen et al., 2011), the Philippines (Alberto et al., 2009), Thailand (Pakoktom

et al., 2009), China (XiuE et al., 2007; Hossen et al., 2010) and Taiwan (Tseng et al., 2010) to monitor seasonal, annual and or inter-annual variations in CO₂ fluxes in rice fields. In rice paddy ecosystems it can be employed to measure net ecosystem CO₂ exchange (NEE) or net ecosystem production (NEP). The technique uses the covariance between rapid fluctuations in vertical wind speed measured with a three-dimensional ultrasonic anemometer and simultaneous measurements of the rapid fluctuations in the CO₂ concentration as measured by a fast-response infrared gas analyzer (IRGA). A positive covariance between vertical fluctuations and the CO₂ mixing ratio indicates the net CO₂ transfer into the atmosphere from plant-soil system and a negative value indicates net CO₂ absorption by the vegetation (Moncrieff et al., 1997).

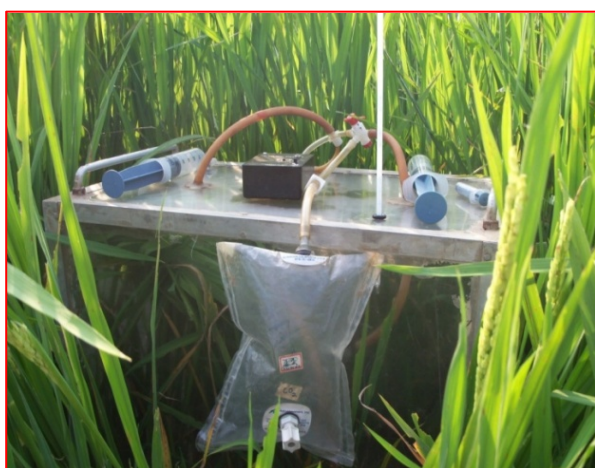
NEE is measured continuously by EC technique applying proper correction terms and gap-filling, if required. NEE is further partitioned into gross primary production (GPP) and ecosystem respiration (RE). RE is extrapolated from night time fluxes to daytime by using temperature response functions and afterwards GPP is calculated by subtracting RE from NEE (Smith et al., 2010).

Thus EC system continuously monitors and stores half-hourly and hourly CO₂ flux (NEE) data, using which carbon footprint analysis of specific ecosystem can be characterized precisely. As because plants exchange most of their carbon as CO₂, eddy flux-derived NEP is an ideal variable for C budgeting from local to regional scales. However, over time, net C fluxes are good proxies for ecosystem total biomass stock change (Baldocchi, 2003). The flux networks use eddy covariance-based measurement system for assessing regional sectoral carbon budgets. There are hundreds of eddy covariance towers monitoring continuously and organized in global network including forests, grasslands and croplands (Smith et al., 2010).

Green House Gases measurement

How it is better than existing ones:

The methods that are generally employed to measure GHG emissions from soil are closed-chamber method, open-chamber method, and micrometeorological method or the eddy covariance technique. Eddy covariance (EC) is the preferable technique for flux measurements since it is the only direct flux determination method.



Comparison Between Eddy Covariance flux monitoring system and Closed Chamber method at CRRI, Cuttack

Closed chambers

Discontinuous measurements (-)
Limited area (-)
Small information on short-term
variation of fluxes (-)
√ Detect low fluxes

Eddy covariance

√Continuous measurements
√larger area coverage in particular
ecology
√Information on short-term variation of
fluxes

Advantages of eddy covariance

- In-situ measurements over the area of interest
- Non-invasive sampling causing no disturbance to the area over which fluxes are measured
- Reliable, verifiable and defensible values of gas exchange or emission rates
- Automated measurement system providing continuous coverage with little intervention

Principle

Eddy covariance requires measurements of 3-dimensional wind speed and gas concentration. High speed, high precision instruments are critical for rapid measurement of small changes in the air samples to accurately determine the flux. Air flow can be imagined as a horizontal flow of numerous rotating eddies, that is, turbulent vortices of various sizes, with each eddy having horizontal and vertical components. The situation looks chaotic, but vertical movement of the components can be measured from the tower.

Eddy covariance systems

A typical eddy covariance installation includes a CO₂/H₂O gas analyzer, 3-dimensional sonic anemometer, data storage unit, and power supply. With the recent development of a low power, high precision CH₄ analyzer, we can now integrate methane measurements into their eddy covariance stations. In addition to high speed (>10 Hz), high precision instruments required by the eddy covariance system, it is also important that the system is flexible and allows easy integration of additional sensors when needed.

The eddy covariance method relies on the combined measurements of gas, temperature and wind speed data to compute flux rates. When selecting instrumentation for eddy covariance research, one critical decision is whether to use an open path or closed path analyzer. Open and closed path instruments each possess certain advantages and disadvantages. For example, open path analyzers have lower power requirements than closed path analyzers, but closed path analyzers are less prone to interruptions caused by rainfall.

CO₂/H₂O analyzer

Water vapor and carbon dioxide are the two most important greenhouse gases affecting global climate change. Fluxes of both of these gases can be measured directly, in a verifiable and defensible manner, using the eddy covariance method. Carbon dioxide flux measurements are required to assess carbon exchange and carbon emission rates, and to construct carbon budgets over natural, agricultural and urban ecosystems, as well as over industrial areas such as sequestration lands, landfills, feedlots, etc. These data could also be used to refine models of the global carbon cycle, to estimate carbon credits or footprints, or to verify compliance with regulations for carbon emissions.

Water vapor flux measurements are critical for a number of applications in precision agriculture such as water management, irrigation, and hydrological applications, agricultural and climate modeling, remote sensing verification, and. Water vapor is also important for computing eddy covariance fluxes of other atmospheric gases because it affects the measured densities of the gases, such as CO₂ and CH₄. Calibration of the analyzer is done every 6 months against a dew point generator for water vapor and a standard gas for CO₂. Span values of two consecutive calibrations usually differ by less than 3%.

Open path CH₄ analyzer

Methane is recognized as the third most important greenhouse gas, after H₂O and CO₂. In 2010, a low power open path CH₄ analyzer made it possible to measure methane fluxes in regions not serviced by grid power. This solved the problem presented by older analyzers, which often require grid power to supply energy to demanding vacuum pumps and temperature control systems. The use of such devices is geographically restricted, and in many remote regions methane dynamics are still not understood nearly as well as those of CO₂ and H₂O.

Especially understudied are important methane-producing areas such as permafrost regions, rice fields, animal facilities, and landfills. Widespread methane flux measurements are now possible and urgently needed in order to understand sources and sinks of atmospheric methane around the globe. A low power, high speed, high precision, self-cleaning methane analyzer is a great addition to an eddy covariance tower.

Sonic anemometer

Vertical wind speed is a critical component of the eddy covariance method. When computing fluxes, the vertical wind speed indicates the direction and the transport rate of energy, carbon dioxide, or other gases into or out of the ecosystem. In addition, the sonic anemometer measures air temperature, an important variable for flux computation (Fig. 3.).

Data storage

Eddy covariance instruments generate large amounts of data. LI-COR provides an analyzer interface unit that outputs data over the Ethernet, and also can store long-term data to a removable industrial-grade USB drive.

Power supply

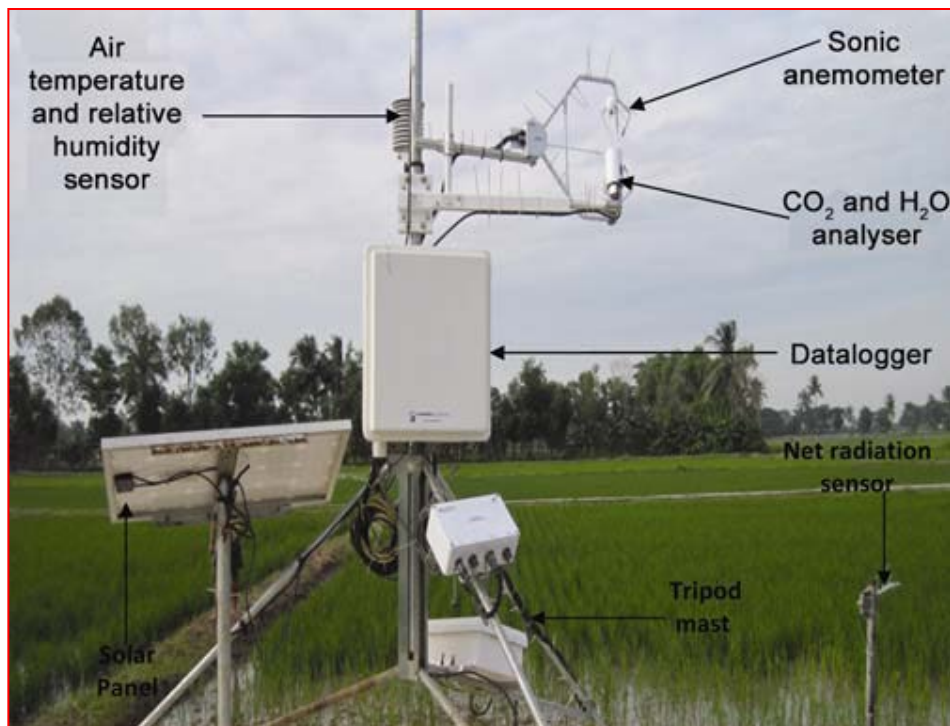
The electrical grid does not extend into most natural and agricultural environments. Instead, small photovoltaic power systems are often used to power eddy covariance systems. A well-designed photovoltaic power system can deliver continuous power to an eddy covariance system, even in cloudy regions.

Additional sensors

Some eddy covariance systems may use additional sensors to provide supporting meteorological data. These sensors might include:

- Net Radiometer – to measure total incoming and outgoing radiation, used to evaluate the energy balance
- Soil Heat Flux Plates (at 3-4 different soil depths)
- Soil Temperature Sensors (at 3-4 different soil depths)

- Soil Moisture Sensors (at 3-4 different soil depths)
- Air Temperature and Relative Humidity Sensors
- Precipitation Sensors
- Quantum Sensor – to measure photosynthetically active radiation
- Data Logger – for studies that use many sensors, an additional data storage device may be required



Eddy Covariance flux tower in flooded rice fields at CRRI, Cuttack

Software and data collection

Eddy covariance instruments are typically configured through computer software. The software usually provides access to basic and advanced configuration options, as well as graphing of the live data stream. The software allows to:

- Configure sampling rate
- Configure auxiliary sensor inputs
 - Select variables to log
 - Set up data logging options

Each software having its own benefits depending on the requirements of the user, e.g. online versus off-line calculation of fluxes, graphical outputs, control tools etc. However, the calculation and correction procedures should not differ between software packages that published by process the same raw data time series with identical conceptual assumptions. Currently (2011) there are several software programs to process eddy covariance and derive quantities such as heat, momentum, and gaseous fluxes. Examples include EdiRe, EdiPro, ECPack, TSA, TK2, Alteddy, and EddySoft.

Data Files

Eddy covariance data sets are typically logged at 10 Hz (10 samples per second) in a regular ASCII text file format, which can be read in most spreadsheet applications. The design, implementation and process of eddy covariance flux tower are given in Fig. 5.

Flux Calculations

Processing eddy covariance data is accomplished using any of multiple flux computation applications. Computing fluxes includes checking data for errors or gaps, aligning data to account for time delays, and computing fluxes based on half-hour or one hour averaging intervals. The data acquisition, processing and archiving of eddy covariance flux tower are given in Fig 6. There are some major assumptions are the pre-requirement of the eddy covariance flux tower, which are following as:

- Measurements at a point can represent an upwind area
- Measurements are done inside the boundary layer of interest
- fluxes are measured only at area of interest
- Flux is fully turbulent – most of the net vertical transfer is done by eddies
- Terrain is horizontal and uniformed; average of fluctuations is zero; density fluctuations negligible; flow convergence & divergence negligible
- Instruments can detect very small changes at high frequency, ranging from minimum of 5 Hz and to 40 Hz for tower-based measurements

Limitations:

- It requires a continuum of high time resolution measurements (e.g. 5–20 Hz).
- The technique is mathematically complex, and requires significant care in setting up and processing data.
- These Flux towers provide information specific to a single ecosystem type or condition.
- Flux data are noisy, and this uncertainty is largely due to random measurement error.
- There are a number of situations where the EC method either could not be used to measure fluxes, or is not the best method to do so. These include environmental conditions with a very small area of study, predominantly low winds, complex terrain, point flux sources etc. Also, for some gases, such as ammonia and volatile compounds, the instrument system may not be sensitive enough to measure small changes at 10 or 20 Hz frequencies.
- The study area should be flat, homogeneous and it should represent the similar ecology
- It requires a number of assumption and correction and demands careful design, execution and processing that is fit to the specific purpose at the specific experimental site.

Evidence of anthropogenic climate change is now unequivocal and the largest imponderables in predicting and preparing for its future course lie in estimating future emissions and the dynamics of terrestrial sinks. At present, the vast amount of information on the mechanism of the land sink that is latent in the terrestrial flux tower can only be accessed with confidence, where the aerodynamic measurements can be reinforced with other data. In the other words, eddy covariance flux tower is the best techniques for measuring the flux of green house gases from the agricultural fields. To understand the processes and mechanisms of agricultural ecosystem, carbon and water cycle and energy balance eddy covariance is a promising technique.

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20. Crop Responses to the Elevated CO₂: Research and Technology - A South Asian Effort

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Introduction

Global climate changes are unique challenges to the agro-ecosystem. The exponential rise in the atmospheric CO₂ is an important global climate change which effectively influences the productivity of crop plants. This has been center of scientific and political debate in recent years after the Rio Earth Summit in 1992. Government of India and ICAR started impact assessment analysis of crop responses to the rising atmospheric CO₂ through an AP CESS fund project at IARI [Uprety and Abrol (1992) and subsequently by a National Fellow Project (Uprety, 1995)].

Innovative approaches for conducting long term experiments have been developed to investigate the impact of rising atmospheric CO₂ on crops (Uprety *et al.*, 1995 1996, 1998 & 2000). The characterization of the responses of crop plants to elevated CO₂ was done using open top chamber technology (Uprety *et al.*, 1995, 1996, 1998, & 2000). It is cost effective for meeting the requirements of field research on CO₂ enrichment and was considered the only realistic choice available for crop response studies to elevated CO₂ environment.

First South Asian PC based system of Free Air CO₂ Enrichment (FACE) technology in IARI fields was designed and developed to generate realistic biological crop response data (Uprety *et al.*, 2000; Uprety *et al.*, 2007a). Addition of these facilities has brought India GCTE research network which is acting in tackling vulnerable issue and adaptation strategies for meeting the rise in global food demand in the phase of global environmental change. This CO₂ enrichment technology was improved and made suitable to South Asian region. A network of CO₂ crop research of Nepal, Bangladesh, Sri Lanka, Pakistan and India was established and coordinated by Indian agricultural research Institute, New Delhi for multi country, multi disciplinary crop response studies.

Crop response studies, using OTC CO₂ enrichment technologies, demonstrated that elevated CO₂ significantly mitigated the adverse moisture stress effects on plant processes in *Brassica* species (Uprety *et al.*, 1995). Studies have also demonstrated the transfer of CO₂ responsive characters from one parent *Brassica campestris* to the hybrid *Brassica oxycamp* (Uprety *et al.*, 1998).

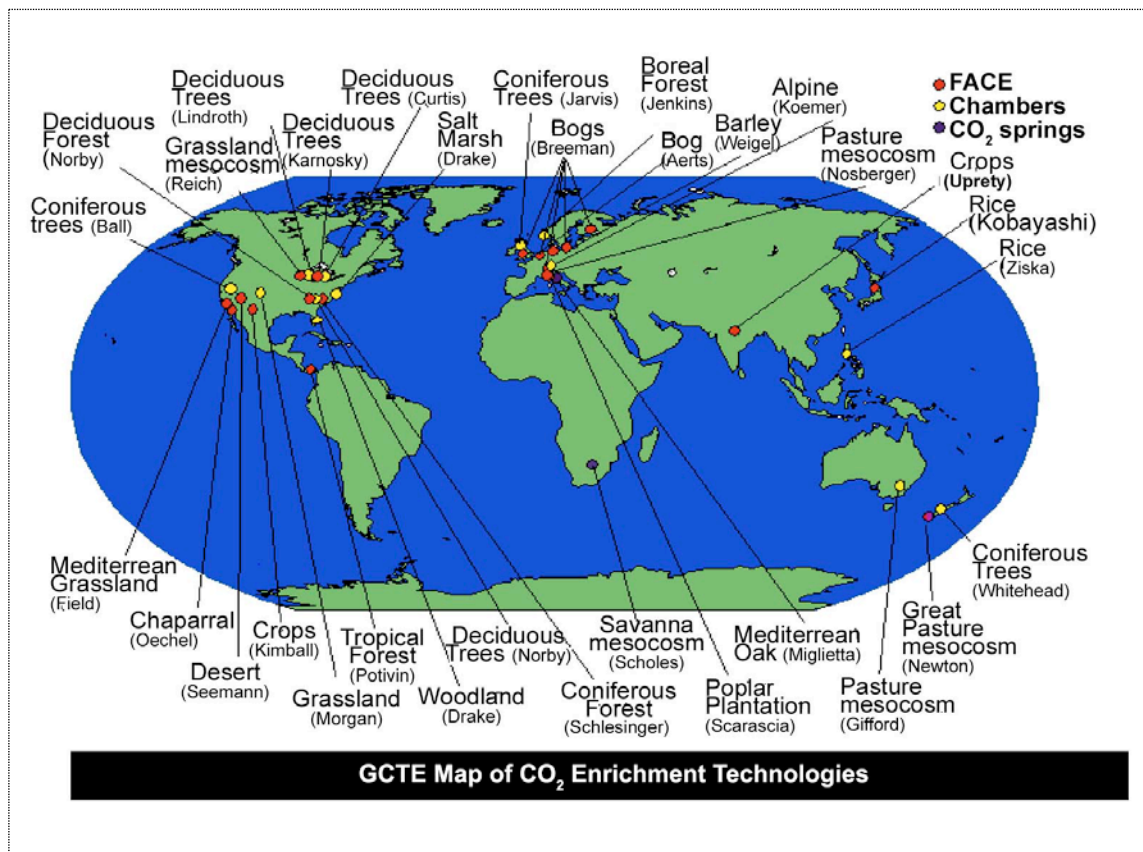
The comparative study between C₃ (mungbean) and C₄ (maize) species showed significant variability in their response to elevated CO₂ particularly in respect to physiological processes (Uprety *et al.*, 1996). Studies were done on C:N dynamics in *Brassica* species (Uprety & Rabha, 1999), micro analysis of photosynthetic parameters (Rabha & Uprety, 1998), changes in chemical composition of *Brassica* grains (Uprety *et al.*, 1997) and the interaction of elevated CO₂ and nitrogen nutrition (Uprety and Mahalaxmi, 2000). The outcome of these studies suggests various physiological, morphological, biochemical and anatomical adaptation strategies demonstrating how *Brassica* cultivars were able to ameliorate the adverse moisture stress effect under high CO₂ environment. Studies on rice cultivars using Phytotron facilities demonstrated the mitigation of high temperature effect due to elevated CO₂ (Uprety, 2005). Earlier studies on the responses of crop plants such as *Brassica* and rice cultivars to the elevated CO₂ showed significant variability in their responses (Uprety and Reddy, 2008). The variable responses of crop cultivars to the elevated CO₂ made the agricultural productivity and food security vulnerable, to the changed climatic conditions. Study was

done to understand the impact of elevating CO₂ on grain quality of *Brassica* species. A significant increase in oil content and changes in its fatty acid composition demonstrated a positive change in the quality of oil. Similarly, in the case of rice cultivars the grain structure, grain chemistry, nutritional and cooking quality were found to be considerably affected by the elevated CO₂ (Upreti & Reddy, 2008).

Open top Chamber



FACE Technology





Studies on the response of wheat species demonstrated (Upreti *et al.*, 2009) that the modern cultivars of *Triticum aestivum* hexaploid wheat were largely source limited. It appeared to have less assimilates than diploid wheat *Triticum monococcum*. While grain and leaf size increased with the ploidy level (Upreti *et al.*, 2010) from diploid to hexaploid wheat forms, the photosynthetic rate was reduced significantly. However, the larger leaf area and greater seed weight caused by elevated CO₂ had additive effect in improving the productivity of hexaploid wheat, whereas such a source sink balance was not present in diploid wheat. Studies also demonstrated that elevated CO₂ brought about significant changes on the grain structure (Sinha *et al.*, 2009) and grain chemistry of wheat species with variation on their response according to their ploidy level. The increasing CO₂ may present opportunities to breeders and possibly allow them to select for cultivars responsive to the elevated CO₂ with better sink potential (Upreti and Reddy, 2008). On the basis of the above study Upreti *et al.*, (2012) identified and described various greenhouse gas mitigation technologies. These newly developed technologies will help farmers, scientists, students and policy makers to identify strategies to counter the challenges of rising atmospheric CO₂.

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21. Analysis of Meteorological Variables for Understanding Climate Change/Variability and Planning of Adaptation Practices

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Introduction

Agriculture will face significant challenges in the 21st century, largely due to the need to increase global food supply under the declining availability of soil and water resources and increasing threats from climate change. There is concern about the impacts of climate change and its variability on agricultural production worldwide. Current research confirms that, while crops would respond positively to elevated CO₂ in the absence of climate change, the associated impacts of high temperatures, altered patterns of precipitation, and possibly increased frequency of extreme events, such as drought and floods, will likely combine to depress yields and increase production risks in many parts of the world. In nutshell, climate change introduces new dynamics and uncertainties into agricultural production and considerable uncertainty remains about the intensity, duration, magnitude and location of impacts. Hence, visualizing and anticipating the processes and impacts of climate change on agricultural production systems are very important for making appropriate policy decisions. Combinations of General Circulation Models, Regional Circulation Models, crop models, soil models, agro-ecological system models, and economic models are being used to illustrate potential impacts of climate change in the coming decades based on various climate scenarios (Olson et al., 2008; Hein et al., 2009; Thornton et al., 2010). In addition to the global/ regional models, agro-climatic analysis of a particular region can help in understanding the climatic characteristics and crop performance of the region and also to know the impact of climatic variability on its agriculture. This will facilitate thorough understanding of the climatic conditions, determining the suitable agricultural management practices for taking advantage of the favorable weather condition and avoiding or minimizing risks due to adverse weather conditions. This chapter deals with various models and analysis of meteorological variables which will help in understanding the climatic conditions of a region and in turn help in determining the suitable agricultural management practices to tide over the possible negative effects of climate change/variability.

Global circulation models

The climate system is global. Observations, theory, and models are all needed in climate research. Comprehensive climate models are based on physical laws and allow for numerical simulations. The climate system is characterized by a broad range of spatial scales and timescales. Consequently, Global Circulation Models (GCMs) can effectively address large-scale climate features such as the general circulation of the atmosphere and the ocean, and sub-continental patterns of, for example, temperature and precipitation (Rummukainen, 2010). Climate models have been demonstrated to reproduce observed features of recent climate and past climate changes. There is considerable confidence that GCMs provide credible quantitative estimates of future climate change, particularly at continental and larger scales (Randall et al., 2007). Confidence in these estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation).

Regional circulation models

The resolution (grid scale) of GCMs is at best around 100–200 km (Meehl et al., 2007). Their real resolution is more like 6–8 grid distances, i.e., of the order of 1000 km (Grotch and MacCracken, 1991). This falls short of many key regional and local climate aspects, e.g. intensive precipitation. Very high global model resolution would of course give rise to simulation of regional and local aspects (Mizuta et al., 2006). Global circulation models of this kind are, however, still not feasible due to their high computational cost.

Hence, Regional Circulation Models (RCMs) were developed with the concept of ‘downscaling’. Its purpose is to obtain regional or local detail from either sparse observations or low resolution numerical simulations. Regional models are sometimes called comprehensive, consistent, and physically based interpolator or, in more popular terms, a magnifying glass. This does not imply that RCMs are simple. Their description of climate processes is as complex as in comprehensive GCMs. Downscaling can in principle be applied to refine any data, regardless of its resolution. The two main downscaling methods are known as statistical and dynamical downscaling. The former involves finding robust statistical relationships between large scale climate variables (e.g., the mean sea level pressure field) and local ones (such as temperature or precipitation). There is a wealth of specific methods for this (Christensen et al., 2007). As already has been alluded to, dynamical downscaling by means of RCMs (Christensen et al., 2007) relies on the same physical–dynamical description of fundamental climate processes that is at the core of GCMs. There are two further approaches to dynamical downscaling. One of these is to use a high resolution atmospheric global model (Christensen et al., 2007). Another technique is a global model with a variable-resolution grid (Fox-Rabinovitz et al., 2008 and Lal et al., 2008). In this case, the computational grid is made dense over the region of interest, but left sparser elsewhere. These two approaches have their own strengths and weaknesses.

The primary assumption in regional modeling is that data on the climate large-scale information is used to force an RCM over a limited area. Such a regional domain, as compared to a global one, allows for high resolution without a prohibitive increase in computational cost. Driving data are supplied to the regional model as lateral (and often also sea surface) boundary conditions. The basic set of boundary conditions contains temperature, moisture, and circulation (winds), as well as sea surface temperature and sea ice. An accurate treatment of boundary conditions is a central issue in regional modeling.

Global and regional climate projections have been calculated as part of the IPCC process but also for national and international projects. The calculated time period covers more than 140 years ranging from e.g. 1960 to 2100. The results are not only available for climate research, but also for studies dealing with climate change impact. This is the first time that experts from other disciplines than climate research can use climate model information as input for impact models. The data records for simulations of present time (e.g. 1961 – 2000) and future (2001 – 2100) climate are very extensive. Statistical methods and evaluation procedures play a key role when dealing with large amounts of data. These methods can be different for questions related to groundwater and river management, heavy rain events or economic impacts. Furthermore, quality characteristics of results can be determined only through statistical analysis, e.g. significance or robustness tests. Another important topic is the analysis of extreme values, since they have a strong impact on economy and society but are difficult to analyze. A detailed account on various statistical methods available for the analysis of data from climate models, climate impact models and observational data was provided by Hennemuth et al (2013) in a report entitled “Statistical methods for the analysis of simulated and

observed climate data, applied in projects and institutions dealing with climate change impact and adaptation”.

The Inter-governmental Panel on Climate Change (IPCC) has projected the following changes in climate with respect to South Asian region (CDKN, 2014) as a whole using GCMs/ RCMs:

Temperature trends

Projections indicate that, compared to the average in the 20th century, average annual temperatures could rise by more than 2°C over land in most of South Asia by the mid-21st century and exceed 3°C, up to more than 6°C over high latitudes, by the late 21st century under a high-emissions scenario. Under a low-emissions scenario, average temperatures could rise by less than 2°C in the 21st century, except at higher latitudes, which could be up to 3°C warmer. Oceans in subtropical and tropical regions of Asia could warm under all emissions scenarios and would warm most at the surface. The frequency of hot days in South Asia is likely to increase further in the future (high confidence).

Rainfall trends

Projections indicate that more rainfall will be very likely at higher latitudes by the mid-21st century under a high-emissions scenario and over southern areas of Asia by the late 21st century. Under a low-emissions scenario, more rainfall at higher latitudes is likely by mid-century but substantial changes in rainfall patterns are not likely at low latitudes. More frequent and heavy rainfall days are projected over parts of South Asia (low confidence).

The future influence of climate change on tropical cyclones is likely to vary by region, but there is agreement between models that rainfall will likely be more extreme near the centres of tropical cyclones making landfall in South Asia. An increase in extreme rainfall events related to monsoons will be very likely in the region. More frequent and heavy rainfall days are projected over parts of South Asia (low confidence).

Analysis of meteorological variables at micro level

The importance of climate and weather assumes greater importance in rainfed regions where moisture regime during the cropping season is highly variable and is strongly dependent on the quantum and distribution of rainfall vis-à-vis the soil water holding capacity and water release characteristics. In addition, weather abnormalities such as cyclones, floods, droughts, hailstorms, frost, high winds and extreme temperatures will lead to natural disasters affecting agricultural productivity. A thorough understanding of the climatic conditions will help in devising suitable management practices for taking advantage of the favourable weather conditions and avoiding or minimizing risks due to adverse weather conditions. Different set of analysis are being used for analyzing the weather variables for different purposes. Some of those are listed hereunder:

S. No.	Name of the analysis	Purpose
1	Co-efficient of variation for RF	Variability of RF
2	Initial probability for RF	Dependability of RF
3	Conditional probability for RF	Predicting RF
4	Onset & with drawl of monsoon	Agricultural planning
5	Length of growing period	Selection of crops and designing of suitable cropping

		pattern
6	Return period	Identifying the frequency of quantum of RF occurrence
7	Markov-chain analysis	Probability of wet and dry spell weeks
8	Trend analysis of climatic parameters	Statistical testing for trend, change and randomness in Rainfall and other time series data
9	Extreme event analysis	To find out weather phenomena that are at the extremes of the historical distribution

Co-efficient of variation for RF

Indian agriculture continues to face rainfall variability. The main features of rainfall variability are its quantity and distribution during the cropping period. Co-efficient of variation (CV) is used to understand such behavior. Assessing the rainfall variability in terms of time and space enables for planning agricultural operations on a sustainable basis. There are several methods of variability analysis available and out of which estimation of co-efficient of variation is quite simple and more suited for agricultural purposes. This is because, there exists a strong relationship between CV and rainfall dependability. The greater the CV, the lesser is the dependability. Similarly, lower the rainfall, the greater the CV. The formula used in this method is $CV = (\text{Standard Deviation}/\text{Mean}) \times 100$

Initial and conditional probabilities

The concept of estimation of probabilities with respect to given amount of rainfall is extremely useful for planning agricultural operations. Two types of probabilities i.e., initial and conditional probabilities are commonly used for analyzing the rainfall in respect of planning agricultural operations. This is very important because all the agricultural operations especially under rainfed condition in a given area is dictated by rainfall events.

Initial probability

Initial probability indicates the minimum quantity of rainfall to be expected for a particular time series data. For computing the initial probability, the concerned time series rainfall data are arranged in descending order. The simple method used for computing initial probability is:

$$\text{Initial probability} = (\text{Sample size (n)} \times \text{Probability required in percentage (p)})/100$$

For example if 30 years rainfall data were taken for analyzing 50 per cent rainfall probability means, $IP = (30 \times 50)/100 = 15$. After arranging 30 years rainfall data of particular time series in descending order, identify the 15th number from the top and this would be 50 per cent probable rainfall amount.

Conditional probability

Chance of occurrence of particular quantity of rainfall for agricultural operations like sowing, weeding, etc.

$$\text{Conditional probability (Cp)} = ((\bar{x} - x) / \sigma)$$

where,

$\bar{x}$ = mean weekly rainfall

x = rainfall required

σ = standard deviation

Since the resultant value does not fall under normal distribution it has to be referred to 'Z' table and multiplied by 100 to find out the actual probability in percentage. If the percentage is >60, it can be accounted for planning.

Length of growing period

Length of Growing Period (LGP) is defined as the period in which the soil is able to provide the moisture requirement of the crops to meet its evapotranspiration. This means that if a plant is grown in an identified LGP, the probability of getting soil moisture stress is negligible. In other words, it is a potential period for reaping potential productivity under selected agro techniques. Many methods viz., Moisture Adequacy Index, Starting and Termination rain method, Rainfall stability period method, Hargreeves Moisture Availability Index Method, FAO model and Jeevananda Reddy method have been employed to identify LGP of a particular region.

In respect of starting and termination rain method, the date of onset and the date of withdrawal of seasonal rainfall are taken into account and the length of period between onset and termination will be taken as LGP. The main feature of Indian rainfall is spatial and temporal variability and as a result, intra seasonal variability is of a great importance. Hence in this method, the length of dry and wet spells within the growing period could not be brought out which again is a major limitation for agricultural planning. Using of probability of weekly rainfall for computing Moisture Availability Index (MAI) under Hargreeves method is varying between different rainfall situations (high rainfall areas, assured rainfall areas and scanty rainfall areas). Hence assessing the right probability for weekly rainfall would be an additional exercise for this method.

The FAO model was used by National Bureau of Soil Survey and Land Use Planning, Nagpur to compute LGP for classifying the Indian areas into different Agro Ecological Regions and Agro Ecological Zones. In this method, if the consecutive monthly rainfall is more than 50% of Potential Evapotranspiration of that month, then this sequence is taken as LGP. In addition, the stored soil moisture at the end of the season is accounted in computing LGP. The limitation of this method is handling of macro level data on monthly basis. The Jeevananda Reddy method uses weekly rainfall and weekly PET as inputs and by computing simple R/PET ratio and 14 weeks moving average, it calculates the LGP. For proper agricultural planning, any method that uses weekly data would be more relevant.

Markov-chain analysis

Agricultural operations are determined by the certain amount of rainfall received in a period. There are specific amounts of rainfall required for the activities like land preparation, sowing and for various agricultural activities. Hence, estimation of probabilities with respect to a given amount of rainfall is useful for rainfed agricultural planning especially in semiarid region. Initial probability rainfall analysis will give percentage probability to get certain amount of rainfall in a given week. Probability of wet week is denoted as P(W) and dry week as P(D). Conditional probability rainfall analysis will give the percentage probability for wet week followed by wet week [P(W/W)], wet week followed by dry week [P(W/D)], dry week followed by dry week [P(D/D)] and dry week followed by wet week [P(D/W)]. It is also important to find out percentage probability of consecutive wet weeks (2W, 3W, 4W) and consecutive dry weeks (2D, 3D, 4D). Several techniques are in use to work out wet and dry spells. The initial and conditional probabilities as per the first order Markov chain model is widely used world over to understand the crop growing seasons based on dry and wet spells.

Trend analysis of meteorological variables

IPCC reported that the impact of climate change is severe in lower latitudes, especially in seasonally dry and tropical regions, where crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger (medium confidence). Decreases in precipitation are predicted by more than 90% of climate model simulations by the end of the 21st century for the northern and southern sub-tropics. However, agricultural productivity can also be increased, costs reduced and impending crop shortfalls mitigated or avoided through the judicious use of information and knowledge about climate and weather, including early warning and agro meteorological advisories. Time series analysis of rainfall and other meteorological parameters helps in understanding the behavior of a particular weather parameter over time in that region.

TREND is software designed to facilitate statistical testing for trend, change and randomness in hydrological and other time series data. TREND has 12 statistical tests, based on the WMO/UNESCO Expert Workshop on Trend / Change Detection. The Trend software program can be downloaded from the TREND homepage www.toolkit.net.au/trend. TREND requires a continuous time series as input data in comma separated value file (.csv file). TREND displays as an output the value of the test statistic, the critical values of the test statistic at 0.01 (90 % significant level), 0.05 (95 % significant level) and 0.1 (90 % significant level), and a statement of the test result, for all the statistical tests selected by the user.

Extreme event analysis

The weather outlook is of great help to agriculture operations. Certain rainfall amount and temperature thresholds have a great influence on crop production. Advises are given to the agricultural community about extreme events like heavy rainfall and high and low temperature event would help to reduce losses to agriculture.

Goswami *et al* (2006) using a daily rainfall data set found (i) significant rising trends in the frequency and the magnitude of extreme rain events and (ii) a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000 and predicted a substantial increase in hazards related to heavy rain over central India in the future.

The frequency of droughts has varied over the decades in India. From 1899 to 1920, there were seven drought years. The incidence of drought came down between 1941 and 1965 when the country witnessed just three drought years. Again, during 1965-87, of the 21 years, 10 were drought years and the increased frequency was attributed to the El Nino Southern Oscillation (ENSO). Among the drought years, the 1987 drought was one of the worst droughts of 20th Century, with an overall rainfall deficiency of 19%. It affected 59-60% of the crop area and a population of 285 million. In 2002 too, the overall rainfall deficiency for the country as a whole was 19%. Over 300 million people spread over 18 states were affected by the drought in varying degrees. Food grains production registered the steepest fall of 29 million tonnes (Samra, 2004). The frequency of occurrence of drought in different meteorological sub-divisions of India is given in Table 1.

Table 1. Probability of occurrence of drought in different meteorological sub-divisions of India

Meteorological sub-division	Frequency of deficient rainfall (75% of normal or less)
Assam	Very rare (Once in 15 years)
West Bengal, Madhya Pradesh, Konkan, Bihar and Orissa	Once in 5 years
South interior, Karnataka, Eastern Uttar Pradesh & Vidarbha	Once in 4 years
Gujarat, East Rajasthan, Western Uttar Pradesh	Once in 3 years
Tamil Nadu, Jammu & Kashmir and Telengana	Once in 2.5 years
West Rajasthan	Once in 2 years

Standardized precipitation index

Standardized precipitation index can detect drought or wetness over different periods at multiple time scales and is produced by standardizing the probability of observed precipitation for any duration. The applicability of SPI varies with time scale because the 1-month SPI reflects short-term conditions and its application can be related closely to soil moisture; the 3-month SPI provides a seasonal estimation of precipitation (Ji & Peters 2003). SPI, calculated at different time scales, e.g. 1- or 3-month SPI of a particular month, represents the deviation in total precipitation amounts for the same month and current plus previous 2 months, respectively. Positive SPI values indicate greater than mean precipitation and negative SPI values indicate less than mean precipitation. If the 1-month SPI for August is -2.00 , then the precipitation is much less than normal and when it is $+1.00$, then the precipitation for the same month is substantially above normal. Using SPI thresholds, the dryness or wetness of a location is categorized into severely wet (>2.0), very wet (>1.5 to 2.0), moderately wet (>1.0 to 1.5), near normal (1.0 to -1.0), moderately dry (<-1.0 to -1.5), severely dry (<-1.5 to -2.0) and extremely dry (<-2.0).

Many studies have demonstrated that a 3-month SPI provides an indication of the seasonal anomaly in precipitation, and thereby, this index is considered as an agricultural drought indicator (McKee et al. 1993; Hayes et al. 1999; Patel et al. 2007). However, in the case of semi-aquatic crops like rice, which are grown in upland, shallow lowland and lowland situations during wet season, a dry period of 7–15 days could affect the yield due to moisture stress. Hence, a shorter time scale (1-month SPI) may capture drought events more precisely as an increase in SPI time scales decreases the frequency of dry periods (Patel et al. 2007; Raja et al., 2014).

To conclude, it is amply clear that the climate change affects all agricultural sectors in a multitude of ways that vary region by region, because it reduces the predictability of seasonal weather patterns and increases the frequency and intensity of extreme weather events such as floods, cyclones and heat waves. In order to reduce the impact of these climate-based risks on agriculture, there are some viable options other than the crop management practices such as crop insurance, market management, financial management, etc. that have been practiced in the developed parts of the world, and have recently been extended into Indian markets to benefit the farmers and their families. The various methods for assessing climate impacts in agriculture and evaluation of adaptation strategies have been refined over many years and widely used by scientists, extension services and resource managers and will continue to be a tool in developing possible adaptation strategies.

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NOTES

22. Climate Change and its Impact on Rice Insect Pests

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Introduction

Rice is one of the important staple foods for half of the world population particularly Asian countries for their livelihood, socio-economic and nutrition. Rice farming is practiced in several agro-ecological zones although most of the rice farming occurs in warm/cool humid subtropics, warm humid tropics and warm sub-humid tropics. Cutting across the agroecological zones, rice land ecosystems have been categorized into four distinct types occurred in India: irrigated rice ecosystem, rainfed lowland rice ecosystem, upland rice ecosystem, and flood-prone rice ecosystem. Global warming is predicted to increase frequency of precipitation/ rainfall, intensity of drought and solar-radiation/UV radiation which might affect the intensity and severity of rice pests in one hand, but also change in other friendly arthropods on the other hand.

Insects are major constraint to rice production. Most of the rice plant parts are vulnerable to insect feeding from the time of sowing till harvesting. Both the mature and immature stages of insects injure rice plants by chewing leaf and root tissues, boring and tunneling into stems, or sucking fluid sap from stems and grains. The injury from feeding leads to damage showing symptoms of skeletonized and defoliated leaves, dead hearts, whiteheads, stunted and wilted plants and unfilled grains. Ultimately insect damage affects the plant physiology leading to reduction in measurable yield, utility or economic return. Ecology-wise key insect pests of rice in India is listed in Table 1.

The average annual losses due to insect pests have been estimated to be 17.5% valued at US\$17.28 billion in eight major field crops (cotton, rice, maize, sugarcane, rapeseed-mustard, groundnut, pulses, coarse cereals, and wheat) (Dhaliwal et al. 2010). Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming. Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1°C by 2025, and 3°C by the end of the next century. The date at which an equivalent doubling of CO₂ will be attained is estimated to be between 2025 and 2070, depending on the level of greenhouse gasses emission (IPCC 1990).

Host-plant resistance, bio-pesticides, natural enemies, and synthetic chemicals are some of the potential options for integrated pest management. However, the relative efficacy of many of these pest control measures is likely to change as a result of global warming. Changes in precipitation are of greater importance for agriculture than temperature changes, especially in regions where lack of rainfall may be a limiting factor for crop production (Parry 1990). Global mean annual precipitation may increase as a result of intensification of the hydrological cycle (Rowntree 1990), which will cause disruption of agriculture as the cropping systems and the composition of fauna and flora will undergo a gradual change (Sutherst 1991). High mobility and rapid population growth will increase the extent of losses due to insect pests. Geographical distribution of insect pests confined to tropical and subtropical regions will extend to temperate regions along with a shift in the areas of production of their host plants, while distribution and relative abundance of some insect species vulnerable to high temperatures in the temperate regions may decrease as a result of global warming. These species may find suitable alternative habitats at greater latitudes. Many species may have their diapause

strategies disrupted as the linkages between temperature and moisture regimes, and the day length will be altered.

Table 1: Ecology-wise key insect pest of rice in India

S. No.	Rice Ecology/ Sub-ecology	Area mha Yield (t/ha)	Insect and mites pests
1.	Rainfed upland <i>a. Plain area upland</i> <i>(bunded & unbunded)</i> <i>b. Hill rice (High altitude Upland)</i>	6.0 (1.3) 5.0 (1.2) 1.0 (0.6)	Termites, GB, MLB, YSB PSB, RLF, WBPH, BSB, RH, White grubs, Black Beetles, GH
2.	Deep water (>50 cm)	4.0 (0.8)	YSB
3.	Semi-deep water (25-50 cm) Unfavourable	3.0 (1.0)	YSB, RCW, RH
4.	Shallow-rainfed lowland (0-25 cm) Favourable <i>a. Drought prone</i> <i>b. Lowland favourable</i> <i>c. Submergence prone</i>	10.0 (1.4) 4.0 (1.5) 3.0 (2.0) 3.0 (0.5)	YSB, GM, SwC, MLB, RPM, YSB, GM, BPH, WBPH, LFs, GLH, Hispa, YSB, LFs, RCW
5.	Coastal saline (coastal wetland)	1.0 (1.0)	YSB, PSB
6.	Irrigated rice (Non-scented/scented /hybrid rice)	20.3 (3.3) (Dry-3.5) (Wet-2.8)	SBs, GM, BPH, WBPH, GLH, GB, RLFs, Thrips, Mealybugs, RLM, RPM

Source: Prakash and Rao (2004)

YSB = Yellow stem borer GM = Gall midge BPH = Brown planthopper WBPH = White-backed planthopper, SBs = Stem borers PSB = Pink stem borer GLH = Green leafhopper GB = Gundhi bugs BSB = Brown shield bug RH = Rice hispa RLFs = Rice leafhoppers RCW = Rice caseworm MLB = Mealy bug RLM = Rice leaf mite RPM = Rice panicle mite GH = Grasshoppers, SwC = Swarming caterpillar

Genetic variation and multi-factor inheritance of innate recognition of environmental signals may mean that many insect species will have to adapt readily to such disruption (Sharma, 2010). Global warming and climate changes will result in:

- o Extension of geographical range of insect pests
- o Increased over-wintering and rapid population growth
- o Changes in insect – host plant interactions
- o Increased risk of invasion by migrant pests
- o Impact on arthropod diversity and extinction of species
- o Changes in synchrony between insect pests and their crop hosts
- o Introduction of alternative hosts as green bridges and
- o Reduced effectiveness of crop protection technologies.

Climate change will also result in increased problems with insect transmitted diseases. These changes will have major implications for crop protection and food security, particularly in the developing countries like India, where there is urgent needs to increase and sustain food production. Long-term monitoring of population levels and insect behavior, particularly in identifiably sensitive regions, may provide some of the first indications of a biological response to climate change. In addition, it will also be important to keep ahead of undesirable pest adaptations, and therefore, it is important to carefully consider global warming and climate change for planning research and development efforts for pest management and food security in future.

Climate change may influence the physiology, abundance, phenology and distribution of the insect pests (Dukes *et al.* 2009), and the major factors include temperature, CO₂ concentration, precipitation, natural enemies and their host plant (Chu and Chao 2000). The possible impacts of major climatic factors on rice insects are illustrated as followings.

Climate and rice insect pests

Modest progress has been made in understanding of insect pests in response to climate change. Oerke *et al.* (1995) estimate pre-harvest losses to pests in major food and cash crops to be 42% of global potential production. Luo *et al.* (1995) a direct yield gain caused by increased CO₂ could be partly offset by losses caused by phytophagous insects, pathogens, and weeds. Fifteen studies of crop plants showed consistent decreases in tissue nitrogen in high CO₂ treatments; the decreases were as much as 30%. This reduction in tissue quality resulted in increased feeding damage by pest species by as much as 80% (Coviella and Trumble, 1999).

In general, leaf chewers (Lepidoptera) tend to perform poorly (Boutaleb Joutei *et al.*, 2000), whereas suckers (aphids) tend to show large population increases (Bezemer and Jones, 1998) indicating that pest outbreaks may be less severe for some species but worse for others under high CO₂. It is important to consider these biotic constraints in studies on crop yield under climate change. Nearly all previous climate change studies excluded pests (Coakley *et al.*, 1999).

a. CO₂ effects

Generally, the impacts of CO₂ on insects are thought to be indirect from changes in their host plant. The majority of plants - particularly those in the C₃ category, which includes rice, respond to increased CO₂ levels by increasing productivity in the form of carbon fixation (Chu and Chao 2000). Increased productivity as a result of the direct fertilization effect of CO₂ leads to lower nitrogen concentrations as C:N ratios rise, and reduces the nutritive value to herbivores (Nicolas and Sillans 1989). A CO₂-induced reduction in host plant quality resulted in increased larval consumption rates in order to obtain adequate dietary nitrogen in generalist (Hunter 2001). In the majority of cases, increased feeding rates do not compensate fully for the reduced quality of the diet, resulting in poor performance, slowing insect development and increasing length of life stages which place them vulnerable to the attack by parasitoids (Coviella and Trumble 1999). However, the change in C:N ratio in the plant, phloem sap becomes more concentrated at higher temperatures, and thus acts as a richer source of amino acids for sap feeders. The concentration of a range of secondary plant compounds tends to increase under drought stress, leading to changes in the attraction of plants to insects (Harrington *et al.* 2001). The atmospheric environment in the future is predicted to include correlated increases in CO₂ concentration and temperature.

The impacts of climate change variables on insect pests presented a model by Newman (2004) using growth chambers, open-top chambers and free air carbon dioxide enrichment (FACE)

approaches *i.e.*, under optimal conditions elevated CO₂ was likely to promote cereal aphid (*Rhopalosiphum padi*) populations, while, this effect was negated by predicted increases in temperature. However, even though *R. padi* did not become more prevalent under simultaneously elevated CO₂ and temperature, Newman (2004) pointed out that the 10% earlier timing of population peaks and the 10% increase in winged forms could result in greater spread and incidence of barley yellow dwarf virus for which this aphid is a vector. While crop biomass is predicted to increase in response to elevated CO₂ concentrations under many circumstances, it is also recognized that crops and soils may subsequently become nutrient limited, especially in terms of nitrogen availability (Diaz et al., 1993).

b. Temperature effects

Insects are ecto-thermic organisms, the temperature of their body changes approximately with the temperature of their habitats. Therefore, temperature is probably the most important environmental factor influencing their behavior, distribution, development, survival and reproduction (Chu and Chao 2000). Depending on the development “strategy” of an insect species, temperature can exert different effects on it (Bale *et al.* 2002). For the insect pests that produce one generation annually or their development lasts several years, or the number of generations is limited by the photoperiod, most facts remain unchanged by climate change. For those species could breed two or more generations a year, they may gradually adapt to the new climatic conditions by shifting the temperature thresholds, effective temperature totals and critical photoperiod lengths without showing any appreciable changes in their development (Bale *et al.* 2002).

Yellow Stem Borer

In general, the duration of different stages of yellow stem borer under varying temperatures varied significantly. YSB took 8.1 mean days for hatching out into larvae at 30°C. However at higher temperature it was found to be decreased. In the same way larval and pupal period showed a decrement. There is a joint influence of rainfall, relative humidity, and mean minimum temperature on stem borer infestation (*Scirpophaga incertulas*). The percentage incidence of dead heart and of white ear heads are both correlated negatively with rainfall and minimum temperature, and positively with maximum temperature. The percentage of white ear head correlated negatively with relative humidity. Very frequently it is stated that certain climatic conditions are related to biological events such as changes in population size, but the evidence is often purely circumstantial.

Manikandan *et al* (2013) reported that the number of eggs laid by YSB increased at higher temperature. At 28.3°C, the YSB laid 143 eggs. But it was increased to 176.5 eggs at 36°C with a standard deviation of 6.6. Insect populations from environments with higher temperatures may have higher fecundity and shorter growth stage to increase fitness. It is reported that the incubation period of *Scirpophaga incertulas* decreases at higher temperature, beginning at 30°C and continuing up to 35°C. Egg hatching percentage of the YSB decreased at higher temperature and increased at lower temperature. The egg hatching percentage was high (90.6%) at 30.6°C followed by 28.3°C. In contrast, only 58.5 per cent of incubated eggs achieved emergence at 36.0°C. Development time taken by different stages of the YSB decreased considerably at higher temperature. The incubation period of YSB eggs was 8.5 days at 28.3°C, whereas it took only 5.75 days at 36°C. The development time taken by the four larval instars varied significantly with respect to the temperature.

Brown Plant Hopper

BPH took 6.7 mean days for hatching out into nymphs. However this period decreased significantly at higher temperature. Decreased developmental duration of instars observed at increasing temperatures might be connected with faster larval growth at these temperatures. Insects develops faster will oviposit early and hence the population will grow earlier than expected. The total life span at 38°C decreased significantly than at 30°C. Faster development rate of *N. lugens* was noticed at 38°C than 30°C.

Panicle mite

There have been increased infestations of panicle mite (*Steneotarsonemus spinki*) 80-120 days after planting; favourable temperature: 25-28°C) and leaf mite (*Oligonychus oryzae*) in states of West Bengal, Andhra Pradesh in recent times (Karmakar, 2008; Lakshmi *et al.*, 2008) leading to chaffy grains and losses in rice yields.

c. Precipitation

Many pest species favor the warm and humid environment. Both direct and indirect effects of moisture stress on crops make them more vulnerable to be damaged by pests, especially in the early stages of plant growth. There are fewer scientific studies on the effect of precipitation on insects. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains. A decrease in winter rainfall could result in reduced aphid developmental rates (Pons *et al.* 1993), because drought-stressed tillering cereals reduce the reproductive capacity of overwintering aphids (Pons and Tatchell 1995).

Natural enemy

Natural enemy and host insect populations may respond differently to the global warming. There will also be instances where warmer conditions will increase the effectiveness of many natural enemy species (Kiritani 2006) and/or increase the vulnerability of their prey (Thomson *et al.* 2010). In extreme conditions, higher abundance of insect pests may partly be due to lower activity of parasitoids (Hance *et al.* 2007) or to disturbed parasitoid-pest relationship and decreased controlling ability. Other studies suggested that higher temperatures will favor parasitoids rather than their hosts (Davis *et al.* 1998). For those insects and their parasitoids with lower developmental threshold (T_0), it seems that they could match very well and the relationship might not be affected dramatically under global warming (Chu and Chao, 2000).

However, parasitoids [*Anagrus incarnatus* Haliday and *Apanteles chilonis* (Munakata)] and predators (*C. lividipennis* Reuter), other than spiders (*Pardosa astrigera* (L. Koch) and *Tetragnatha vermiformis* Emerton) of rice insects, would breed two to three more generations a year. These facts imply that the extent of biological control of rice pests by natural enemies will increase in intensity under the global warming (Kiritani 1999).

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23. Basics of Elemental Analysis

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Boldly FORWARD

the Concern....

Element	Toxic Effects
Pb	Brain/ Kidney damage/Central Nervous system
Cd	Lung Cancer/ Stomach Irritation/Prostate
Cr	Cr +6 Carcinogenic in lungs/Dermatitis
As	Skin Damage/Carcinogenic/Chromosomes
Hg	Nervous Centre-Brain/Kidney/Fetuses
Mn	Paralysis/Convulsions
Ni	Nasal & Lung Cancers/Asthma
Al	Liver/Kidney Dysfunction, Alzheimer's/Parkinson's disease

Toxic Metals: A concern for Everybody

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Technical Centre: Basics of Elemental Analysis

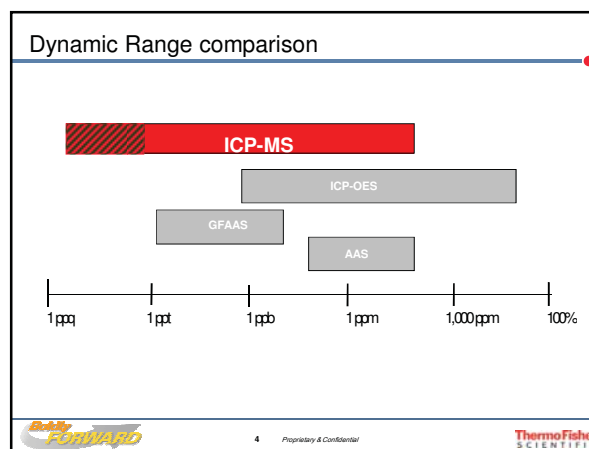
```

graph TD
    A[Metal Analysis] --> B[% Purity :  
Classical methods  
Gravimetric  
Volumetric etc]
    A --> C[Trace Level  
(<0.5%, ppm, ppb, ppt)  
Colourimetry  
AAS(Flame / Furnace)  
ICP/OES / ICP/MS]
  
```

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Technical Centre : Basics of Elemental Analysis

Samples / Matrices

- Solids :- Metals, Metal alloys, Food, Pharma, Textiles, Rubber, Specialty chemicals, Consumer products, Toys, Ayurvedic medicines, Environmental, -etc.
- Liquids : All types of water, Effluents, Oils, Petroleum Products, Pharma, Honey, Blood, Urine, Fruit juice, --etc.

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Technical Centre : Basics of Elemental Analysis

How the Samples should be !!!

- Homogeneous
- Representative of Bulk
- Free of suspended particles
- Free flowing
- Introduction in the form of droplets / fine spray
- Preferably Acidic
- Uniform Introduction of Standards / Samples

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Technical Centre : Basics of Elemental Analysis

Sample Preparation

- Solids : As Such : XRF, FTIR etc.

Extraction in solvent

Dissolution in Acidic water

Cold Digestion

Ashing / dissolution

Microwave Digestion (in Close System)



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Technical Centre : Basics of Elemental Analysis

Sample Preparation

Liquids :

As such

Dilution with Acidic Water / solvent

Extraction

Cold Digestion

Microwave Digestion



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BASIC PRINCIPLE

AAS, GFAA, ICP

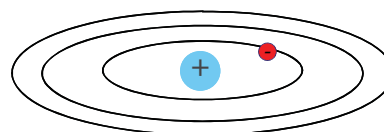


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Bohr Model of Hydrogen



Ground State Electron
Quantized Orbitals

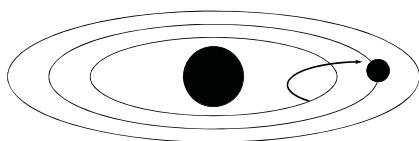


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Excitation of an Atom



- When electrons are excited, they move to a different orbit.
- Energy is needed to excite these electrons

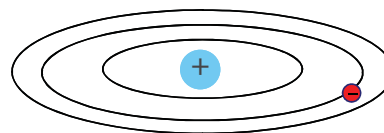


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Excitation



Quantum of energy is added
Energy Source

- ✧ Heat
- ✧ Energetic electrons and ions
- ✧ Light

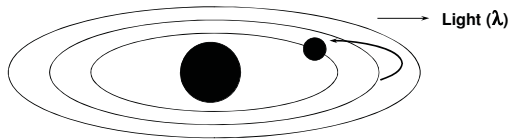


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Decay and Emission



- When the electron goes back into its normal orbit, light is emitted

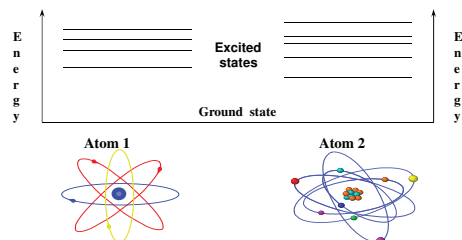
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Atomic spectroscopy theory



- Each atom has a unique set of energy states
- Atoms usually exist in their ground state
- Atoms may be raised to the excited states by applying energy

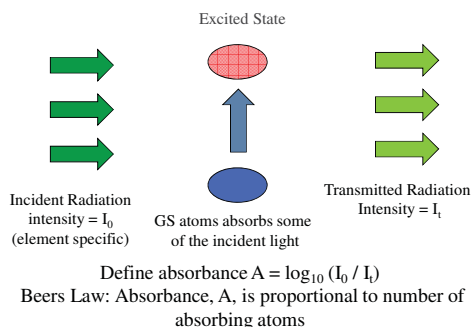
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Quantitative AA spectrometry



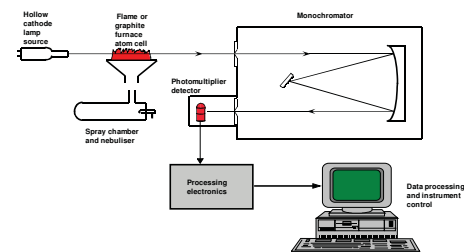
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Practical AA spectrometer



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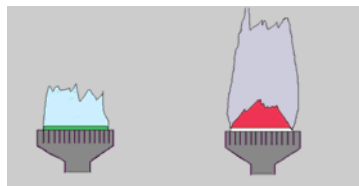
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AAS

Flame Types



Flame Type	Air/ Acetylene	Nitrous Oxide/ Acetylene
Flame Temperature	2450°C	3200°C
Fuel Flow Rate	0.8-2.3L/min	3.8-5.0L/min
Oxidant Flow Rate	5L/min @ 30psi	5L/min @ 40psi
Burner Size	50 or 100mm	50mm only

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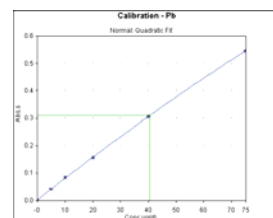
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Starting an Analysis

- A series of aqueous calibration standards are prepared.
- The instrumental operating conditions are then optimised for the particular analysis.
- The aqueous calibration standards are run under optimum conditions.
- Absorbance values are measured
- A calibration graph of concentration versus absorbance is plotted to establish the working range.



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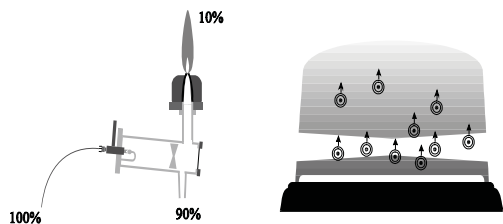
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Limits of Flame Sensitivity

- Atomiser Transport efficiency
- Only about 10% of sample contributes to the signal
- Sample Residence Time
- Typically 10^{-5} - 10^{-4} seconds, less than the lifetime of many atoms



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Principle of Graphite Furnace

- Flame is replaced by tubular graphite cuvette
- HCL radiation passes along the cuvette
- Sample is placed inside the cuvette
- Cuvette is heated to atomise the sample
- Atomic absorption signal measured as a transient peak

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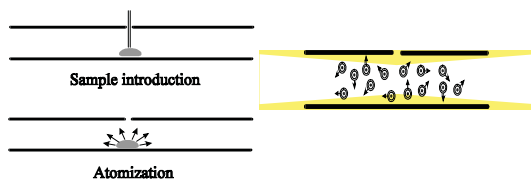
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Graphite Furnace Advantages

- Atomiser transport efficiency
- Virtually 100% of sample contributes.
- Residence time
- Atoms are confined by hot cuvette walls
- Residence times typically 10^{-3} - 10^{-2} seconds



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Graphite Furnace Sensitivity

- Sample volume required is a few microlitres
- Concentration sensitivity increased by 1000X relative to flame atomiser
- Mass sensitivity of the order of 10^{-12} g

	Lead	Copper	Arsenic
Flame	0.10 mg/l	0.04 mg/l	0.40 mg/l
Furnace	0.07 µg/l	0.09 µg/l	0.26 µg/l

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Cuvette Material Properties

- Stable to very high temperatures
- Mechanically strong and easily machined
- Chemically unreactive
- Non-porous
- Good electrical and thermal properties
- Available in very high purity state

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Food & Drink elemental measurements – what?

- Toxic metals
 - Pb, Cd, As, Hg, Al, Cr, Cu
 - Low PPM levels in original material
 - Recent interest in radio-nuclides Pu, Am and Np.
 - Cs-137, Cs-134, Sr-90 and K-40
- Nutrition elements
 - Ca, Mg, Na, K, P
 - %age to high PPM levels in original material
- Micro-nutrients
 - Zn, Se, Mo, etc...
 - high PPM to PPB levels in original material
- Process monitoring and control
 - Fe, other transition elements in frying oil
 - Ni in fat hydrogenation
 - Levels vary with process, typically 1000 – 10PPM

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Sample Excitation

- The steps are – nebulisation, evaporation, atomisation and ionisation

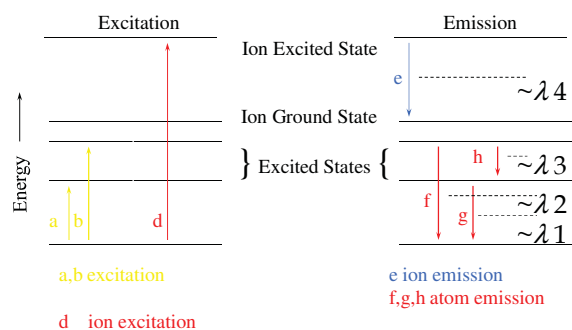


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Energy Level Diagram

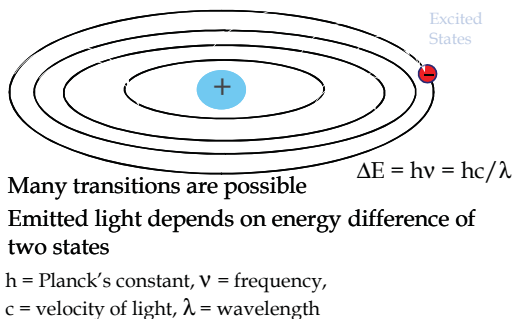


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Origins of Atomic Spectra



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Origins of Atomic Spectra

$$\Delta E = k/\lambda$$

$k = 12400$ when energies are in eV

Emitted wavelength is inversely proportional to the difference in energy levels, or the excitation potential required for that transition

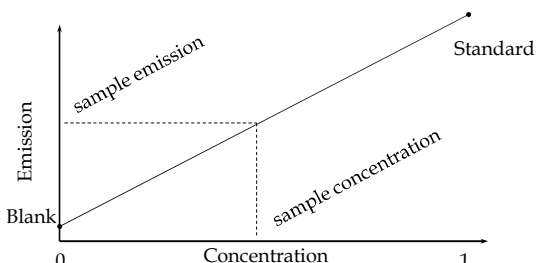
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Quantitation in Atomic Emission

- Concentration proportional to intensity emitted at the analyte wavelength.



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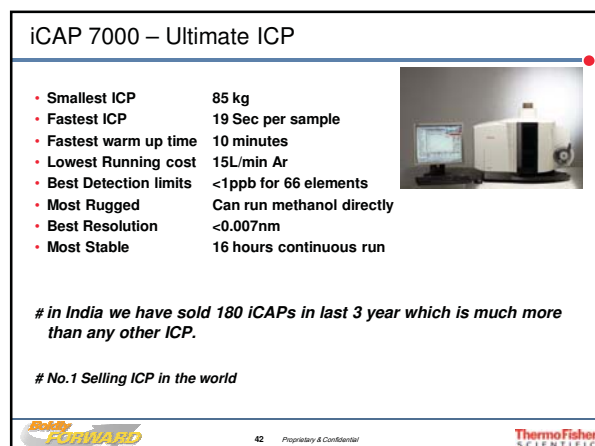
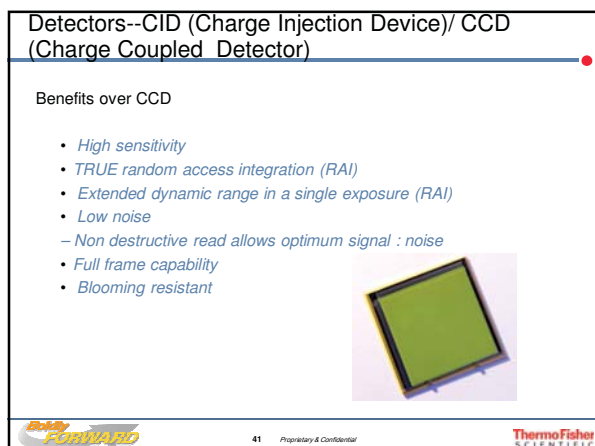
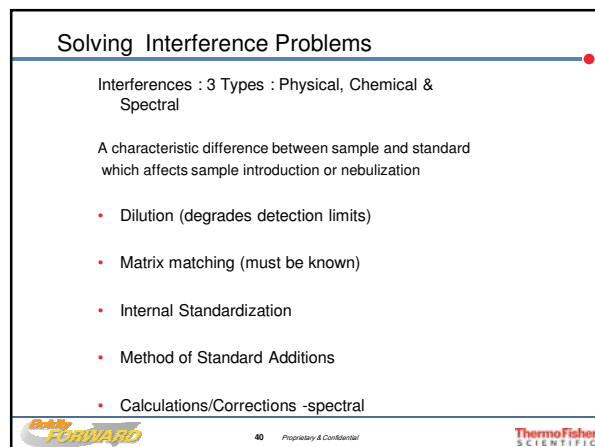
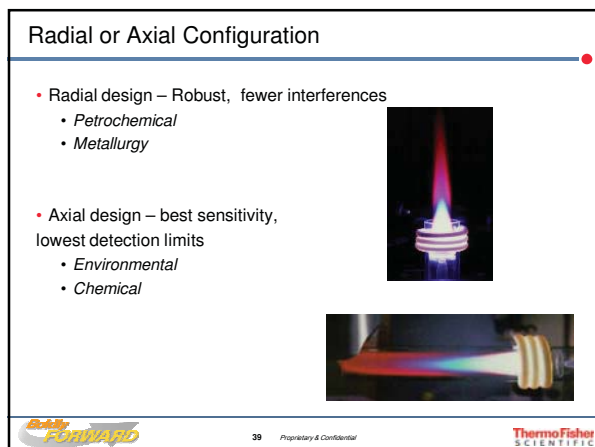
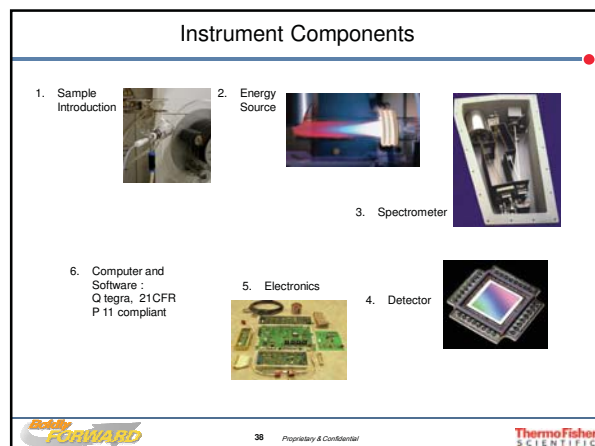
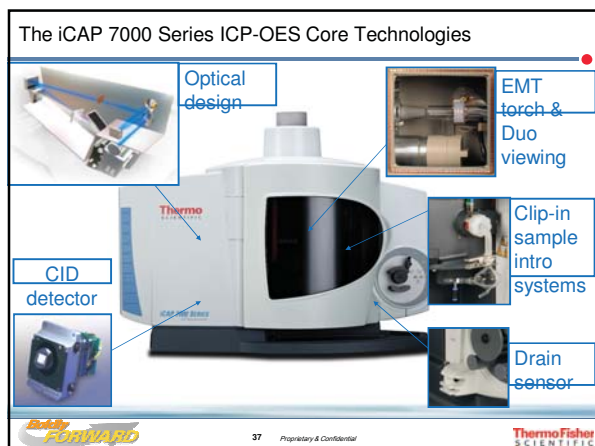
What is a Plasma?

- A plasma is a stream of highly ionized gas containing an equal number of electrons and positive ions
- A plasma is electrically conductive
- A plasma is affected by a magnetic field

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Thermo Scientific iCAP 7000 Series ICP-OES			
	iCAP 7200 ICP-OES	iCAP 7400 ICP-OES	iCAP 7600 ICP-OES
Plasma View	Duo	Radial or Duo	Radial or Duo
λ Range	175 – 847 nm	166 – 847 nm	166 – 847 nm
Gas Flow Controls	Pressure/Solenoid	Neb/MFC	Full MFC
Additional Gas	No	No	Yes as standard
Full Spectrum Capture	No	Fullframe	Fullframe
Spray Chamber/Neb	Aqueous (see 847) Others Available	Aqueous (see 847) Others Available	Aqueous (see 847) Others Available
Detector	CID96	CID96	CID96
Sample Pump	3-channel std per pump	4-channel mini pump	4-channel mini pump & Integrated Loop
RF Source	Pre-optimized 1150 W	1500W	1600W
Operating Gas Cons. (L/min)	14	16	16
Detection Capability	Standard iCAP – 1ppb	Standard iCAP – 1ppb	Standard iCAP – 1ppb
Software	Qtegra Basic	Qtegra Standard	Qtegra Enhanced
Method Templates (MT)	Enhanced set of MT	Enhanced set of MT	Enhanced set of MT

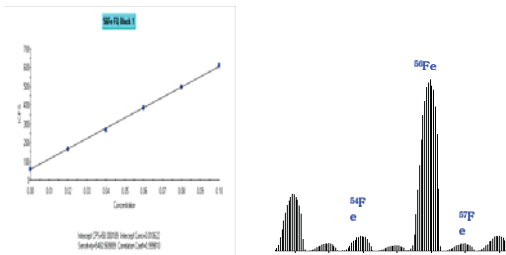
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Summary : ICP/OES : iCAP 7000 series	
• DL <1 ppb for most of the elements, & Less expensive in comparison	
• Unique CID detector & simultaneous detection	
• Argon consumption about 40 % less compare to competition	
• Warm up time is less than 15 minutes	
• Hydride generation is required for Hg, As etc.	
• Smallest in size & weight compare to competition.	
• Caters to the most of the needs of Pharma & Applied	

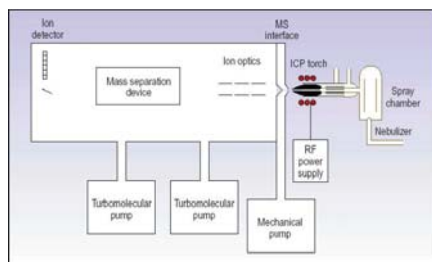
Basics of ICP/MS	
ICP/MS	
Thermo iCAP Q Series	

Basics of ICP/MS :- Definition	
It is a technique for the determination of	
• <u>Elements</u> using	
• <u>Mass Spectrometry</u> of	
• <u>Ions</u> generated by an	
• <u>Inductively Coupled Plasma</u>	
• Used for quantitative/qualitative <u>analysis of elements at mainly ppb, ppt levels.</u>	
• It is based on mass Spectra & hence complimetry for <u>structural illucidition & isotope ratios</u>	

Characteristics of ICP-MS	
• Elemental and isotopic information in a single analysis	
	

Thermo Scientific iCAP Q ICP-MS	
	

ICP-MS Basics



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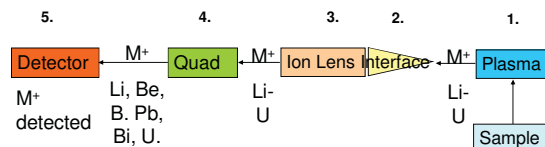
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The ICP-MS Technique

5 Basic Stages

1. Sample Introduction and Ion Generation
2. Ion Sampling (Ion Extraction)
3. Ion Focusing
4. Separation of Analyte Ions in Quadrupole Mass Filter
5. Ion Detection



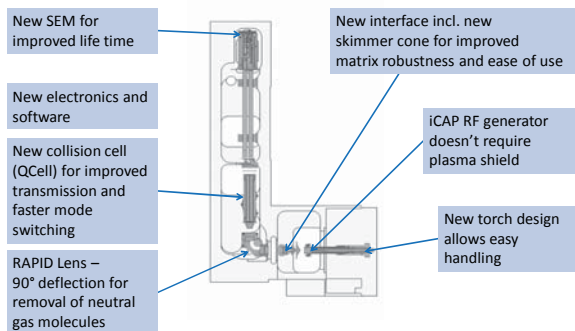
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iCAP Q - Overview



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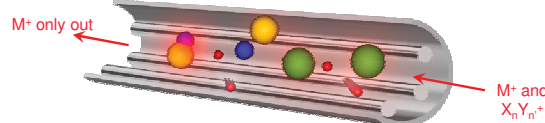
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iCAP Q Collision/Reaction Cell Technology

Collision/Reaction Cell Technology (CRC)

- A multipole enclosed in a cylinder
- Controlled flow of gas into the cell
- Interaction of ions with the gas
- If reactive gas used, reactions occur
 - All cells are reaction cells



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Interference Attenuation Processes

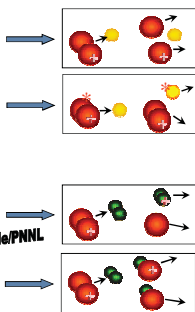
COLLISIONAL

- Collisional dissociation (least likely)
 - e.g. $ArAr^+ + He = Ar + Ar^+ + He$
- Collision retardation / energy filtering
 - e.g. $ArAr^+ + He = ArAr^+ + He$

REACTIVE

- Chemical reaction
 - e.g. $ArAr^+ + H_2 = ArH + ArH^+$
- Charge transfer
 - e.g. $ArAr^+ + H_2 = ArAr + H_2^+$

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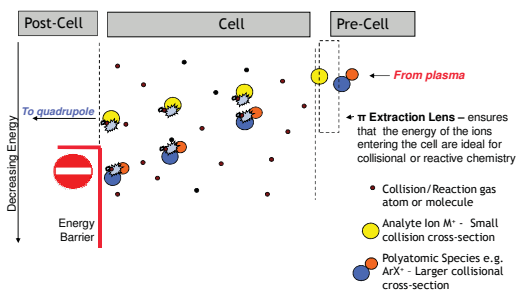
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KED Technology



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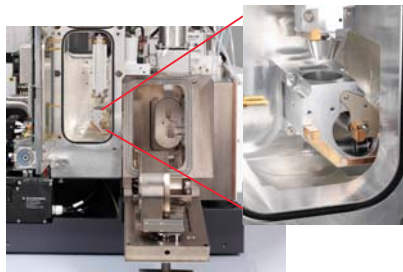
Dramatically Different Ion Focusing – RAPID Lens

Right Angle Positive Ion Deflection

- 90° Ion Deflection and Focusing done right
- Elimination of neutral species and photons

for
Highest Signal to Noise ratio of any

Quadrupole ICP MS



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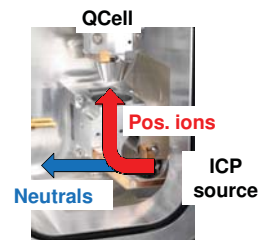
RAPID Lens – Simplicity and ion optics done right

- “Simple” design of 3 parts:

- Lens at entry and exit
- Deflection lens in between

- Simple operation due to single, fixed voltage

- Optimal ion deflection and focusing properties



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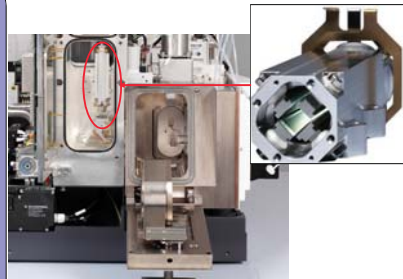
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Dramatically Different Interference Removal with QCell technology

New patented QCell with low mass cut-off

- Flatapole technology for improved transmission
- Non-consumable, zero-maintenance
- 50% smaller volume for faster mode switching, <10s
- Single mode interference removal with He
- Can also use reactive mode with O₂, H₂ or NH₃ mixes



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Dramatically Different Quadrupole Mass Analyser

Solid Molybdenum Quadrupole rods

Low abundance sensitivity
(< 0.5ppm at m-1 (m= 238U))

Class leading mass stability
(± 0.025 u / 8 h)

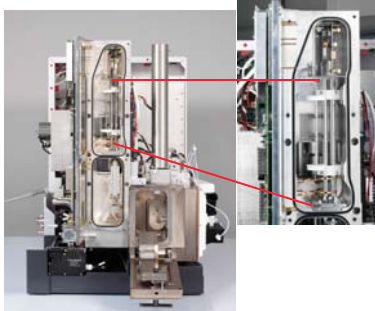
High Scan speed:

>90000 u/s (Li-U-Li in <5ms,
100µs at each mass)

Mass range: 4 - 290 u.

User definable resolution for improved dynamic range and improved abundance sensitivity

Mass calibration assessed and automatically updated when necessary through One Click Setup.



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New detector – ETP - Improved life time



- Gain of analog section decreased by change in dynode design
- Two more dynodes added to analog section (“more shoulders to carry the load”).
- Reduced current in analog mode
- Increased supply voltage range (1.5 kV more on analog, 0.5 kV more on counting).
- Voltage divider improved; overall resistance decreased for improved linearity

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Qtegra 21 CFR Part 11 Compliance Technical Note

Technical
Note: 43106

Thermo Scientific Qtegra ICP MS software
for 21 CFR Part 11 compliant labs

Introduction
Part 11 of Title 21 of the Code of Federal Regulations, Electronic Records, Electronic Signatures (21 CFR Part 11) includes the US federal guidelines for storage and protection of electronically stored data and the production of electronic signatures. These guidelines have been developed to ensure that electronic records are reliable, authentic, and non-repudiable.
This document examines all sections of the code and describes how the Thermo Scientific Qtegra software supports all 21 CFR Part 11 compliant environments. The new Qtegra software provides a wide range of features which enable laboratories to operate within total compliance.



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iCAP Qc Pharma Application Note

43100, KB#

Application Note: 43100

Multi-element determination in pharmaceutical preparations using the Thermo Scientific iCAP Q ICP-MS

Dr Simon Nims, Thermo Fisher Scientific, UK

Key Words

- iCAP Q
- Pharmaceutical preparations
- ICP-MS
- USP 232
- USP 233



pharmaceutical production must include robust means to maintain the integrity of the analysis method and results, allow audit tracing, and eliminate disparities as well as provide security features to ensure that alterations cannot be made without clear indication of what has been changed, who changed it and why.

Non-aqueous flow (or synthesis) of a new compound, ICP-MS, the Thermo Scientific iCAP Q, to the detection and quantification of the 14 target elements specified in USP 232 in accordance with the ICP-MS procedures described in USP 233. In order to comply with the requirements described above for 21 CFR Part 312 compliance, the Thermo Scientific iCAP Q provides robust audit of



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iCAP Q - Models

Product	iCAP Qa	iCAP Qc	iCAP Qs
			
Description	Routine 24/7 workhorse For laboratories upgrading from AA or ICP-OES. The entry level iCAP Qa ICP-MS provides multi-elemental analytical capabilities without the need to invest in collision cell technology.	High sensitivity cell mode performance Configured for high quality analyses in routine, high throughput laboratories such as those specializing in environmental analysis, oil analysis, food quality control and geochemical exploration.	Demanding applications made simple Equipped with an acid resistant sample introduction system and platinum tipped cones, the iCAP Qs is configured for high purity applications.



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Alternate Sample Introduction Systems

- Laser Ablation for **direct analysis of solid samples**
- LA-ICP-MS

- Chromatography for **speciation studies**
- LC-ICP-MS
- IC-ICP-MS
- GC-ICP-MS



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