CARBON SEQUESTRATION AND CROP WEATHER RELATIONS IN LONG TERM FERTILIZER EXPERIMENTS

By

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THESIS

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DECLARATION

I, hereby declare that the thesis entitled "**Carbon sequestration and crop weather relations in long term fertilizer experiment**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Carbon sequestration and crop weather relations in long term fertilizer experiment"** is a record of research work done independently by Ms. Sudhamani P. (2013-20-114) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship with any other person.

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DEDICATED TO MY LOVABLE PARENTS, BROTHER AND GUIDE THULASI MA'AM

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%	per cent
@	at the rate of
AESU	Agro Ecological Studies Unit
AEU	Agro Ecological Unit
AEZ	Agro Ecological Zone
AICRP	All India Co-ordinated Research Project
BD	Bulk density
C	Carbon
CD	Critical Difference
CERES	Crop Estimation through Resource and Environment Synthesis
CFC	Chloro Fluro Carbon
CH_4	Methane
CI	Carbon inputs
cm	centimetre
CO_2	Carbon Dioxide
d	thickness of the soil layer
DAP	Day After Planting
DOC	Dissolved Organic Carbon
DSSAT	Decision Support System for Agro-technology Transfer
et al	and co workers
etc	et cetera
Fig	Figure
FOM	Fresh Organic Matter

FYM	Farmyard Manure
g cm^{-3}	gram per centi meter cube
g kg^{-1}	gram per kilogram
g	gram
GDD	Growing Degree Days
GHG	Greenhouse gas
Gt C yr^{-1}	Giga tonne carbon per year
Gt	Giga tonne
H_2SO_4	Sulphuric acid
ha	hectare
ha^{-1}	per hectare
hrs	hours
IBSNAT	International Benchmark Sites Network for
IPCC	Intergovernmental Panel on Climate Change
$K_2Cr_2O_7$	Pottasium dichromate
K_2O	Pottasium oxide
KAU	Kerala Agricultural University
kg ha^{-1} year^{-1}	kilo gram hectare per year
km hr^{-1}	kilometer per hour
LTFE	Long Term Fertilizer Experiment
LUP	Land Use Planning
Mg ha^{-1} yr^{-1}	Mega gram hectare per year
mg L^{-1}	milligram per litter
Mg	Mega gram
mm	millimetre

MMT	Metric tonne
MSOC	Mass of Soil Organic Matter
Mt	Mega tonne
N	Nitrogen
N	Normality
n	Observed variable
N_2O	Nitrous oxide
NBSS	National Bureau of Soil Survey and Land
No.	Number
NPK	Nitrogen, Phosphorus and Potassium
NS	Non significant
NUE	Nutrient Use Efficiency
^oC	Degree Celsius
^oE	Degree East
Oi	observed value
^oN	Degree North
P_2O_5	Phosphorous pentoxide
pg	Pico gram
Pi	predicted value
POP	Package of practices recommendation
ppm V	Parts per million volume
RARS	Regional Agricultural Research Station
RBD	Randomized block design
RH	Relative humidity
RMSE	Root Mean Square Error

SAT	Semi-Arid Tropics
SEO	Sequestration
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSR	Sequestration rate
TOC	Total Organic Carbon
ton ha^{-1} $year^{-1}$	tonne per hectare per year
UNFCC	United Nations Framework on Climate Change
viz	namely
Wm^{-2}	Watt per square meter
WUE	Water Use Efficiency

INTRODUCTION

1. INTRODUCTION

Faced with the fact that anthropological activities are contributing to drastic global climate changes, the researchers in climate sciences are increasingly being primed to address the problems of global proportions. Accelerating changes in the earth's environment are being driven by the growth in human populace, increasing level of resource consumption and changes in the technologies as well as socio-political organizations. The well documented global changes affecting agriculture are the variations in land use and land cover, worldwide decline in biodiversity, changes in atmospheric composition of gases and climate.

Climate is unequivocal and also climate change is a very slow process. The Earth's climate has changed throughout history, naturally very small variations in earth's orbit that causes climate variability. One of the major driving forces for global climate change is the relatively rapid increase in the greenhouse gases (GHG) in the troposphere. Concerns are emerging nowadays about global climate change driven by increasing atmospheric contents of the GHGs, especially CO_2, the prime GHG with a contribution of 50 per cent to global warming.

Global warming is referred to as climate change. Many studies found that the average global temperature increases in the last decades. The main human influence has been the release of greenhouse gases especially carbon dioxide, methane, and nitrous oxide. These three GHGs have increased in atmosphere since industrialization. Latest studies documented that CO_2 concentration of atmosphere has increased from 280 ppm in 1750 to 367 ppm in 1999 and is currently increasing at the rate of 1.5 ppm per year. According to IPCC reduction of yields in tropical area due to temperature rise of 1– 2.5°C, thereby enhanced the risk of famine, spread of climate diseases and natural calamities. Climate change causes weather related mortality, infectious diseases and respiratory illnesses. In all cultivation practices, crop yields and irrigation demands are primary concern and are the most affected. In the case of water resources, water supply, quality and composition of water are affected.

Carbon dioxide is the most commonly produced GHG present in atmosphere and carbon sequestration is the method of capturing atmospheric CO_2 into the soil. It is long-term conversion of atmospheric carbon to soil carbon. Major potential for increasing soil carbon occur in restoration of degraded soils and adoption of different conservation practices. IPCC (2007) reported that about 1550 Pg of organic carbon contained in world's total soil which is more than twice the amount in the atmosphere.

Removal of carbon dioxide from atmosphere is achieved through carbon sequestration. Carbon sequestration is the removal of atmospheric carbon dioxide into the pools with a extended mean residence time in such a manner that it is not re-emitted to the atmosphere in near future. Soil is the largest pool of terrestrial organic carbon (C) in the biosphere, with additional carbon than that stored in plants and the atmosphere. The balance between the rate of soil organic C (TOC) inputs and the rate of mineralization in each of the organic C pools define the amount of organic C stored in various soil pools. Moreover, the type of soil, climate, management, mineral composition, topography, soil organisms, and other unidentified features are able to storing C in soil.

Managing soils to surge the mass of carbon deposited as soil organic matter (SOM) can be estimated to decrease the rate of increase in atmospheric CO_2. Consequential improvement in soil quality thus resulting is of additional benefit. Islam *et al.*, (1999) stated that the rise in atmospheric carbon dioxide could be increased net productivity of crops, sometimes which is reduced through soil *via* root growth and exudation. The only way to moderate the atmospheric carbon is through carbon sequestration. Therefore the possible feedback controls method for global warming by the balance of carbon from soil and atmosphere.

The impact of agricultural management practices on the sequestration of carbon in the context of climate change is not well documented. This was attempted in the long term fertilizer experiments at RARS Pattambi by studying the carbon sequestration pattern and by extrapolating the trends in yield to varying

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climatic scenarios using simulation modeling. Unpredictable weather events and climate conditions are always weakening agriculture. Several advanced technologies are adopted for increasing agricultural productivity such as improved varieties, management practice of irrigation and nutrients, timely available weather and climatic data.

Rice soils are known to hold greater quantities of resilient carbon compared to other ecosystem. Sahrawat (2005) reported that slower breakdown of organic matter and higher net productivity of submerged paddy soils lead to net carbon accumulation. This condition credentials the scientists to identify the eco-friendly system of rice cultivation to promote carbon sequestration thereby curtailing the global warming impacts.

All India Co-ordinated Project on Long term fertilizer experiment in rice have been laid out at Regional Agricultural Research Station, Pattambi with the main objective of studying the effect of continuous application of plant nutrients (NPK) in organic and inorganic forms and in combinations on sustainable production in the rice-rice cropping sequence. The determination of organizing long term fertilizer experiments at fixed sites in different agro ecological zones (AEZ) with important cropping systems was not only to monitor the changes in soil properties and yield responses but also to help in synthesizing the strategies and policies for rational use and management of fertilizers to improve soil quality and to minimize environmental degradation. The data exuding from such experiments explain the nutrient behavior in soils over years under seasonal influences and their residual accumulation in soils leading to reinforcement of soil fertility.

Here twelve treatments are combined with both organic and inorganic (N, P, K) fertilizers and a control. Long-term experiments are most cost-effective research method; it will be done by comprehensive and coordinated evaluation processes. Latest studies show that farmers get aware than previous years, so they have selecting good quality products. It is an intensive cropping and continuous fertilizer/manure application and also providing valuable evidence for sustainable agriculture.

Weather parameters have been influencing on plant's physiological process like respiration, transpiration and photosynthesis. Rice is the greatest affected crop by climate change and the climate relations in long term studies acquire great importance in this context. For studying the impact of climate change, the DSSAT is an advanced physiologically-based rice crop growth simulation model used to understand the relationship between crop and its environment.

Modeling can be used to predicting large ecosystem responses, sometimes which includes small scale greenhouse and laboratory incubation studies. The short term controlled environmental studies can be complemented using the model approaches in this regard. With these ideas in background the present work was undertaken with the following objectives:

1. Assessment of C sequestration pattern in long term fertilizer experiment (LTFE)
2. Estimation of the SOC sequestration efficiency of different nutrient management options
3. To analyze and establish crop weather relations in LTFE

This study will help in planning better and judicious nutrient management strategies for sustainable soil carbon and improved crop production.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The importance of long term fertilizer experiments in studying the effects of continuous cropping and fertilizer or manure application on sustenance of crop production is widely recognized. The All India Co-ordinated Research Project (AICRP) on Long Term Fertilizer Experiment has been laid out at Regional Agricultural Research Station, Pattambi and the data exuding from such experiments explain residual behavior in soil over years under seasonal influences. This study evaluates the SOC sequestration efficiency under long-term fertilization practices in lateritic soils with rice-rice cropping system. Furthermore, crop weather relations in rice are established by using available long term data using DSSAT. So this study will help in planning better and judicious carbon management strategies and recommendations for these soils for sustainable health and crop production.

The consulted literature relevant to the current study is reviewed under the following headings:

2.1 Climate change

2.2 Rise in atmospheric CO_2 and its climatic effects

2.3 Carbon sequestration

2.4 Carbon sequestration in rice soils

2.5 Climate change and Agriculture

2.6. Crop-weather relations in rice

2.7 DSSAT modeling

2.1 CLIMATE CHANGE

Climate change is the hardest reality faced by earth, it caused from natural or anthropogenic reasons. Human activities like burning of fossil fuel, industrialization, deforestation, desertification and agricultural operations will enhance the production of greenhouse gases like CO_2, CH_4, CFCs, SO_2 and N_2O. These greenhouse gases cause global warming (IPCC, 2014). IPCC, 2007 cleared

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that warming of the climate system is now unequivocal. The global annual mean temperature will increase by 1.1 to 6.4°C at the end of 21st century. The IPCC reports give comprehensive projections for the 21st century which reported that global warming will continue and accelerate. Latest studies have estimated that the Earth might warm by 3°C by the year 2100. Some large-scale climatic events occurred by impacts due to altered frequencies and intensities of extreme weather, climate and sea-level events (Meehl *et al.*, 2007). Resources like water, soil and environment like ecosystem and biodiversity are largely affected by climate change (UNFCCC, 2007). The impacts of climate change on various sectors of agriculture and agro-ecosystems are clearly visible (Polley *et al.*, 2000).

Adopting correct methods to decrease the negative effects of climate change and creating proper adjustments and changes to climate change are marked as climate change adaptation. But is it not easy there are many barriers, limits, and costs which may lead to a climate more vulnerable.

Global warming is one of the serious issues we are facing in present condition. Burning of fossil fuels, deforestation, and combustion of chemicals generate greenhouse gases. Clearly GHGs can trap outgoing long wave radiation thereby warming the atmosphere.

UNFCCC (2007) mentioned that temperature is the major reason for climate change. Impact of climate change are sudden rise of average global temperature, changes in cloud cover, unpredictable rainfall, melting ice caps and glaciers and rises in ocean temperatures and ocean acidity. There are harmful disasters like sea-level rise, increased frequency and intensity of wildfires, floods, drought, tropical storms, unpredictable rains, snowfall and runoff etc.

Quite a few studies propose that the terrestrial biosphere is eliminating large amounts of CO_2 from the atmosphere (Ciais *et al.*, 1995; Keeling *et al.*, 1996; Rayner *et al.*, 1999; Battle *et al.*, 2000; Schlesinger, 1984 and 1990), but the location of the stored carbon is a mystery. One conceivable place is in soil. Harrison and Butterfield (1996) stated that soil carbon and radiocarbon measurements are conducted for determining loss of atmospheric CO_2 and to be the origin is known as 'missing sink'. Thus soil carbon sequestration can be an alternative to mitigate greenhouse gas emission which has beneficial effect on soil fertility too (Lal, 2004). Smith *et al*., (2008) mentioned that 89 per cent of global potential for agricultural GHGs mitigation would be through carbon sequestration.

2.2 RISE IN ATMOSPHERIC CO_2 AND ITS CLIMATIC EFFECTS

2.2.1 Rise in atmospheric CO_2

Global climate changes are unique research challenges to the agricultural scientists. The exponential rise in CO_2 concentration of the atmosphere is one of the essential changes that efficiently influence the output of the crop. Last 50 years atmospheric CO_2 have speedy intensification on earth, which triggered by over abuse of fuels and other energy rising resources in the west (particularly North America and Europe). The outcome of the scenario developed deforestation in the third world countries (particularly South America, Southeast Asia and Indonesia). Atmospheric CO_2 contributes from anthropogenic activities are comparatively higher than absorbed or emitted gas from natural geochemical methods.

Compared to past geological time scale data shows the slight variation in CO_2. Obviously the increase of temperature has huge contribution to weather happening through the years. Measurement of CO_2 in the atmosphere, which initiated in Antartica in 1957, and Mauna Loa in (Hawaii) in 1958 indicates plainly that the concentration of CO_2 in the atmosphere is growing rapidly. Prior to industrial revolution, the global CO_2 concentration was about 270 ppm V, which remained stagnant for 10,000 years.

The drastic increase in human population since the preindustrial revolution increased the concentration of CO_2 due to large-scale usage of fossil fuels, deforestation, industrialization and urbanization. Gifford (1994) showed that burning of fossil fuel puts 5.8-6.2 Gt C $year^{-1}$ into the atmosphere and tropical deforestation adds another 1.5-3.0 Gt C $year^{-1}$accumulating about 8.0 Gt C $year^{-}$

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^{1}with atmospheric level. Of this 4.7 Gt C is being absorbed by the oceanic and terrestrial biota per year and 3.3 Gt C year^{-1} remains in the atmosphere leading to the rise in its concentration (Tans and Bakwin., 1995). Among the countries, the major contribution of the total CO_2 emissions of the world is by USA (41%), followed by Germany (22%) and Japan (21%). India contributes only 2 per cent of the total CO_2releases of the world (WB, 2001).

2.2.2 Importance of CO_2-climatic effect

The influence of greenhouse gases (GHGs) on climate can be broadly dealt with using the idea of radiative forcing. It is a measure of the influence expressed in terms of its capacity to alter the balance of incoming and outgoing energy in the earth atmosphere system. As a key factor it valid for climate change mechanisms. The total radiative forcing due to increase of the well-mixed GHGs from 1750 to 2000 is estimated to be 2.43 Wm^{-2}. Out of this, respective contributions from different GHGs are: 1.46 Wm^{-2}from CO_2; 0.48 Wm^{-2} from CH_4; 0.34 Wm^{-2} from the halocarbons; and 0.15 Wm^{-2} from N_2O. The increase in CO_2 concentration in the atmosphere caused global warming by absorbing long wave heat radiations from earth's surface, often termed as 'climatic effect'.

The cumulative value of surface temperature change without such feedback during the period 1850-1980 was 0.56 °C of which carbon dioxide increase contributed an increase of 0.4 °C and the contributions from other trace gases were approximately 0.16 °C. A number of hypothetical models have predicted that near global temperature will increase 3-4 °C with doubling of CO_2 concentration (IPCC, 2001). Long-term temperature records have concluded that global temperature has increased about 0.5 °C about the last 100 years (Hurrel, 1998). Warmer spring summer air temperature might be beneficial to crop yield at north (Jones *et al.,* 1985). However, more recent experiments indicate that the temperature rise will be less than 0.26 °C for a doubling of CO_2 concentration in temperate latitude where length of growing season could increase (Bazzaz, 1990). However, the increased temperature may have adverse effect in Mediterranean

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type of environment, where high summer temperature and water stress are already limiting production of crops.

2.3 CARBON SEQUESTRATION

Carbon is the major building blocks of all living organisms. It exists in different forms like plant biomass, soil organic matter, geologic deposits, and is dissolved in water bodies. The long-term storage process of carbon in soil is known as carbon sequestration. Some amount of carbon from atmosphere is stored in vegetation, ocean and geologic formations. Kimble *et al.,* (2002) defined that in global carbon cycle soils have a significant contribution compared to atmosphere, it recorded as 55 to 878 Giga tonnes (Gt). Withdrawing of CO_2 from atmosphere and sequestering it in to the biomass is the only practical way for mitigating the increased level of carbon dioxide release to atmosphere (Kyoto protocol, 1997).

Soil is the 3rd largest carbon sink after ocean and geologic sinks. This transfer or sequestration helps to enhance soil quality and agricultural productivity. Agronomic advances can improve the sequestration rate through conservation of soil and water, minimum soil disturbance, and enrich soil flora and fauna. Non-till crop production is primary concern.

Davidson and Verchot (2000) mentioned that the ability to capture the carbon in soils are twice than atmosphere, therefore soil is an important medium of global carbon conservation. The global soil carbon (C) is 4.5 times the size of the biotic pool and 3.3 times the size of the atmospheric pool (Lal, 2004). Geo-engineering is one of the well-organized approaches for carbon sequestration. It would sequester carbon in geosphere, ocean and biosphere (Lal, 2008). Carbon storage potential of soil depends on physical and chemical characteristics (Lal, 2003).

Organic C inputs can be added into the soil through crop residues and other organic amendments such as compost, farm yard manure, green leaf manuring, animal manures etc. The efficiency of SOC sequestration is the relationship between annual C input and SOC accumulation rate. This is an indicator of soil C sequestration ability (McLachlan, 2006).

Prasad and Singh (1980) reported that continuous use of FYM and NPK fertilizers over a period of 20 years helped in maintaining and improving the physical properties and organic matter content of an acidic red loam soil, while the application of fertilizer nitrogen alone slightly deteriorated soil physical properties and organic carbon content. In an eleven year experiment on sugarcane crop, combined application of FYM and NPK fertilizers resulted in increased soil organic carbon (Rabindra and Honnegowda, 1986).

Rogasik *et al.,* (2004) stated that Long-term experiments can be used to understand the carbon sequestration pattern in soil and for the quantification and prediction of carbon sink potential of arable soils. The incorporation of stubbles left after harvest led to an increase in the organic carbon even in control plots of the long term fertilizer experiment at RARS Pattambi. SOC increase in plots was more, which received both organic manures and fertilizers (Thulasi *et al.,* 2013). The use of organic manures like farm yard manure and compost in combination with inorganic fertilizers initiate carbon sequestration in soils through addition of increased amounts of biomass (Swarup, 1998).

Impact of long term organic and inorganic amendments on C sequestration pattern of rice-rice system under LTFE in Kerala have not yet been examined which indicate the importance of the present study. The study analyzed the effect of different management practices on carbon sequestration in the long term fertilizer experiment maintained. Climate factors especially temperature affects organic matter distribution (Davidson and Janssen, 2006). Singh *et al.,* (2010) reported that increasing global temperature results in increased respiration and mobilization of soil organic matter with positive feedback for climate change.

According to IPCC (2007) the coming two or three decade's sequestration and emissions will stabilize levels of atmospheric CO_2 and mitigate impacts of climate change (Pachauri and Reisinger, 2007). Many researchers documented that external supply of nutrients are essential to sustain productivity and organic carbon in soil (Jha *et al.,* 2014). In nature, micro and macro organisms mineralize the organic matter. It promotes the soil physico-chemical and biological activities. Carbon in plant parts is derived from atmosphere and withdrawal of CO_2 from atmosphere can mitigate climate change. Incorporation of crop residues also encourages carbon sequestration (Lal and Cummings, 1979 and 2004).

Studies indicated that quantity of residual biomass is proportional to above ground productivity (Kundu *et al*., 2001). Supplying balanced nutrients and good irrigation managements are required to increase crop productivity. Imbalance in soil nutrient and mining of nutrients by crops in a quantity larger than applied to soil are the key constraints for achieving the potential productivity of crops (Singh and Wanjari, 2013).

IPCC (2000) reported that about 125 MMT and 258 MMT of carbon could be sequestrated by crop management in 2010 and 2040 respectively. India has divers agro-climatic zones with different nutrient application, which results carbon sequestration potential is projected to range between 2.1 and 4.8 Mg C ha^{-1} with a total potential of 300 to 620 Mt (Pathak *et al*., 2011).

Carbon-sequestration potential in rain fed production structures under altered nutrient management practices ranges between 0.04 and 0.45 Mg ha^{-1} yr^{-1} (Srinivasarao *et al*., 2014). Doran (1987) stated that soils getting organic amendments have higher biologically active carbon segment correlated to chemically fertilized soils. In Ohio, a long-term experiment demonstrated that the continuous application of NPK fertilizer and cattle manure was the finest method for SOC sequestration, but in the absence of organic manure application, the SOC diminished drastically (Hao *et al*., 2002).

Over 30 years of experiments in India specified that incorporated practice of farmyard manure (FYM) with chemical fertilizers (100% NPK+ FYM) revealed significant rise in organic carbon content than fertilizer alone (100%

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NPK) in rice-jute-rice cropping system in humid tropical climate (Manna *et al.*, 2006).

Soil aggregation can improve the physical properties of soil which is also proposed to explain the strong SOC sequestration in paddy soils (Zhou *et al.*, 2008). Lal (2008) observed that in India organic carbon in soils is severely depleted, and is below the critical limits for soil and ecosystem functions. Soils of Kerala exhibits low organic carbon content in lower elevation and high in mid and higher elevations.

Lal (2002) stated that contribution of plant carbon into soil was quantified for understanding dynamics of carbon cycle in ecosystem. In the case of paddy field soil serves as chief carbon sink. Root exudation is a mechanism which provides carbon to soil and substrate inputs to soil micro-organisms (Li and Yagi, 2004). Addition of fresh organic matter (FOM) increases the rate of soil organic matter (SOM) mineralization. This may enhance carbon storing ability of soil (Kuzyakov, 2010). Kastovska and Santruckova, (2007) found that processes of atmospheric carbon to soil have influence on active soil carbon pools. Nie *et al., (*2012) had quantified photo-assimilated carbon input into soil organic carbon pool through labeled studies in rice. They reported that 6.62 per cent of the photo assimilated rice carbon gets incorporated into soil organic carbon pools.

Hutsch *et al*., (2002) found that only 2-5 % of net plant carbon is reserved in soil. Low molecular weight compounds like carbohydrates, amino acids and organic acids in root exudates makes root-derived carbon. These simple compounds are the source of dissolved organic carbon (DOC) and substrates for soil microorganisms (Lu *et al.,* 2002). Many studies describe linear relationship between carbon inputs and total soil organic content across number of nutrient management practices in long term fertilizer experiments (Larsen *et al*., 1972 and Paustin *et al*., 1997). Climate variables have driving force for faster cycling of C and other soil nutrients (Hassink *et al.,* 1997).

In carbon sequestration process soil microbes have a significant role in degradation of crop residue and other organic amendments. Soil microbes can help to convert larger carbon molecules to smaller carbon molecules. Soil fungi and soil bacteria have ability to transform organic matter. These natural agents are enhancing biomass production. Abundant microbes in soil decompose the plant inputs and improve carbon sequestration efficiency (Six *et al.,* 2006).

Long term cropping system experiment at Kellogg Biological Station at Michigan State University over 12-year period of an organic management system reported an increase soil carbon. This experiment showed net positive difference between carbon inputs and CO_2 emission to atmosphere (Syswerda *et al.*, 2011). Increasing carbon in soil can mitigate carbon emission and enhance soil productivity and agro ecosystem productivity. Soil carbon can define soil structure, ensure soil water retention, strengthen healthy soil microbial communities and boost fertility (Bronick and Lal, 2005, Rawls *et al.,* 2003), Wilson *et al.,* (2009) and (Schmidt *et al.,* 2011). Simply permitting land to lay fallow in an early successional state after intensive agricultural use can lead to enlargements in soil carbon (Syswerda *et al.,* 2011).

Post and Kwon (2000) mentioned that the amount of organic C deposited in various soil pools is the balance between the rate of soil organic C (TOC) input and the rate of mineralization in each of the organic C pools.

Smith & Conen (2004) stated that agricultural lands can removes methane from atmosphere by oxidation. Better agronomic practices that increases productivity and create greater contributions of C residue can lead to improved soil C storage (Follett, 2001). Lal (1999) mentioned that fertilizer application has proved to be strengthening C sequestration. Emissions can also be reduced by implementing less intensive cropping systems, which reduce reliance on pesticides and other inputs (Paustian, 2004). Since soil C in soil through improved decomposition and erosion. Evidently, reduced- or no-till agriculture often results in soil C gain (West & Post 2002; Alvarez 2005; Gregorich *et al*., 2005; Ogle *et* *al*., 2005). Using more efficient irrigation measures can develop C storage in soils through enriched yields and residue returns (Follett 2001; Lal 2004a).

2.4 CARBON SEQUESTRATION IN RICE SOILS

Generally, Yan *et al*., (2003) stated that soils of wetland cultivation discharge major amounts of CH_4. Smith & Conen (2004); Yan *et al.,* (2003) mentioned that for the period of growing water drained more than once from the rice soils, which can be successfully weakens the production of methane. And it effectively reduced N_2O emissions, and the practice may be controlled by water supply. To compare addition of carbon inputs in dried periods than flooded periods on wetland could shows reduced CH_4 emissions (Xu *et al*., 2000; Cai *et al*., 2004). The anaerobic digestion of manures could be making best use of capturing CH_4 as an energy source (Clemens & Ahlgrimm 2001; Clemens *et al*., 2006).

Intensive use of N fertilizers in the Green Revolution is motivateded by the economic value of high grain yields and is generally considered to sequester SOC by rising the crop residues (Powlson *et al*., 2016; Luo *et al.,* 2010).The rate of soil organic matter decomposition is declined in submerged rice soils, apparently due to excessively reduced conditions (Wantanabe *et al.,* 1994; Jenkinson, 1990).

Schlesinger (1997) opined that long term storage is often limited by rapid decomposition processes and release of C to the atmosphere from paddy fields. Ramesh *et al*., (2007) found that various land use systems of semi-arid tropics (SAT) have shown that paddy systems had highest content of organic carbon and nitrogen irrespective of bioclimatic zones. Bandari *et al.,* (2002) reported that results informed on LTFE revealed that SOC under rice-wheat system in the Indo-Gangetic plains are declined over years. Alternatively prolonged submerged soil surroundings stimulate SOM accumulation and C sequestration in wetland soils and sediments (Pampolino *et al.,* 2007).

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Wetlands are advantageous for storing carbon into soil; it helps to attain the capacity through higher productivity, higher water table and lower disintegration of manures of the specific soil (Whitting and Chanton, 2003). Long-term fertilizer experiments in paddy fields proves that straw after harvest used to an adoptive method for improving carbon storage (Yan *et al.,* 2007).

Swarup (1998) stated that continuous application of farmyard manure (FYM) and green manure substantially developed the organic carbon under diverse soils and cropping systems. Long term application of manure alone or in combination with chemical fertilizers improved the organic matter status and carbon mineralization in soil in paddy fields. Sarkar *et al*., (1989) found that the cumulative effect of long term use of chemical fertilizers on organic carbon content and its mineralization potential of the ploughed layer were relatively less compared to continuous incorporation of FYM. Soils of unfertilized plots revealed a reduction of about 50 per cent in organic carbon by 12 years of cropping as compared with initial value (Alokkumar and Yadav, 1993).

In Denmark, a long-term fertilizer experiment conducted by Schjonning *et al.,* (1994) showed that after 90 years, the plots receiving annual application of NPK fertilizers and FYM had 11 per cent and 23 per cent higher soil organic content than unfertilized control plots. Singh and Kashyap (1999) reported that the continuous application of chemical fertilizers can lead to drastic reduction in organic carbon content whereas application of 5 t FYM ha^{-1} along with fertilizer nitrogen helped in maintaining the original status.

Fan *et al.,* (2005) detected that for improved buildup of SOC and sustained productivity the combined use of organic and inorganic fertilizers is beneficial. Application of FYM enhanced the organic carbon content in soil (Ravankar *et al.,* 2005). Baldock and Skjemstad (1999) reported that measurement of soil organic C is the substitution of measurement of soil organic matter due to the ease associated with determination of soil organic C. In Indian soils the unfertilized and N–fertilized plots had low initial level of soil organic

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carbon related to the initial level because of crop roots being retained in the soil has replenished the loss of SOC (Hati *et al.,* 2006).

Beneficial and harmful effects of climate change may affect Agriculture and geography has essential role in climate change. Agricultural practices act both as sources and sinks for greenhouse gases. Application of nitrogen based fertilizers, burning of crop residues, appropriate waste management, and digestive systems of ruminant animal's results in methane emissions. Management practices in agriculture encourage profitability, farm energy efficiency, and air and water quality. Practices such as conservation tillage, organic production, cover cropping and crop rotations, improved cropping systems, land restoration and irrigation adds to carbon sequestration.

2.5 CLIMATE CHANGE AND AGRICULTURE

Climate change and Agriculture are interlinked on global scale. Global warming is the important climate change condition affecting agriculture. The distribution of crop over diverse regions can be influenced by climate whereas the potential production of a particular crop can be determined by weather.

Climate is always dynamic in nature and changes with time. However, in the recent past change is very rapid. The CO_2 concentration in atmosphere is rising at the rate of 2ppm yr^{-1} and the present concentration of CO_2 is 400 ppm. Prevailing climatic factors are being synchronized over any region of agricultural production. The climatic factors which include temperature, rainfall, light intensity, radiation, and sunshine hours define the yield (Goswami *et al.,* 2006).

Sustainable agriculture is adopted for conserving biodiversity and nutritional quality of soil. Crop production clearly defines climate factors of particular region. So every crop has particular weather condition for better productivity.

In plants atmospheric CO_2 enrichment promotes photosynthetic rate and water-use efficiency (WUE). Climate change scenarios have impacts on economic

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welfare rather than productivity. In India, every year mean air temperature increases about 2°C, it may decrease yield of rice by about 0.75 ton ha^{-1} in the high yield areas and about 0.06 ton/ hectare in low yield coastal regions (Sinha and Swaminathan, 1991).

In all the time agriculture are vulnerable to unpredictable weather events and climate conditions. Technological advances can be making improved food security.

Over half of the world population consumes rice as major staple food. India and China are largest producers of rice. Asia attained highest productivity in rice which amounts to about 90 per cent. Rice economy has been prompted by monsoon seasons compared to other weather conditions. After the green revolutions, productivity increased. China is the largest producers of rice compared to other countries, which is about one-third of global production (Coats, 2003). Erda *et al.,* (2005) unequivocal variations of temperature and carbon dioxide could be reducing the production. The total area covered by rice crops about 153 million ha (IPCC, 2007).

IPCC working group on mitigation have assessing GHG mitigation potential (Smith *et al.,* 2008). Using different agricultural approaches and conservation of ecosystem practices on wetlands can be develops wide-ranging database of studies based on global agricultural GHGs mitigation. Smith *et al.*, (2008) approximate a total technical potential of 5500-6000 Mt CO_2-equivalent per year between now and 2030, with 89 per cent of that figure being derived from reduced soil CO_2 emissions.

In global carbon cycles wetlands have an important role in carbon storage. They are highly productive ecosystems that accumulate large amounts of organic matter in the soil, and act as carbon sinks (Mitra *et al.*, 2005).

Some negative effects of climate change on agriculture can be reduced or overcome by implementing a widespread of adaptive actions. Famers have already adapted a wide range of practices proposed to raise crop yield (Barbier *et* *al*., 2008). Ghosh and Singh (1998) established that planting date can have an intense outcome on crop development and yield.

2.6. CROP-WEATHER RELATIONS IN RICE

Weather elements have been influencing plant's physiological processes like respiration, transpiration and photosynthesis. Growth and yield will be affected by slight changes in weather. Rice is a very sensitive crop compared to others, so abiotic stress may damage the production. The important weather parameters are temperature, solar radiation, relative humidity, wind velocity and rainfall.

2.6.1. Temperature

Rice is mainly grown in the tropics with the critical absolute temperature for the growth ranging from 20 to 40°C. Every Crop has certain specific temperature for their needs, even slight changes brings drastic changes in crops.

The temperature required for accelerating shoot and root growth is 26°C and low temperature weakens the rate of germination (Sreedharan, 1975). Optimum temperature of about 25°C and 30°C is needed for leaf emergence and elongation (Bardhan and Biswas, 1983). Tillering rate is privented by lowering temperature. At high temperature the period of tillering is extended, resulting in more tillers and more panicles (Sreenivasan, 1985).

The presence of high temperature accelerates the floral initiation in rice (Vergara and Heu 1972). Mackill *et al*., (1982) established that temperature above 34 °C results in poor pollen shedding as well as inadequate pollen growth. The day time temperature ranging between 32°C and 38°C promotes sterility. Delayed floral initiation due to low temperature was reported and the critical minimum was around 15°C (Ghosh *et al.,* 1983) for rice.

Generally, temperature influences the ripening of rice in two ways. Low temperature favor an increase in grain weight and low daily mean temperature rise the length of ripening period. During grain filling if the temperature is less than 28ºC, its duration and seed size will be increased (Tashiro and Wardlaw, 1989). Kobata and Uemuki (2004) reported a direct indication of decreased rice yields from increased night temperatures.

2.6.2. Solar Radiation

Biswas (1996) recorded that during summer season solar radiation becomes almost double of that of monsoon season in eastern and southern India. At vegetative stage low light intensity affects the yield and yield components of rice (Yoshida, 1981). It also decreases the tiller growth due to lack of photosynthates. Murthy *et al.*, (1975) detailed that in long duration varieties, low light stress coordinates with the vegetative lag phase result in considerable tiller mortality and fewer panicles m^{-2}.

According to Stansel (1975) and Sreedharan (1975) the yield attributes and grain yield recorded a positive correlation with solar energy during ripening stage. At low light intensity, photosynthesis becomes low causing mortality of the weak and unproductive tillers during this phase when there was greater demand for photosynthesis from the developing grains (Thangaraj and Sivasubramanian, 1990).

Thangaraj and Sivasubramanian (1990) noted that the percentage of filled grains and test weight are reduced due to low light intensity or shading during ripening stage, hence resulting in yield reduction. Patro and Sahu (1986) detailed that the reduction in grain number per panicle by shading of the plants from flowering to harvest is only due to poor grain filling, which was evident from the high sterility percentage.

2.6.3. Rainfall

Rice is a rain fed area crop, popularly known as *kharif* crop of India. Most critical weather component in rain fed rice ecologies is amount and distribution of rainfall (Upland, lowland and flood prone) and its effect on

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evapotranspiration of the crop through variations in temperature, solar radiation and wind speed. The daily rainfall is more critical than monthly or annual rainfall in crop growth.

According to Kamalam *et al.*, (1988) during the tillering phase of the crop growth accumulated rainfall over and above the normal requirement had an adverse effect on the straw yield. During the active growth period high rainfall resulted in taller plants. High rainfall may result in the reduced availability of sunlight. Rainfall variability can also affect the stand establishment and growth duration of the crop.

During nursery stage total rainfall was negatively correlated with grain yield in non-significant manner but with straw yield it was significant and positively correlated (Narayanan, 2004). At vegetative stage rainfall had a significant negative correlation with straw yield. During the vegetative stage water deficit reduces the plant height, tiller number and leaf area but the crop can recover without much loss in yield if water is available before flowering.

When rain occurred continuously for three days rice flowering was affected (Vijayakumar, 1996). Due to continuous rain coupled with strong wind at flowering in wet season low yield was obtained (Pradhan and Dixit, 1989). Narayanan (2004) found that a positive non-significant correlation between grain yield and total rainfall; whereas total rainfall was negatively correlated with straw yield in non-significant manner.

Panicle initiation and flowering stages are more sensitive to submergence (Jeyaraman and Balasubramanian, 2004). They also invent that muddy or turbid water inflicts more harm to plants than clear water because sediments in turbid water block the pores in the plant body and hamper the respiration and photosynthesis.

Viswambaran *et al.*, (1989) noted a negative correlation between yield and number of rainy days during maturity phase. Total rainfall during this stage was negatively correlated with grain and straw yield in a non-significant manner (Narayanan, 2004).

2.6.4. Relative Humidity

Relative humidity is a function of temperature and moisture in the atmosphere. It is invariably much more in the morning than in the afternoon. For rice cultivation stagnant water builds up an environment with high relative humidity which helps for better growth. Rice requires a significant high degree of humidity. RH of 80-85 per cent is ideal for shoot growth. Photosynthetic rate is increased with increase in humidity and vice versa, the increase is greatest at 28 °C and smallest at 34 °C.

The increase in humidity can also increase the leaf temperature and stomata aperture (Hirai *et al.*, 1989). Hirai *et al.*, (1992) found that root dry weight production was more influenced by RH than shoot dry weight. At low temperature the root-shoot dry weight of plants at 90 per cent was lowest than in plants grown at 60 per cent RH. Relative humidity had little effect on root-shoot dry matter ratio at the intermediate temperature.

Sunil (2000) reported that during active tillering increase in relative humidity can increase the number of panicles per hill. At high relative humidity, high solar radiation positively influenced the number of leaves per plant and low relative humidity shortened the days taken from transplanting to panicle initiation.

Rangasamy (1996) stated that relative humidity has a major role in altering the days to first flowering. Ghildyal and Jana (1967) noted that relative humidity affects the rate of transpiration. The increased transpiration may stimulate the physiological process affecting the yield. The yield declined with the increasing relative humidity during this phase.

Relative humidity had negative correlation with straw yield and positive correlation with grain yield during this stage (Narayanan, 2004). Ghildyal and Jana (1967) shows that low relative humidity (around 43%) during grain development with a temperature range of 12-13 °C was favorable to yield increase.

2.6.5. Wind

Kamalam *et al*., (1988) mentioned that wind velocity at tillering stage had a positive significant correlation with grain yield.The effect of strong winds caused leaf breakage and delay in crop maturity (Lin-Meng, *et al*., 1994).

Sunil (2000) analyzed that during active tillering to heading stage wind speed had a significant negative correlation with number of panicles per plant and straw yield. Lenka (2000) found that wind during flowering stage in *kharif* season resulted in 63 per cent panicle grain sterility and heavy loss in grain yield. Due to wind at this stage grain yield was more affected than straw yield. At the time of the flower opening strong winds may induce sterility and increase the number of abortive endosperms (Sreenivasan, 1985).

A hot and dry air causes white head, particularly when it occurs during panicle exertion (Hitaka and Ozawa, 1970). Sunil (2000) noticed that a negative correlation between grain yield and wind speed during flowering stage.

During flowering high wind speed had caused pollen dehydration and consequent spikelet sterility in rice (Rao, 2003). In rice, fertilization was inhibited by wind speed of more than four meter per second (Viswambaran *et al*., 1989). During the ripening period strong winds lead to the shredding of leaves, serious lodging and shattering of grains (Datta and Zarate, 1970 and Sreenivasan, 1985).

Viswambaran *et al*., (1989) found that the occurrence of white grains was increased by wind at 14-21 days after heading. Kamalam *et al.,*(1988) pointed that the wind velocity is significantly correlated with grain yield. Under strong winds, grain development and maturity were found to be poor.

The weather parameters like temperature, solar radiations, moisture are the critical factors for determining growth and productivity. These factors are influencing fertility of soil which effects the nutritional requirements. These factors are required to define the optimum density of plant population per unit area necessary to maximize grain yields.

2.7 DSSAT

The Decision Support System for Agro technology Transfer (DSSAT) is a crop growth simulation model developed by International Benchmark Sites Network for Agro technology Transfer project (Tsuji and Thronton, 1998; Uehara, 1998; Jones *et al.,* 1998).

DSSAT is an advanced crop growth model for understand the relationship between crop and its environment. It will be established by integrated knowledge about crop, weather and soil data (Uehara, 1998; Tsuji and Thronton, 1998). It also helps the decision-makers by decreasing the time and human resources essential for studying complex alternative decisions (Tsuji *et al.*, 1994).

Ritchie and Otter (1985) and Hoogenboom *et al.*, (2003) have delivered a complete explanation of the model. The users prepare the databases and compare simulated results with observations and finally calibrate the model incorporating modifications required to progress accuracy (Uehara, 1998; Jones *et al.,* 1998).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled 'Carbon sequestration and crop weather relations in long term fertilizer experiment at Pattambi' was formulated with the objectives of studying the effect of long term application of fertilizers and manures on soil carbon sequestration pattern and crop weather relations under long term fertilizer experiments with rice-rice cropping sequence. AICRP on Long Term Fertilizer Experiments (LTFE) at RARS, Pattambi formed the study material.

The details of the field experiments from which the soil samples were collected, the laboratory analytical methods followed and statistical techniques adopted for rational interpretations are discussed in this chapter.

3.1 DETAILS OF FIELD EXPERIMENTS AT RARS, PATTAMBI

All India Co-ordinated Research Project on LTFE has been laid out at Regional Agricultural Research Station, Pattambi and is being continued with the main objectives of studying the effect of continuous application of plant nutrients (NPK) in organic, inorganic forms and in combinations on sustainable production in the rice-rice cropping sequence. Geologically Pattambi is located $10^{0}48^{1}16^{11}$ North latitude and $76^{0}11^{1}00^{11}$ East longitude. Based on agro ecological classification (NBSS & LUP, 2012) Pattambi is located in AESU (3) – Laterite terrain/AEU (10) – North central laterite/ AEZ (2) - Mid land laterites.

3.2 EXPERIMENTAL DETAILS

Plant yield and related parameters were taken from the individual plots of the LTFE (Long Term Fertilizer Experiment) of RARS, Pattambi during Mundakan Crop, 2017-18. Soil samples collected after Mundakan crop of 2017-18 were used for analysis. The details of the field experiment are given below:

3.2.1 AICRP on long term fertilizer experiment

Design	:	Randomized Block
No. of replications	:	4
Variety	:	Aiswarya
Plot size	:	125 m^2
Treatments	:	12

T_1 : 50 percent NPK

T_2 : 100 percent NPK

T_3 : 150 percent NPK

T_4 : 100 percent NPK + $CaCO_3$ @ 600 kg ha^{-1}

T_5 : 100 percent NPK

T_6 : 100 percent NP

T_7 : 100 percent N

T_8 : 100 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_9 : 50 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_{10} : 100 percent NPK + in situ growing of *Sesbania aculeata* (in Virippu crop only)

T_{11} : 50 percent NPK + in situ growing of *Sesbania aculeata* (in Virippu crop only)

T_{12} : Absolute control (No fertilizers/ manures)

(100 % NPK as per KAU POP recommendation is 90:45:45 N: P_2O_5: K_2O kg ha^{-1})

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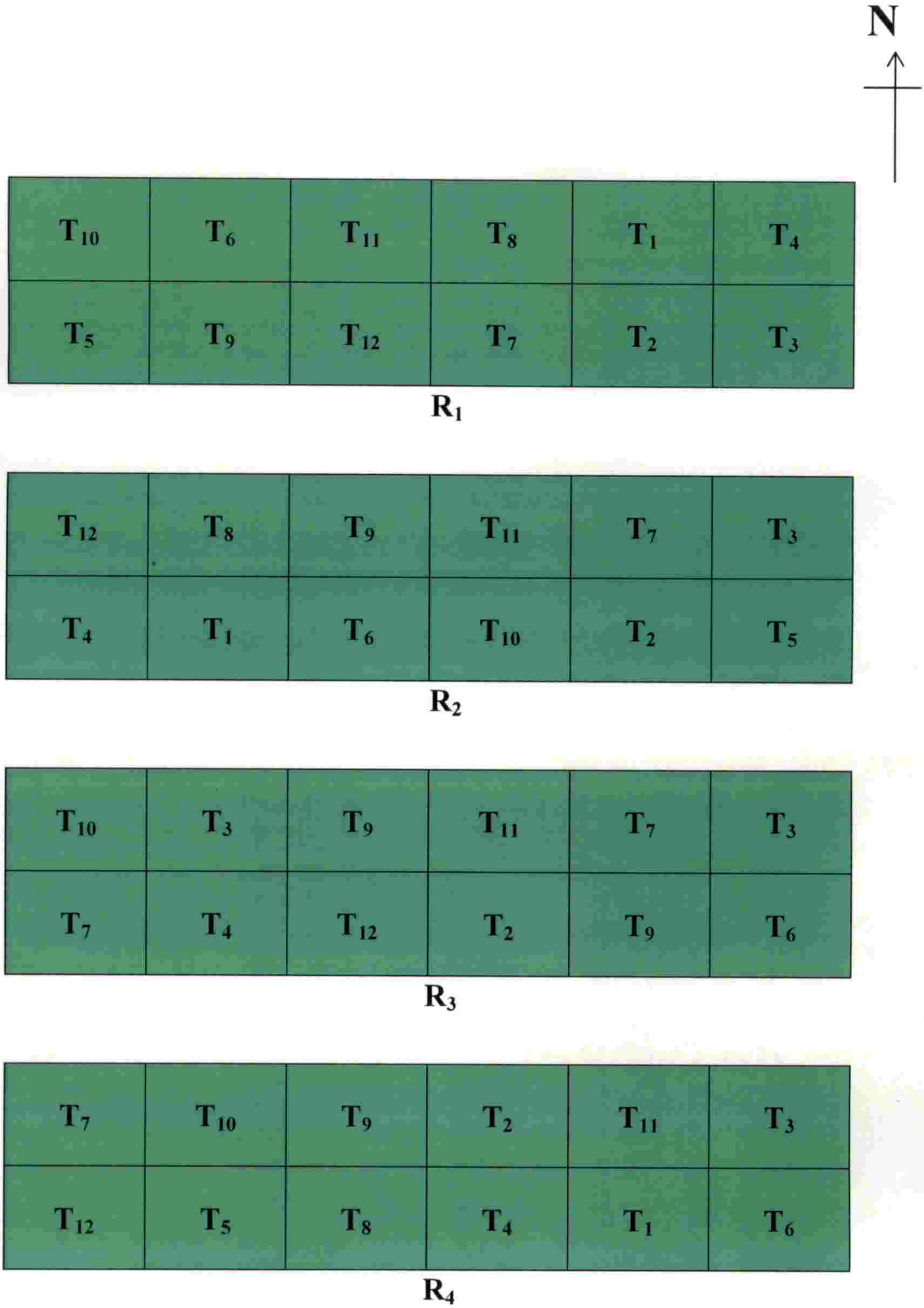

T_{10}	T_6	T_{11}	T_8	T_1	T_4
T_5	T_9	T_{12}	T_7	T_2	T_3

R_1

T_{12}	T_8	T_9	T_{11}	T_7	T_3
T_4	T_1	T_6	T_{10}	T_2	T_5

R_2

T_{10}	T_3	T_9	T_{11}	T_7	T_3
T_7	T_4	T_{12}	T_2	T_9	T_6

R_3

T_7	T_{10}	T_9	T_2	T_{11}	T_3
T_{12}	T_5	T_8	T_4	T_1	T_6

R_4

Fig.1. Layout of LTFE experimental plots at RARS Pattambi

Plate 1. Field view of LTFE plots at RARS Pattambi

Plate 2. Transplanting of rice seedling in LTFE plots

Plate 3. Weighing stubble biomass

Plate 4. Preparation of plant material for organic carbon analysis

3.3. OBSERVATION FROM FIELD EXPERIMENT (2017-18)

3.3.1. Biometric observations- These observations were taken one day prior to harvest of the Mundakan crop, 2017-18.

3.3.1.1. Plant height- The height was measured in cm from the bottom of the culm to tip of the longest leaf at one day prior to harvest.

3.3.1.2. No. of tillers per plant- No. of tillers per plant were counted and recorded randomly from each plot.

3.3.1.3. Panicle length- The length of panicles were recorded randomly from each plot and expressed in cm.

3.3.1.4. No. of panicles per plant- No. of panicles per plant were recorded randomly from each plot.

3.3.2 Crop yield- Observations were taken in both Virippu and Mundakan crops after harvest. The crop was harvested in two seasons annually and measured the grain and straw yield for all the plots of study area.

3.3.3. Stubbles- The stubbles were dug out from each plot, washed, dried and dry weight was recorded. Percent carbon content of the stubbles was analysed which was 42 %.

3.3.4. Weed biomass- The weed biomass was recorded by pulling out the weeds from each plot at 50 DAP and at harvest. Biomass contribution into soil through un-removed weeds was quantified at 50 DAP and at harvest by weighing the dried weeds in the plots. The carbon input share to soil was calculated taking the per cent carbon content as 30 as analysed in the weeds.

3.3.5. Biomass of daincha- The quantity of daincha biomass being added to the soil was quantified by harvesting the daincha from 1 m^2 area.

3.3.6. Carbon content in different plant materials

The carbon content in different materials such as stubbles, weeds, daincha, FYM and biomass were determined by loss-on-ignition method using muffle furnace.

3.3.7. Soil organic carbon

3.3.7.1. Collection of soil samples

Soil samples were collected from each plot after harvest of the Mundakan 2017-18. Soil samples were collected from depths of 0-15, 15-30 and 30-45 cm from surface.

3.3.7.2 Preparation of soil sample for analysis

Field fresh soil samples were air dried. Soil samples (one gram) were processed for organic carbon analysis.

3.3.7.3. Determination of Organic carbon in soil

Organic carbon determination is often used as a basis for estimation of organic matter. Organic fraction of the soil was determined through oxidation by treatment with a mixture of potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) and titrating the solution with 0.5N ferrous ammonium sulphate in the presence of ferroin indicator. Make a blank determination in the same manner, but without soil for the calculation (Walkely and Black, 1947).

$$\text{O C (\%)} = \frac{(\text{Blank value} - \text{Titer value}) \times 0.5 \times 0.003 \times 100}{\text{Weight of soil}}$$

3.4. ESTIMATION OF CARBON INPUTS, SOIL ORGANIC SEQUESTRATION RATE AND EFFECIENCY

Carbon inputs into the top soil included materials from crop residues (stubbles and root), organic amendments (FYM and daincha) and un-removed weed biomass. The annual amount of photo assimilated carbon inputs by the crop biomass and roots was calculated as 6.62 % (taken from reports) of the total biomass for the two seasons. The inputs from left over stubbles and roots after harvest and the un-removed weeds were quantified separately. The carbon content of the biomass stubbles, weeds, farmyard manure and daincha were estimated regardless of treatments and were used in the calculation.

Contribution of carbon inputs from the photo assimilated biomass was found out using the pooled average yield (grain and straw yield together) of the past 41 seasons. Carbon per cent of 40 in the biomass and 6.62 per cent as the contribution of biomass carbon into SOC pool were used in the calculations.

Total carbon inputs were calculated by adding the carbon inputs from stubbles, biomass and weeds.

Mass of soil organic carbon (MSOC ton ha^{-1}) in top soil was calculated using the equation. Mass of soil organic carbon, $MSOC = \frac{SOC \times B.D \times d}{10}$

Where,

SOC = soil organic content ($g\ kg^{-1}$)

B.D = bulk density ($g\ cm^{-3}$)

D = thickness of the soil layer (20 cm)

SOC sequestration rate (SSR, ton $ha^{-1}year^{-1}$), $SSR = (MSOC_t - MSOC_0)/\ t$

Where,

$MSOC_0$ = SOC at time 0 ie, in the initial year (1997)

$MSOC_t$ = SOC at time t ie, 21 years after start (2018) of experiment

The contributions from the organic manures were calculated as follows:

ΔSOC sequestration rate (ΔSSR, ton $ha^{-1}year^{-1}$) = $(SSR_{NPK+OM} - SSR_{NPK})$

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Where, SSR_{NPK+OM} and SSR_{NPK} were the SOC sequestration rates in treatments with organic amendments combined with mineral NPK fertilizers and the treatments with mineral NPK fertilizers alone respectively.

C sequestration efficiency of organic amendments (SEO),

$$\text{SEO (\%)} = \frac{\Delta \text{ SSR} \times 100}{\text{CI}}$$

Where,

CI (ton $ha^{-1}year^{-1}$) = annual C inputs via organic amendments

3.5. STATISTICAL ANALYSIS

The data generated from long term fertilizer experiment were analyzed using statistical package in Excel. Correlation studies were carried out between grain yield and weather parameters.

3.6. CROP WEATHER MODEL

CERES-Rice (Crop Estimation through Resource and Environment Synthesis) has been used in this study to model the influence of weather parameters on crop growth and yield. It has been widely used for assessment of the impact of climatic change on crop production (Singh and Virmani, 1994).

Crop simulation models incorporate weather, soil and crop management data for attaining better simulated results. Model based on same input and output data format that are ensemble into DSSAT (Tsuji *et al.*, 1994).

Validation of CERES-Rice requires to develop genetic co-efficient based on the varietal characters of the variety and the details are as follows **(Table 1.)**.

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Table.1. Genetic Coefficients for the CERES Rice model

P1	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence to end of juvenile phase during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.
P2O	Critical photoperiod or longest day length (in hours) at which the development occurs at maximum rate. At values higher than P2O the development rate is slowed (depending on P2R), there is delay due to longer day length.
P5	Time period in GDD in °C from beginning of grain-filling (3-4 days after flowering) to physiological maturity with base temperature of 9.0°C
G1	Potential spikelet number coefficient as estimated from number of spikelet per g of main culm dry weight (less leaf blades and sheaths plus spikes at anthesis. A typical value is 55.
G2	Single dry grain weight (g) under ideal growing conditions .i.e., non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient (scalar value) relative to IR64 cultivars under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.
G4	Temperature tolerance coefficient.Usually 1.0 for cultivars grown in normal environment. G4 for japonica type rice grown in warmer environments would be ≥ 1.0. Tropical rice grown in cooler environments or season will have G4 < 1.0

The minimum data set required for the operation and calibration of the CERES - Rice is (Hoogenboom *et al.*, 2012(a)) given below,

3.6.1. Data required

3.6.1.1. Level 1 Data

Weather Data Required (Daily)

1. Minimum and maximum temperature
2. Rainfall
3. Total solar radiation or sunshine hours
4. Dew point temperature or relative humidity
5. Average daily wind speed

Soil Data

1. General site information
2. Soil surface information
3. Soil profile data, for each soil horizon in which roots are likely to grow

Initial Conditions

1. Previous field historys
2. Initial soil profiles - conditions
3. Surface residues at the start of simulation or at planting

Management Data

1. Planting
2. Input information

3.6.1.2. Level 2 Data

Crop and Soil Response Measurements

1. Treatments
2. Yield and yield components
3. General observations

3.6.1.3. Level 3 Data

1. Growth analysis measurements
2. Soil water content versus depth
3. Soil fertility versus depth

3.6.2. Calibration of CERES-Rice Model

Data obtained from the experiment carried out with rice variety Aiswarya under LTFE under fourteen dates of transplanting were used for estimating the genetic parameters. The genetic coefficients that affect the occurrence of development stages in the model were resulting iteratively, by manipulating the relevant coefficients to achieve the best possible match between the predicted and observed events as well as the model was calibrated for yield parameter.

3.6.3. Validation of CERES-Rice Model

Validation is the process of comparison of the results of simulations with observations that were not used for calibration. The secondary data available for fourteen seasons of LTFE experiment with twelve treatments were used for independent model validation. RMSE was used as a statistical index for model validation.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{n}}$$

Where, Pi and Oi refers to the predicted and observed value for the studies variables respectively and n is the mean of the observed variables.

RESULTS AND DISCUSSION

4. RESULT AND DISCUSSION

The results of the study entitled 'Carbon sequestration and crop weather relation in long term experiments' conducted at RARS, Pattambi during the year 2017-18 are presented below.

4.1. GROWTH AND YIELD

4.1.1 Grain yield

The grain yields obtained for the crop in Virippu and Mundakan seasons (2017-18) as affected by the long term application of different nutrient management practices are given in **Table 2.** Statistical analysis of data revealed that grain yield was influenced by the treatments in LTFE. In virippu season, grain yield ranged from 3248 to 5148 kg ha^{-1}. The highest grain yield of 5148 kg ha^{-1} was recorded by the treatment T_8 (100 percent NPK + FYM @ 5t ha^{-1} (to Virippu crop only)) which is on par with T_3 (150 percent NPK) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The plots which received nitrogen alone (T_7) registered lowest grain yield of 3248 kg ha^{-1} which is on par with T_{12} (Absolute control).

In Mundakan season, grain yield ranged from 2231 to 3749 kg ha^{-1}. The highest mean value of 3749 kg ha^{-1} was recorded by the treatment T_8 (100 percent NPK + FYM @ 5t ha^{-1} (to Virippu crop only)) which is on par with T_3 (150 percent NPK) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The plots which received nitrogen alone (T_7) registered lowest grain yield 2231 kg ha^{-1} which is on par with T_{12} (Absolute control).

4.1.2. Straw yield

The effect of long term application of different nutrient management practices on straw yield in the Virippu and Mundakan seasons (2017-18) of the rice crop under LTFE is given in **Table 3.** In Virippu season, long term application of various nutrient management practices significantly influenced straw yield. The straw yield ranged from 3342 to 5230 kg ha^{-1}. The highest straw yield 5230 kg ha^{-1} was recorded by the treatment T_8 (100 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) which is statistically on par with T3 (150 per cent NPK), T_9 (50 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) and T10 (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The treatment T_{12} (Absolute control) recorded the lowest straw yield of 3342 kg ha^{-1}.

Long term application of various nutrient management practices significantly influenced straw yield in Mundakan season and data is given in **Table 3.** The values ranged from 2582 to 4214 kg ha^{-1}. The highest straw yield of 4214 kg ha^{-1} was recorded by the treatment T_8 (100 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) which is on par with T_3 (150 per cent NPK) and T10 (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The treatment T_{12} (Absolute control) recorded the lowest mean value of 2582 kg ha^{-1} straw yield.

4.1.3. Plant parameters

The effect of long term application of different nutrient management practices on rice growth parameters is given in **Table 4**. In general, all the plant parameters corroborated the trends in grain and straw yields.

4.1.3.1. Plant height

The average plant height ranged from 94.37 to 112.5 cm among the treatments (**Table 4).** Treatment T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)) recorded the maximum plant height (112.5 cm) which is on par with T_3 (150 per cent NPK), T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) and T_9 ((50 per cent NPK + FYM @ 5 t ha-1 (to Virippu crop only)). The treatment T_{12} (Absolute control) produced plants with lowest height (94.37 cm) which is on par with T_1 (50 per cent NPK (100 per cent NPK as per KAU POP recommendation is 90:45:45 N: P_2O_5: K_2O kg ha^{-1})), T_6 (100 per cent NP) and T_7 (100 per cent N).

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4.1.3.2. Number of tillers per plant

Average number of tillers per plant ranged from 7.30 to 12.45 (**Table 4**). Treatment T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) recorded the maximum number of tillers per plant (12.45) which is on par with T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The treatment T_7 (100 per cent N) produced plants with lowest number of tillers (7.30) which is on par with T_{12} (Absolute control).

4.1.3.3. Panicle length

Data revealed that there was significant difference in panicle length between the various treatments in **Table 4**. The mean values ranged from 15.98 to 24.85 cm. Treatment T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) recorded the maximum panicle length (24.85 cm) which is on par with T_3 (150 per cent NPK) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The treatment T_{12} (Absolute control) produced plants with lowest panicle length (15.98 cm) which is on par with T_7 (100 per cent N).

4.1.3.4. Number of panicles per plant

The effect of long term application of different nutrient management practices on number of panicles per plant is presented in **Table 4**. Average number of panicles per plant ranged from 7.18 to 11.15. Treatment T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) had the maximum no of panicles per plant (11.15) which is on par with T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)).The lowest value for number of panicles per plant was 7.18, noticed in T_7 (100 per cent N) and is on par with T_{12} (Absolute control) and T_6 (100 per cent NP).

4.1.4. Pooled grain yield

The pooled grain yield (pooled over 41 seasons from 1997 to 2018) is significantly affected by long term application of different nutrient management practices (**Table 5).** The average grain yield ranged from 2074 to 3592 kg ha^{-1}. The highest grain yield of 3592 kg ha^{-1} was recorded by the treatment T_8 (100 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) which is followed by T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The treatment T_{12} (Absolute control) recorded the lowest mean value of 2074 kg ha^{-1}.

4.1.5. Pooled straw yield

Pooled straw yield from 1997 to 2018 (41seasons) was significantly affected by nutrient management practices (**Table 5).** The values ranged from 2310 to 4023 kg ha^{-1}. The highest pooled straw yield of 4023 kg ha^{-1} was recorded by the treatment T_8 (100 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) which is followed by T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The treatment T_{12} (Absolute control) recorded the lowest straw yield of 2310 kg ha^{-1}.

4.2 CARBON SEQUESTRATION PATTERN

The carbon sequestration pattern can be explained by quantifying carbon inputs into the soil and carbon sequestration rate in soil. The carbon inputs being incorporated into the soil include carbon from stubbles, un-removed weeds, assimilated biomass share and organic amendments.

4.2.1. Stubble - biomass

Statistical analysis showed that biomass of stubbles is significantly affected by long term application of different nutrient management practices (**Table 6**). The average biomass of stubbles ranged from 952.0 to 1493 kg ha^{-1}. The highest stubble biomass 1493 kg ha^{-1} was recorded by the treatment T_8 (100 percent NPK + FYM @ 5 t ha^{-1} which is on par with T_{10} (100 per cent NPK + *in* *situ* growing of *Sesbania aculeata* (for Virippu crop only)) and T_3 (150 percent NPK). The treatment T_{12} (Absolute control) recorded the lowest biomass (952.0 kg ha^{-1}) of stubbles which is on par with T_6 (100 per cent NP) and T_1 (50 per cent NPK (100 per cent NPK as per KAU POP recommendation is 90:45:45 N: P_2O_5: K_2O kg ha^{-1})).

4.2.2 Weed biomass

The cumulative biomass of weeds (measured twice) is affected by long term application of different nutrient management practices and is shown in **Table 6.** The average biomass of weeds ranged from 134.7 to 194.0 kg ha^{-1}.

4.2.3. Carbon inputs other than organic amendments into soil (kg $ha^{-1}year^{-1}$)

The carbon inputs other than organic amendments into soil are significantly affected by long term application of different nutrient management practices and are given in **Table 7.** Carbon inputs into the experimental top soil included assimilated biomass carbon and biomass carbon from stubbles and weeds.

Nie *et al., (*2012) had quantified photo-assimilated carbon input into soil organic carbon pool through labeled studies in rice. They reported that 6.62 per cent of the assimilated rice carbon gets incorporated into soil organic carbon pools.

Thus the assimilated carbon ranged from 232.1 to 403.3 kg $ha^{-1}year^{-1}$. The share was highest (403.30 kg $ha^{-1}year^{-1}$) in the plots which received 100 per cent NPK along with FYM in treatment T_8. The incorporation of daincha along with fertilizers also had higher proportion of assimilated biomass carbon inputs into the soil. The lowest amount of 232.1 kg $ha^{-1}year^{-1}$ was recorded in T_{12} (Absolute Control).

The carbon inputs from stubble biomass ranged from799.7 to 1254.4 kg $ha^{-1}year^{-1}$. The highest amount of stubble biomass carbon (1254.4 kg $ha^{-1}year^{-1}$) was recorded by the treatment T_8 (100 per cent NPK+ FYM). T_3 (150 per cent

NPK) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)) had comparable amounts of carbon inputs into soil through the un harvested stubble biomass. The lowest amount of stubble biomass content of 799.7 kg $ha^{-1}year^{-1}$ was recorded by the treatment T_{12} (Absolute control).

The contribution of carbon inputs into soil through un-removed weed flora ranged from 80.81to 116.42 kg $ha^{-1}year^{-1}$. The weed population was higher in control treatment T_{12} and the contribution of weed carbon inputs as well.

The total carbon inputs excluding organic amendments being added into soil ranged from 1148 to 1747 kg $ha^{-1}year^{-1}$. The treatment T_8 (100 percent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)) had highest value which is on par with T_3 (150 per cent NPK) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). The lowest amount (1148 kg $ha^{-1}year^{-1}$) was recorded in treatment T_{12}.

Table 2. Effect of long term application of different management practices on rice grain yield (2017-18)

Treatments	Grain yield (kg ha^{-1})	
	Virippu	Mundakan
T_1	4215	2932
T_2	4528	3105
T_3	4985	3716
T_4	4489	3207
T_5	4538	3198
T_6	3547	2967
T_7	3248	2231
T_8	5148	3749
T_9	4795	3480
T_{10}	4989	3502
T_{11}	4558	3475
T_{12}	3278	2566
CD (0.05)	242.8	258.3

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha $^{-1}$

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

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Table 3. Effect of long term application of different nutrient management practices on rice straw yield (2017-18)

Treatments	Straw yield (kg ha^{-1})	
	Virippu	Mundakan
T1	4229	3518
T2	4674	3524
T3	5058	4105
T4	4622	3754
T5	5060	3658
T6	3702	3461
T7	3605	2758
T8	5230	4214
T9	4967	3985
T10	5123	4085
T11	4918	3847
T12	3342	2582
CD (0.05)	308.2	193.6

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha^{-1}

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

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Table 4. Effect of long term application of different nutrient management practices on rice growth parameters

Treatments	Plant height (cm)	No of tillers per plant	Panicle length (cm)	No of panicles per plant
T1	99.45	9.50	19.10	8.21
T2	105.4	9.61	20.80	8.48
T3	111.4	9.81	24.08	9.87
T4	104.2	9.64	20.54	8.47
T5	103.4	9.67	20.85	8.50
T6	100.1	8.74	18.90	7.84
T7	98.88	7.30	16.40	7.18
T8	109.6	12.45	24.85	11.15
T9	107.9	10.87	22.40	9.58
T10	112.5	11.24	23.47	10.64
T11	106.5	9.98	21.98	9.24
T12	94.37	7.58	15.98	7.45
CD (0.05)	5.92	1.10	2.32	0.74

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha $^{-1}$

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

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Table 5. Effect of long term application of different nutrient management practices on pooled yield (1997- 2018, 41 seasons)

Treatments	Yield	
	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T1	2724	3143
T2	2985	3350
T3	3156	3665
T4	2964	3378
T5	3016	3495
T6	2726	3256
T7	2545	2950
T8	3592	4023
T9	3130	3442
T10	3405	3830
T11	3009	3386
T12	2074	2310
CD (0.05)	94.35	127.4

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha^{-1}

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

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Table 6. Effect of long term application of different nutrient management practices on stubbles and weed biomass being incorporated into soil

Treatments	Stubble biomass (kg $ha^{-1}season^{-1}$)	Weed biomass (kg $ha^{-1}season^{-1}$)
T1	1088	183.3
T2	1263	170.5
T3	1460	152.5
T4	1289	163.3
T5	1291	165.2
T6	1096	160.0
T7	1142	175.2
T8	1493	149.1
T9	1330	152.3
T10	1476	134.7
T11	1300	151.8
T12	952.0	194.0
CD (0.05)	159.3	26.14

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha^{-1}

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

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Table 7. Total carbon inputs excluding organic amendments being added into soil as affected by the long term application of different management practices

Treatments	Assimilated biomass carbon share ($kgha^{-1}yr^{-1}$)	Stubble biomass carbon ($kgha^{-1}yr$)	Weed biomass carbon ($kgha^{-1}yr^{-1}$)	TOTAL ($kgha^{-1}yr^{-1}$)
T1	310.7	913.9	110.00	1335
T2	335.5	1061.1	102.30	1499
T3	361.2	1226.8	91.47	1679
T4	335.9	1082.4	98.00	1516
T5	344.8	1084.3	99.12	1528
T6	316.8	920.2	96.00	1333
T7	291.0	959.4	105.12	1356
T8	403.3	1254.4	89.43	1747
T9	348.0	1117.6	91.38	1557
T10	383.1	1240.1	80.81	1704
T11	338.6	1091.7	91.08	1521
T12	232.1	799.7	116.42	1148

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha $^{-1}$

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

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4.2.4. Carbon inputs including organic amendments into soil (kg ha^{-1}year^{-1})

The treatments T_8 to T_{11} are INM practices which include the organic manure addition into soil. In T_8 and T_9, FYM at the rate of 5000 kgha^{-1} was being added along with fertilizers. The average carbon content of FYM was analyzed to be 45 per cent age. Thus the carbon contribution into top soil through FYM is to the tune of 2.25 tonnes ha^{-1}year^{-1} (**Figure 2**).

The *in situ* growing of daincha produced an average biomass of 6860 kgha^{-1}, the per cent carbon content of which was analyzed to be 40, thus contributing 2.744 tonnes of carbon ha^{-1}year^{-1}.

The average annual total carbon inputs including those from organic amendments are given in the **Figure 3.** It ranged from 1148 to 4448 kg ha^{-1}. Highest carbon inputs was being incorporated into the plots which received 100 per cent NPK along with *in situ* green manured daincha. Though the inputs excluding organic amendments was highest in T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)), the higher biomass of daincha being produced and incorporated through *in situ* green manuring, increased the total carbon inputs in T_{10} making it the treatment with highest value. The annual total carbon input into soil was lowest in T_{12} (Absolute control).

4.2.5. Soil organic carbon distribution with soil depth

The effect of long term application of different nutrient management practices on distribution of soil organic carbon with soil depth is given in **Table 8.** There was significant difference between treatments with respect to OC in soil at 0-15 and 15-30 cm depths from surface. However the treatments did not differ significantly with respect to OC in soil at a depth of 30-45 cm from surface.

In 0-15 cm soil layer the OC ranged from 1.38 to 1.98 per cent. The highest organic carbon was recorded in T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) and the lowest in T_{12} (Absolute control).

Regarding the 15-30 cm layer, highest OC (1.42 per cent) was observed in T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) which is on par

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with T_9(50 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)), T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only) and T_{11} (50 per cent NPK + *in situ* growing of*Sesbania aculeata* (for Virippu crop only)). The lowest OC was 1.08 per cent in T_{12} (Absolute control).

4.2.6. Soil organic carbon mass and rate of carbon sequestration in top soil

The soil organic carbon in top soil at the start of the experiment in 1997 was 0.935 per cent. The change in OC content in soil under LTFE over years is given in **Figure 4.** The OC in soil increased from initial value at different rate in the twelve treatments. However the rate of increase was higher in the initial years regardless of the treatments of experimentation. Highest SOC was recorded in T_8 (100 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)).

The mass of soil organic carbon (MSOC) in top soil as affected by different treatments are given in **Figure 5.** The MSOC ranged from 27.95 to 34.75 tonha^{-1} measured in 2018 after 21 years from start. Highest MSOC was recorded by T_8(50 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) and lowest by T_{12} (Absolute control).

Effect of long term application of different nutrient management practices on soil carbon sequestration rate in top soil is given in **Figure 6.** The rate of sequestration of carbon (SSR) ranged from 0.461 to 0.785 tons ha^{-1}year^{-1}. Highest rate (SSR) was recorded by T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) followed by T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)). When we compare among the INM treatments T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)), T_9(50 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)), T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)) and T_{11} (50 per cent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only)), the reduction of fertilizer dosage to half of the recommendation could reduce the rate of sequestration of SOC.

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4.3 EFFICIENCY OF CARBON SEQUESTRATION

Figure 7. shows that the rate of sequestration of carbon had a linear relation with total carbon inputs. There was significantly positive linear correlation between carbon inputs and SOC sequestration rate under LTFE. The slope of the equation is 0.0083. It indicates that on an average 8.3 per cent of the total carbon inputs into soil was sequestrated into soil organic carbon. Hence the mean carbon sequestration efficiency was 8.4 per cent.

The average sequestration efficiency of the organic amendments is given in **Figure 8.** The carbon inputs from FYM and *insitu* growing of daincha are quantified as 2.25 and 2.74 tonsha^{-1} year^{-1}. The average carbon sequestration efficiencies for FYM and daincha were 12.17 and 8.58 per cent respectively. It is noted that when associated with 100 per cent NPK, the efficiency of FYM was 12.92 per cent and it decreased by 11.6 per cent when the NPK recommended along was reduced to half.

Likewise, the carbon sequestration efficiency of daincha was 9.0 per cent when combined with 100 per cent NPK while it decreased by 9.7 per cent when the NPK recommended was reduced to half.

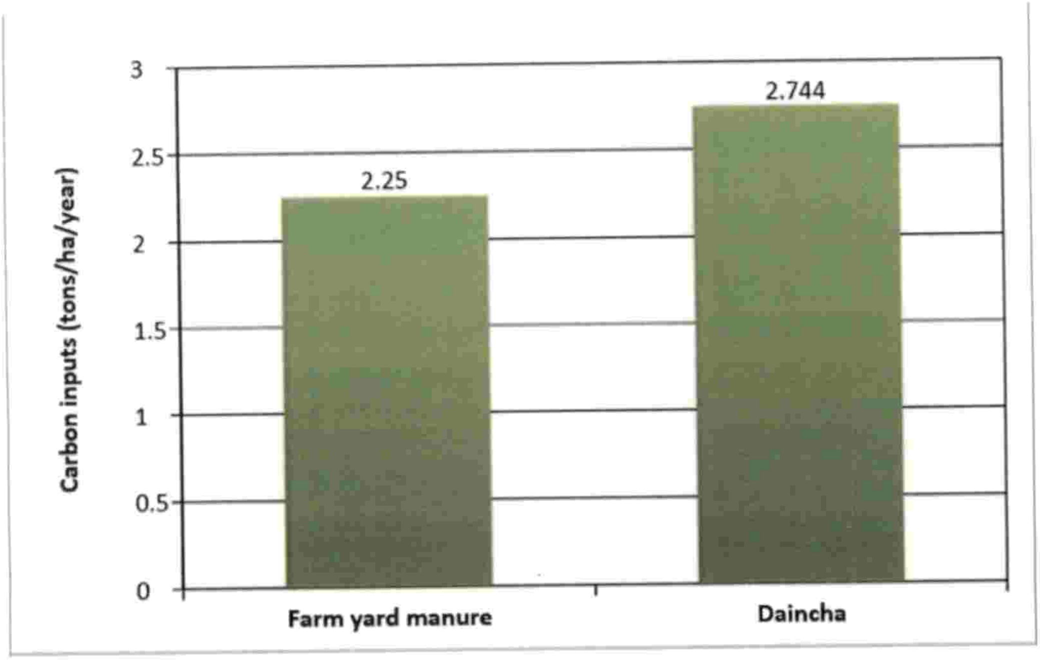

Fig.2. Carbon input addition from different organic amendments

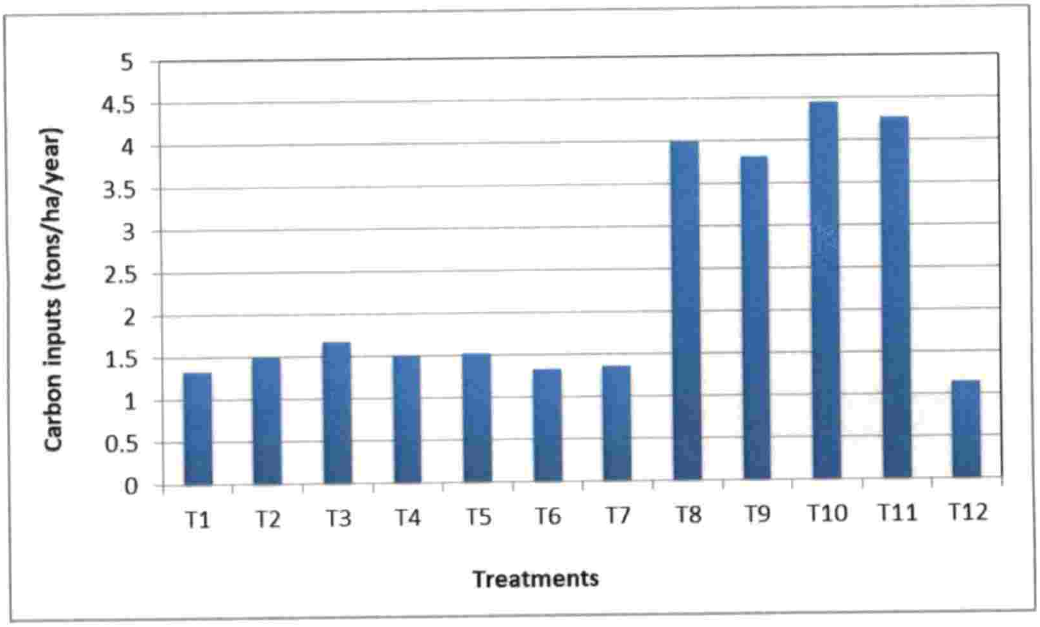

Fig.3. Effect of long term application of different nutrient management practices on total carbon inputs into soil (tons ha^{-1}year^{-1})

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Table 8. Effect of long term application of different nutrient management practices on distribution of soil organic carbon with soil depth

Soil organic carbon (%)			
Treatments	**0-15 cm**	**15-30 cm**	**30-45 cm**
T1	1.52	1.1	0.61
T2	1.54	1.21	0.58
T3	1.65	1.2	0.59
T4	1.58	1.15	0.62
T5	1.55	1.18	0.61
T6	1.45	1.04	0.55
T7	1.47	1.09	0.71
T8	1.98	1.42	0.79
T9	1.83	1.31	0.76
T10	1.88	1.32	0.69
T11	1.72	1.28	0.75
T12	1.38	1.08	0.68
CD (0.05)	0.08	0.14	NS

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha $^{-1}$

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (inVirippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

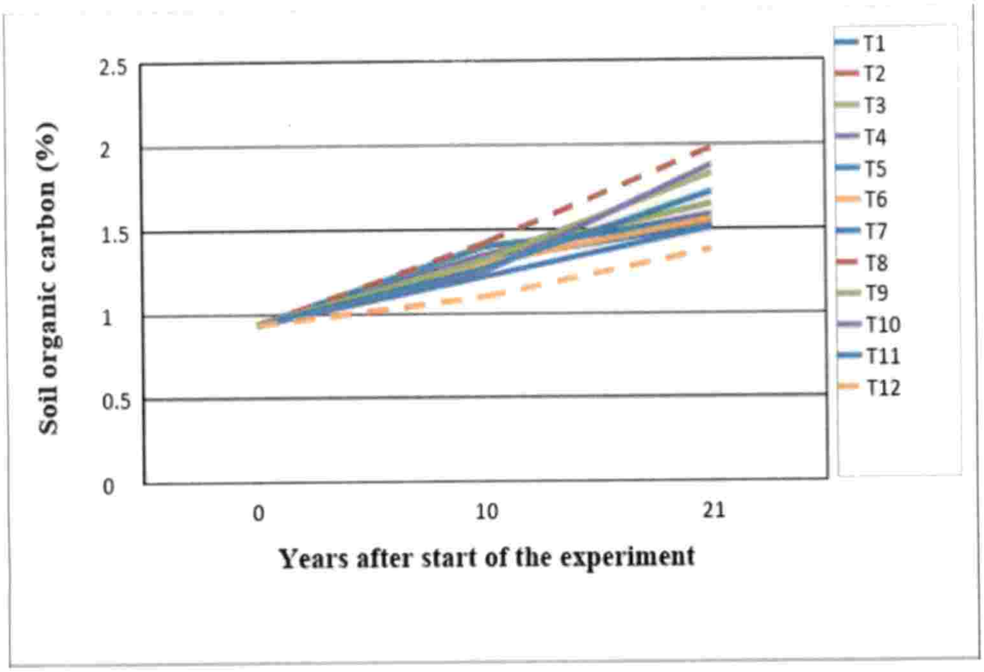

Fig.4. Change in soil organic carbon over years of experimentation under LTFE

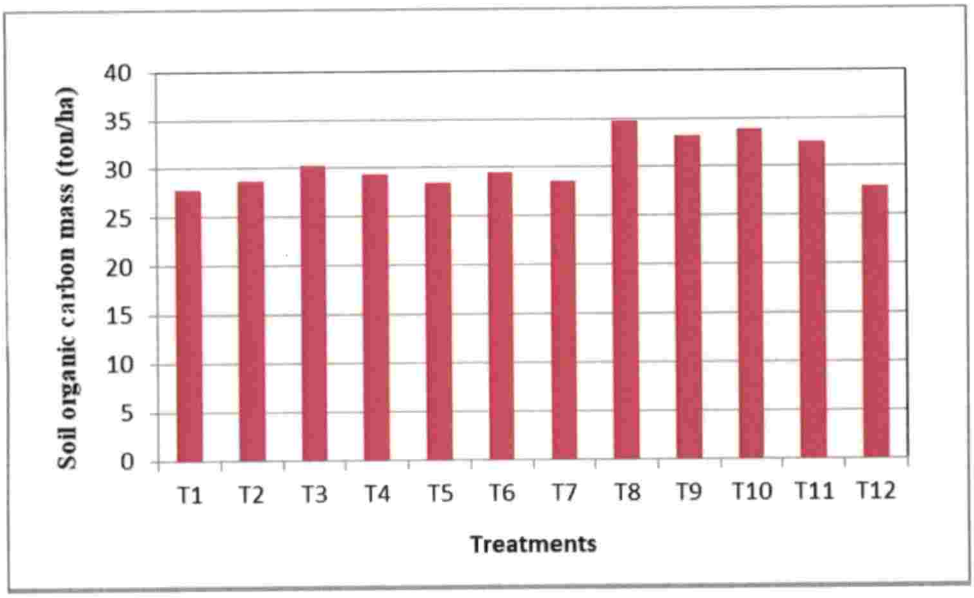

Fig.5. Mass of soil organic carbon in top soil in 2018 as affected by different treatments

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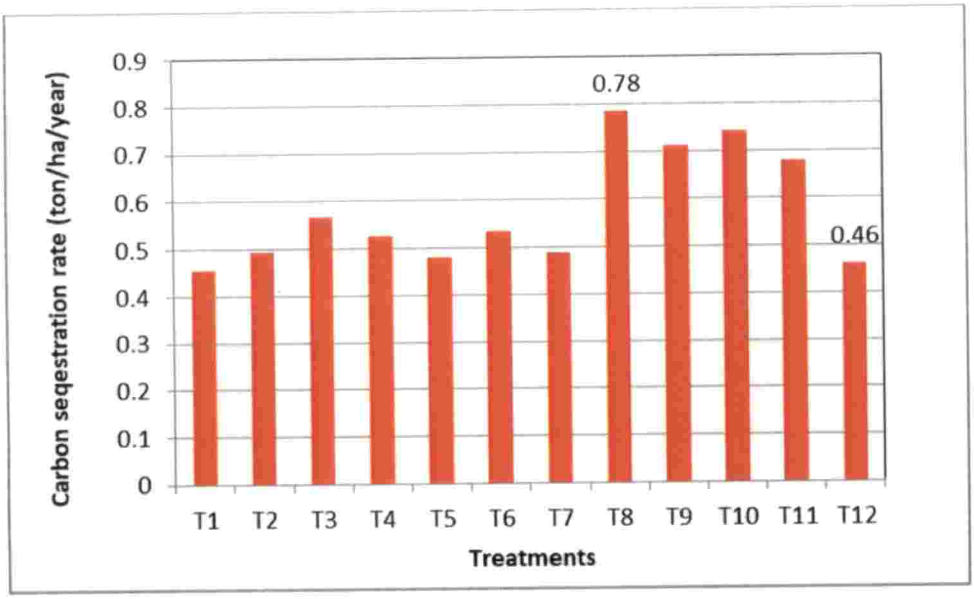

Fig.6. Effect of long term application of different nutrient management practices on soil carbon sequestration rate in top soil

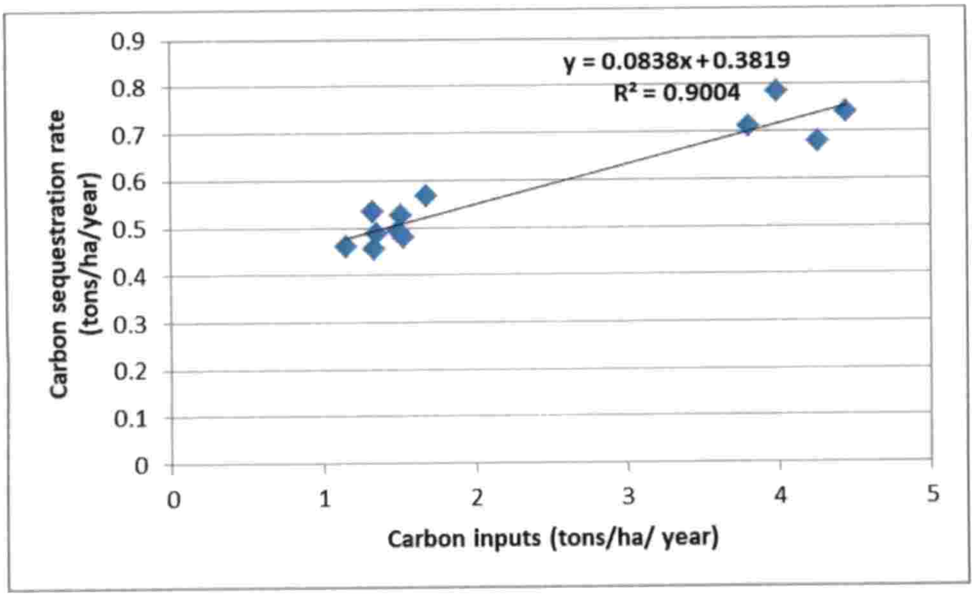

Fig.7. Relationship between total carbon inputs and SOC sequestration rate in experimental soil under LTFE

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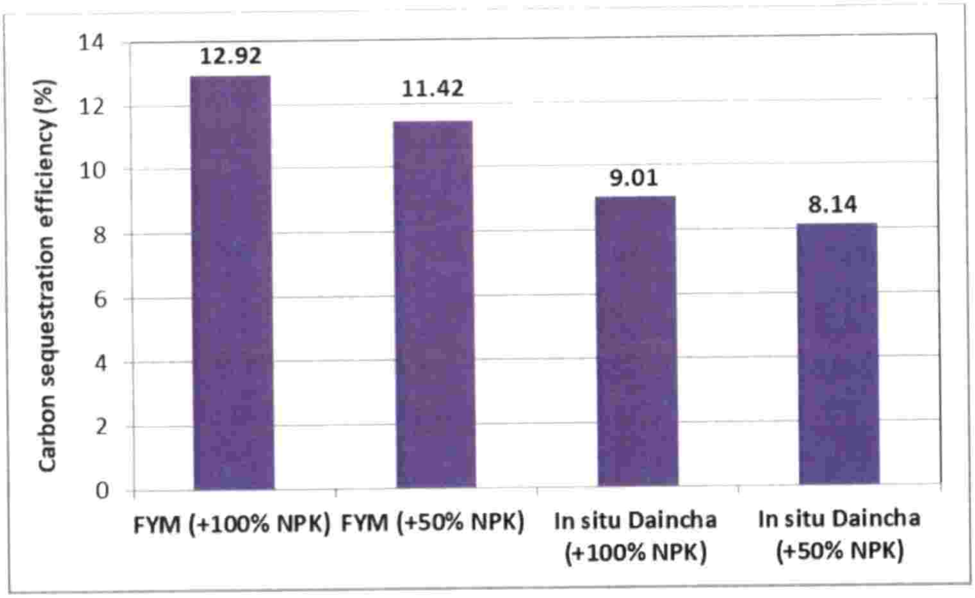

Fig.8. Carbon sequestration efficiency of different organic amendments as affected by fertilizer dosage

4.4. CROP WEATHER RELATIONS

4.4.1. Change in weather parameters during the period from 1998-2016

Variation in weather parameters is a significant character for agricultural productivity. Weather parameters such as maximum and minimum temperature, rainfall, sunshine hours, relative humidity and wind speed during the last two decades are analyzed. (Appendix □)

4.4.1.1. Temperature (^oC)

The maximum and minimum temperature over last 2 decades is given in **Figure 9.** The graph clearly describes that there are slight changes in temperature over years. Maximum temperature was highest (32.97°C) in 2011 and lowest (31.97°C) in 1999.

The minimum temperature was highest (23.58°C) in 1998 and lowest (22.67°C) in 2015.

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4.4.1.2. Rainfall (mm)

The rainfall pattern and trend over the last 2 decades is presented in the **Figure 10.** It shows a decreasing trend of rainfall at Pattambi over years. An anomalous increase in rainfall was observed in 2007(3714.4 mm per year). A drastic reduction in rainfall was observed in 2016, much lesser (1328.2 mm per year) compared to previous years. During the period from 2013 to 2016 there is a declining trend in rainfall and a drought condition in 2016-17.

4.4.1.3. Sunshine hours (hrs.)

The trend in sunshine hours past 2 decades is presented in the **Figure 11.** The amount of sunshine hours was highest (6.88 hrs.) in 2004 and lowest (4.47 hrs.) in 2015.

4.4.1.4. Relative humidity (%)

The yearly averaged maximum and minimum relative humidity over last 2 decades are presented in **Figure 12.** During the period from 1998-2016 the highest maximum relative humidity (91.3 per cent) was recorded in 2005 and lowest (88.45per cent) in 2000 and 2013.

Regarding the minimum relative humidity the highest value (60.24 per cent) was observed in 1998 and lowest value (59.99 per cent) in the year 2015.

4.4.1.5. Wind speed (km hr^{-1})

The wind speed over last 2 decades are given in the **Figure 13.** From the figure, it is evident that the wind speed distribution at Pattambi shows a decreasing trend over years. The highest wind speed was recorded in 2006 (4.8 km hr^{-1}) and the lowest value (2.2 km hr^{-1}) in 2015.

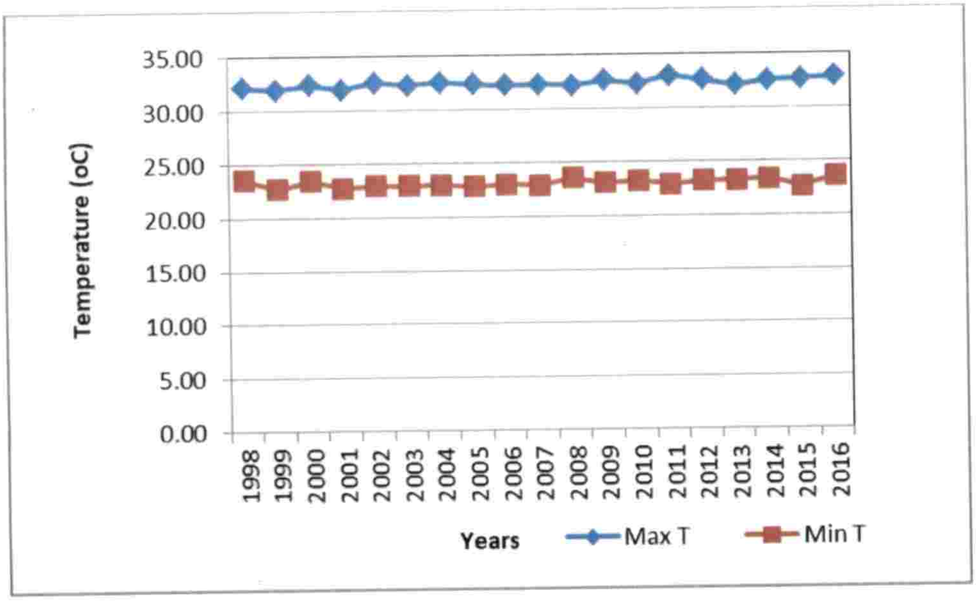

Fig.9. Temperature variation at Pattambi for the period from 1998-2016

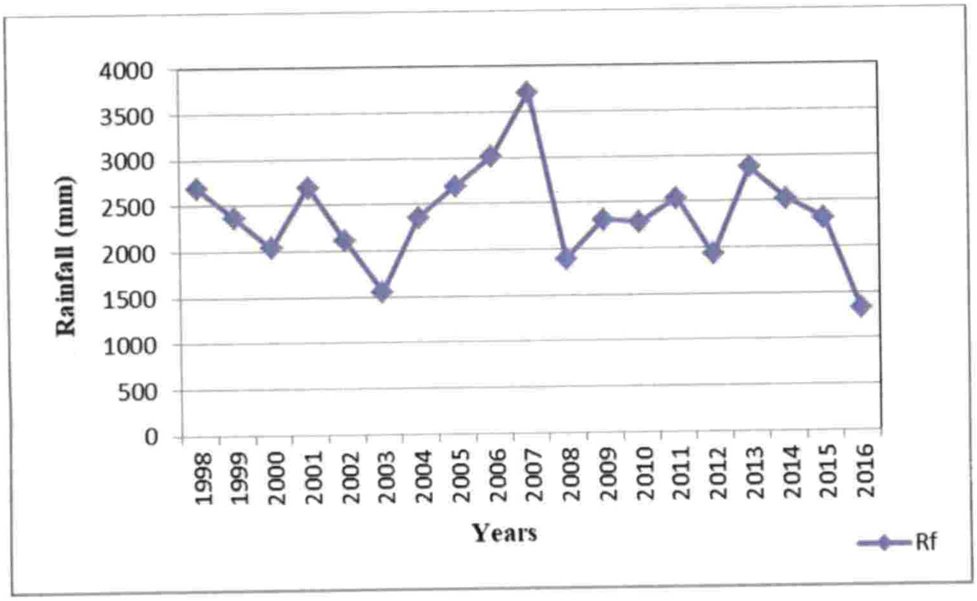

Fig.10. Rainfall pattern at Pattambi for the period from 1998-2016

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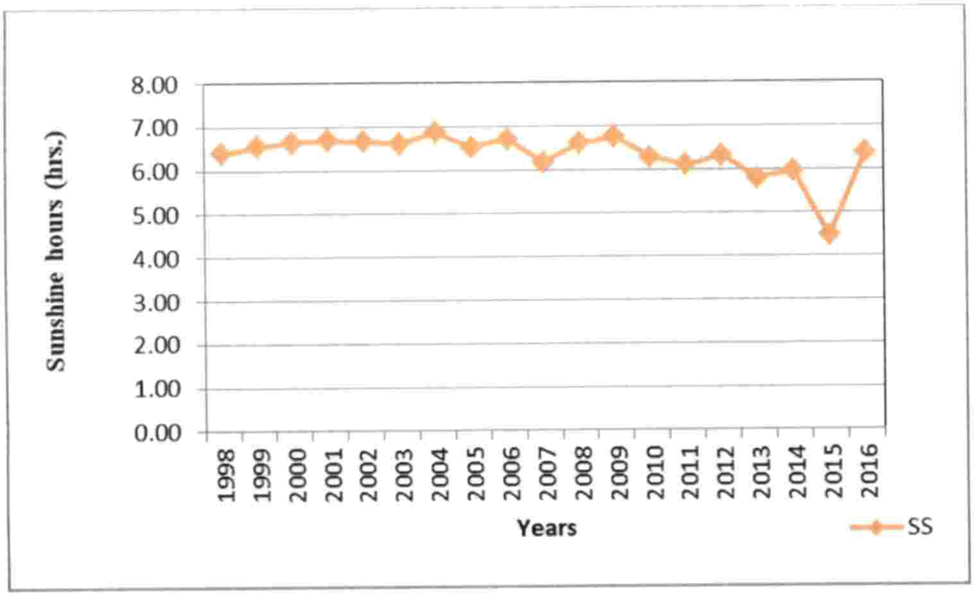

Fig.11.The amount of sunshine hours at Pattambi for the period from 1998-2016

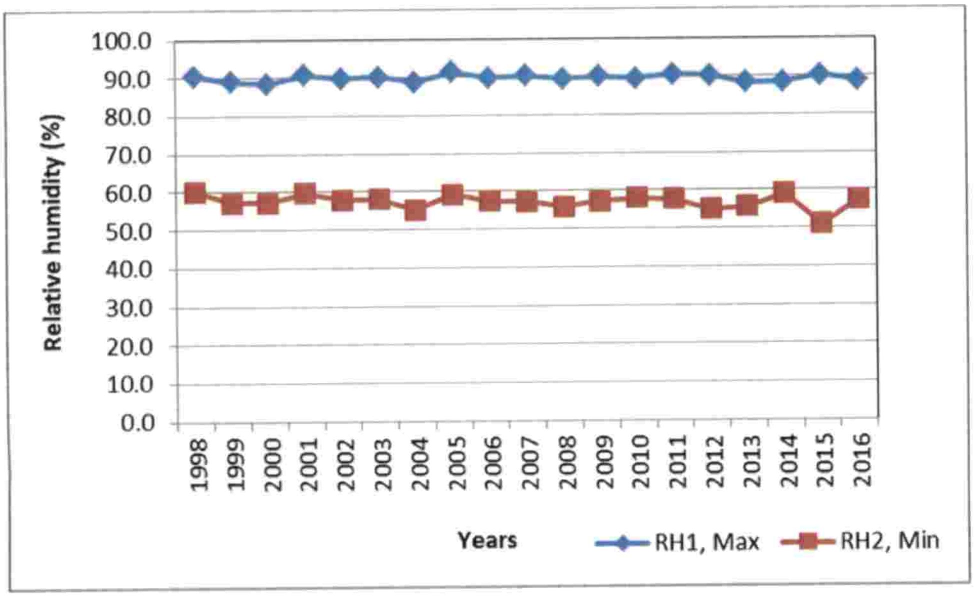

Fig.12. Relative humidity variation at Pattambi for the period from 1998-2016

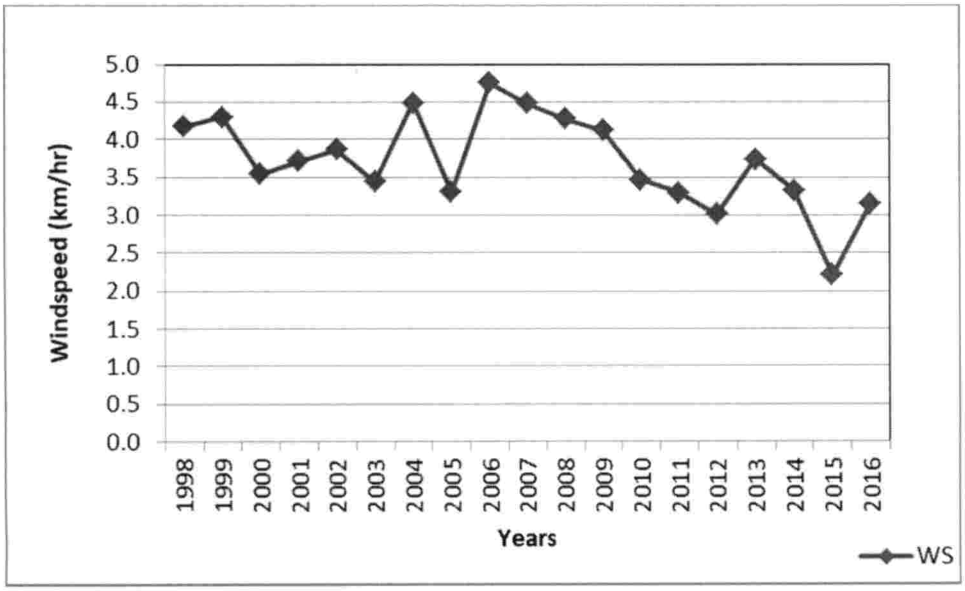

Fig.13. Variation in wind speed at Pattambi for the period from 1998-2016

4.4.2. Correlation studies between grain yield and weather parameters(1998-2016

The Correlation between final grain yield of Virippu and weather parameters were done and the results are depicted in **Table 9.** As per the results it can be seen that during Virippu (first crop season) season, maximum temperature had a positive influence on grain yield throughout the growing period, whereas the effect of Minimum temperature was not significant.

Rainfall had no significant impact on final grain yield. The impact of morning relative humidity is more predominant in determining grain yield. The effect of morning relative humidity was significant only from sowing to transplanting stages, whereas the impact of evening RH was not significant throughout the cropping season. The amount of bright sunshine hours also had positive correlation during tillering to flowering stage. Wind speed had a negative significant impact on grain yield during transplanting to tillering.

The Correlation between final grain yield of Mundakan and weather parameters were done and the results are depicted in **Table 10.** As per the results it can be seen that during Mundakan (second crop season), Maximum temperature had a positive influence on grain yield throughout the growing period. The effect of maximum temperature was significant only from transplanting to tillering. The effect of Minimum temperature was significant only from sowing to transplanting.

Rainfall during sowing to transplanting and tillering to flowering stage had a significant impact on final grain yield. The effect of morning Relative humidity was not significant only from flowering to maturity stages, whereas the impact of evening RH was significant throughout the cropping season. The amount of bright sunshine hours also had a negative influence on grain yield throughout the growing period. The effect of wind speed was not significant only from sowing to transplanting.

Table 9. Correlation between grain yield of Virippu season and weather parameters

Stages	**T max (°C)**	**T min (°C)**	**Rain fall (mm)**	**Sun shine (hrs)**	**RH$_1$ Max (%)**	**RH$_2$ Min (%)**	**Wind speed (km/ha)**
Sowing to Transplanting	0.61	-0.27	-0.19	0.12	-0.35	0.03	-0.12
Transplanting to Tillering	0.68	-0.11	0.16	-0.25	0.13	0.14	-0.47
Tillering to Flowering	0.63	0.08	-0.02	0.34	0.14	-0.01	-0.19
Flowering to Physiological Maturity	0.69	0.20	-0.08	0.13	-0.14	-0.07	0.21

Table 10.The correlation between grain yield of Mundakan season and weather parameters

Stages	T max (°C)	T min (°C)	Rain fall (mm)	Sun shine (hrs)	RH$_1$ Max (%)	RH$_2$ Min (%)	Wind speed (km/ha)
Sowing to Transplanting	0.11	0.44	-0.36	-0.54	0.36	-0.35	-0.24
Transplanting to Tillering	0.89	0.15	0.30	-0.58	0.52	-0.40	0.53
Tillering to Flowering	0.02	0.24	-0.38	-0.43	-0.47	-0.41	-0.35
Flowering to Physiological Maturity	0.01	-0.13	-0.16	-0.53	-0.15	-0.37	-0.46

4.4.3. DSSAT CERES- Rice modeling

CERES-Rice has been used in this study to model the effect of weather parameters on crop growth and yield. The CERES models have been extensively used for assessment of the impact of climate change on agricultural crop production.

The data from the experiment under fourteen dates of transplanting in two seasons (Virippu and Mundakan) has been used for validating CERES-Rice model (DSSAT 4.7). The Genetic coefficients of the variety were developed and presented in the **Table 11.**

The results of the CERES-Rice model prediction and observed yields over a period from 2007 to 2013are presented in **Table 12.**There is a perfect concurrence between predicted and observed yields in all the treatments. The observed and predicted yields indicate that Mundakan season had always more

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yield than Virippu season. The RMSE (Root Mean Square Error) for rice prediction and model efficiency were calculated and presented in **Table 13.**The observed and predicted yields of the twelve treatments under LTFE indicated a perfect concurrence **(Fig. 14-25).**(Appendix I)

Table 11. Genetic coefficients of rice variety, Aiswarya

Variety	Genetic coefficients								
	P1	**P2R**	**P5**	**P20**	**G1**	**G2**	**G3**	**G4**	**PHINT**	**G5**
Aiswarya	530.0	062.0	170.0	10.8	38.0	0.020	1.00	1.00	75.0	1.1

Table 12. Observed and Predicted grain yields of rice variety, Aiswarya

Treatments	Observed yield (kg ha^{-1})	Predicted yield (kg ha^{-1})
T_1	2774.8	2551.9
T_2	2710.5	2571.3
T_3	3272.4	3056.0
T_4	3214.7	2970.6
T_5	3208.2	2941.0
T_6	2836.7	2577.8
T_7	2684.0	2235.1
T_8	3848.5	3694.3
T_9	3229.6	3162.9
T_{10}	3482.4	3535.9
T_{11}	2842.6	3026.7
T_{12}	2378.5	1926.4

T_1 : 50 per cent NPK

T_2 : 100 per cent NPK

T_3 : 150 per cent NPK

T_4 : 100 per cent NPK + CaCO3 @ 600 kg ha $^{-1}$

T_5 : 100 per cent NPK

T_6 : 100 per cent NP

T_7 : 100 per cent N

T_8 : 100 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_9 : 50 per cent NPK + FYM @ 5 t ha $^{-1}$ (to Virippu crop only)

T_{10} : 100 per cent NPK + *in situ* growing of *Sesbania aculeata* (in Virippu crop only)

T_{11} : 50 per cent NPK + *in situ* growing of *Sesbania aculeata* (in Virippu crop only)

T_{12} : Absolute control (no fertilizers or manures)

100 per cent NPK as per KAU POP recommendation is 90.45:45 N: P_2O_5: K_2O kg ha^{-1}

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Table 13. Root Mean Square Error (RMSE) for DSSAT prediction

Model	RMSE
CERES-Rice	4.44 (good)

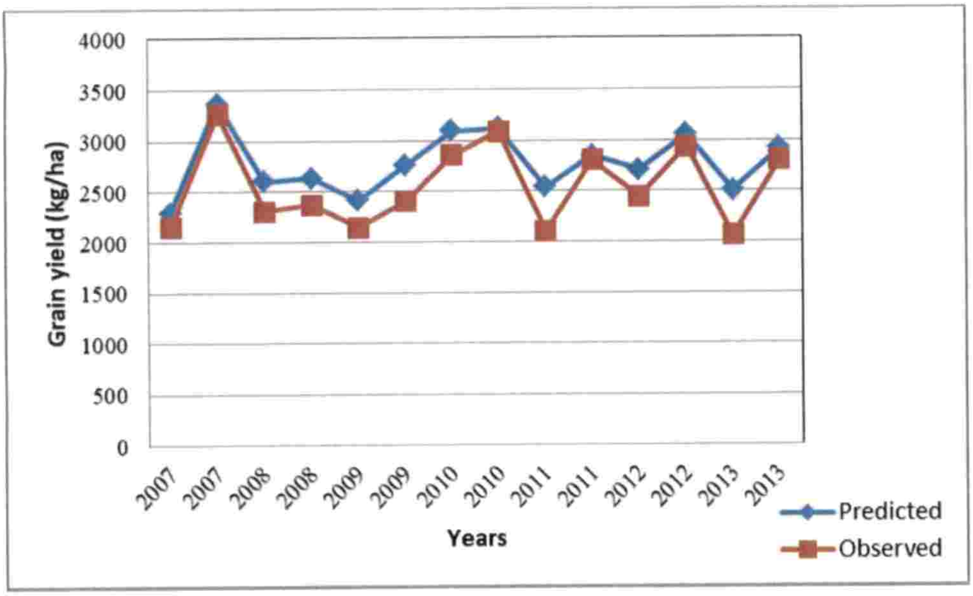

Fig.14. Observed and simulated yields of Treatment 1 using DSSAT model

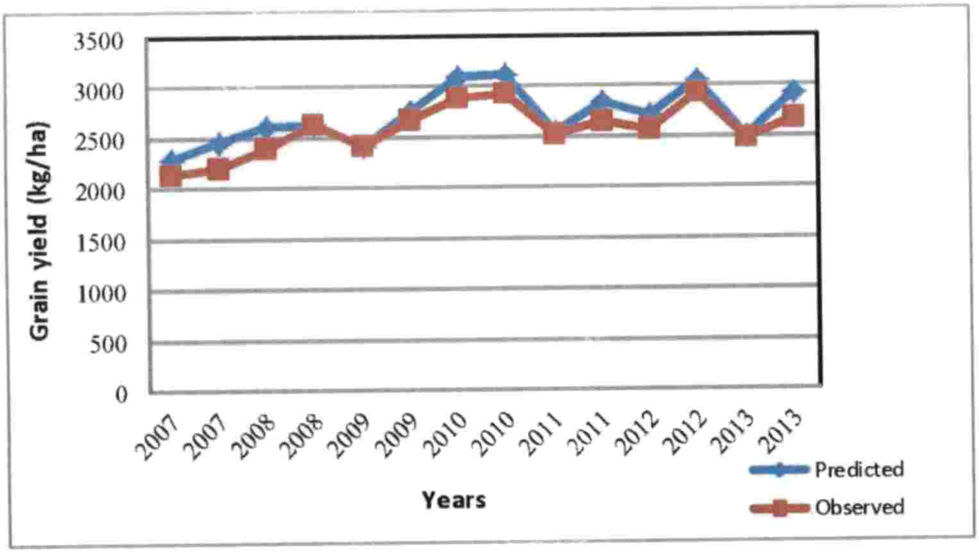

Fig.15. Observed and simulated yields of Treatment 2 using DSSAT model

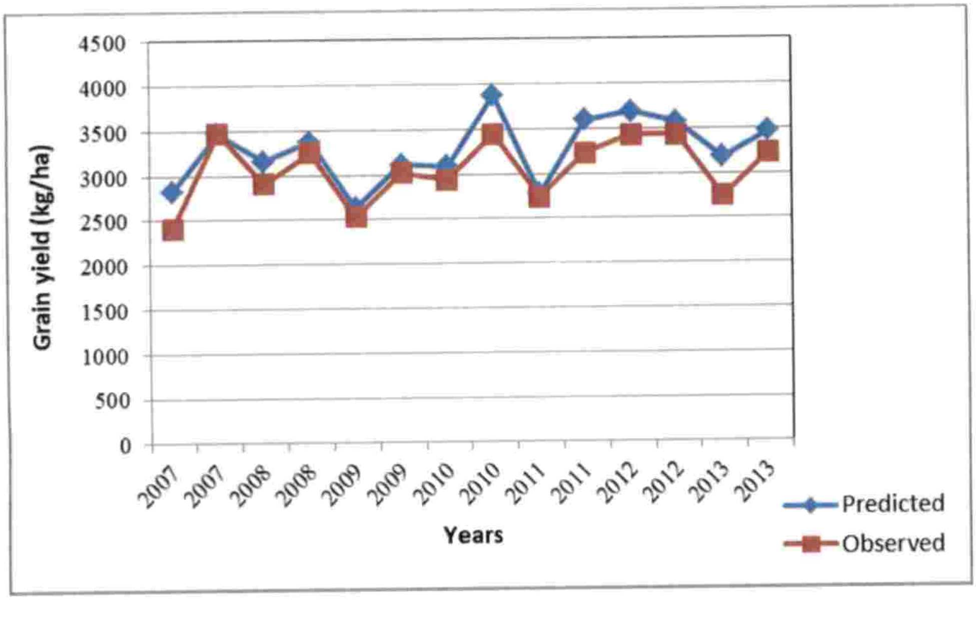

Fig.16. Observed and simulated yields of Treatment 3 using DSSAT model

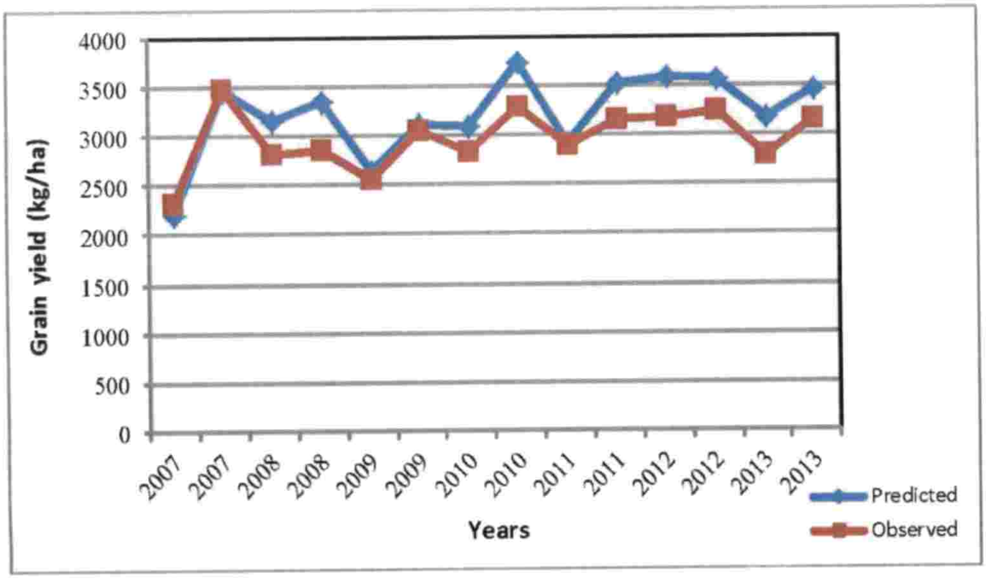

Fig.17. Observed and simulated yields of Treatment 4 using DSSAT model

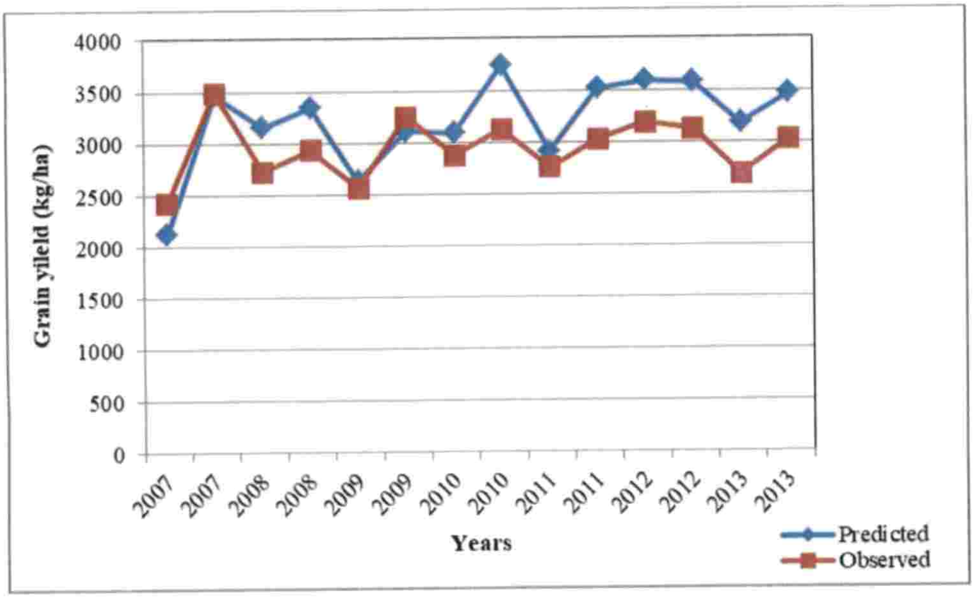

Fig.18. Observed and simulated yields of Treatment 5 using DSSAT model

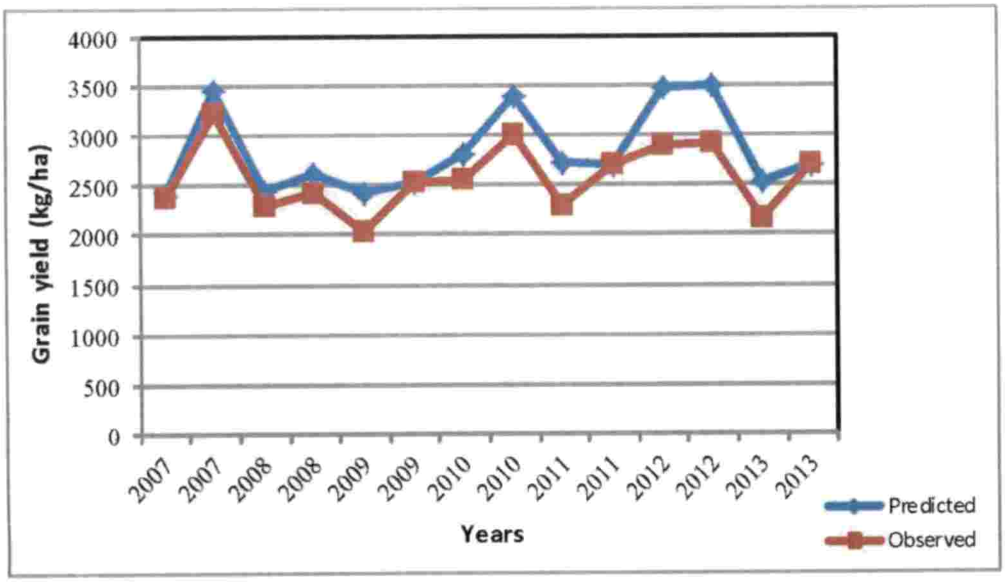

Fig.19. Observed and simulated yields of Treatment 6 using DSSAT model

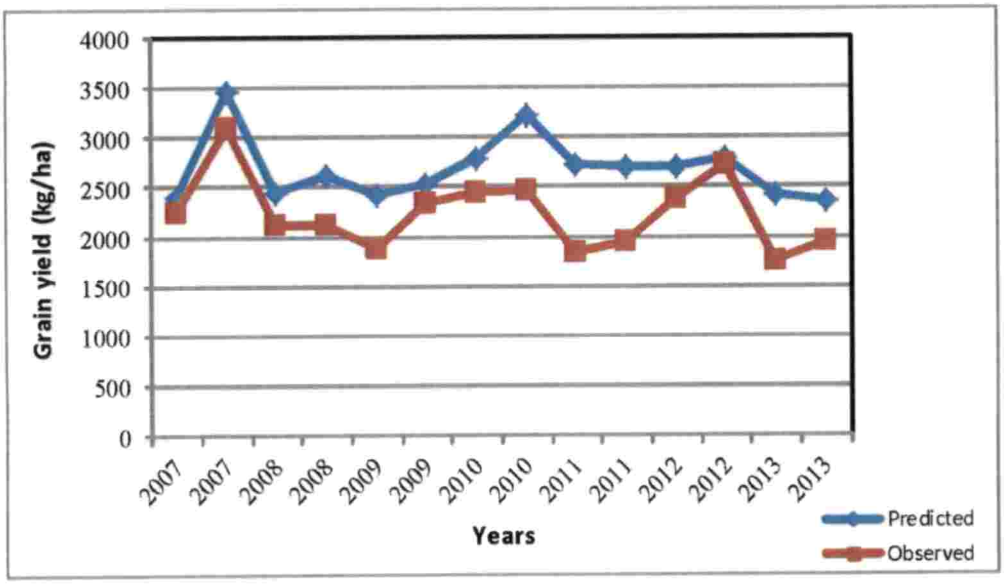

Fig.20. Observed and simulated yields of Treatment 7 using DSSAT model

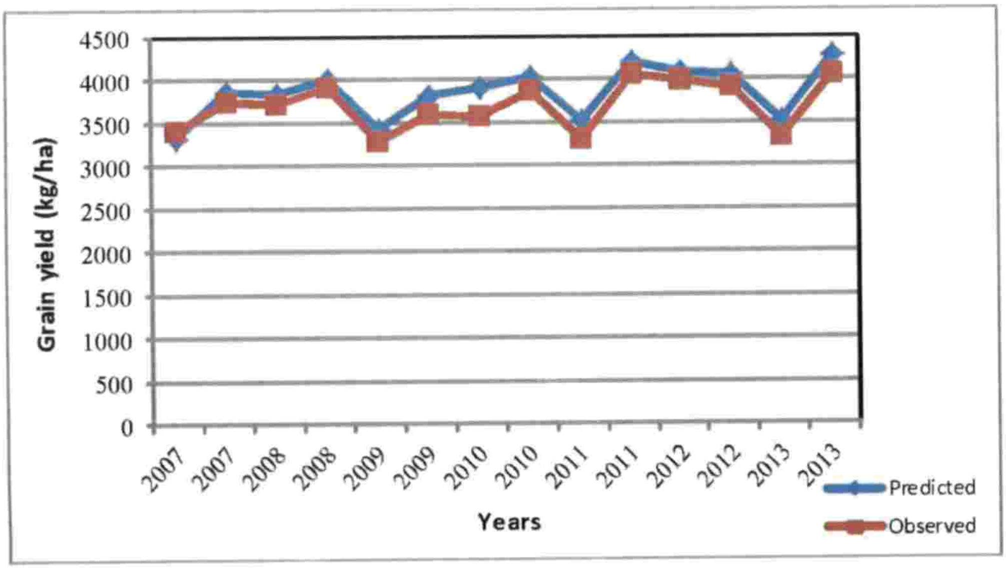

Fig.21. Observed and simulated yields of Treatment 8 using DSSAT model

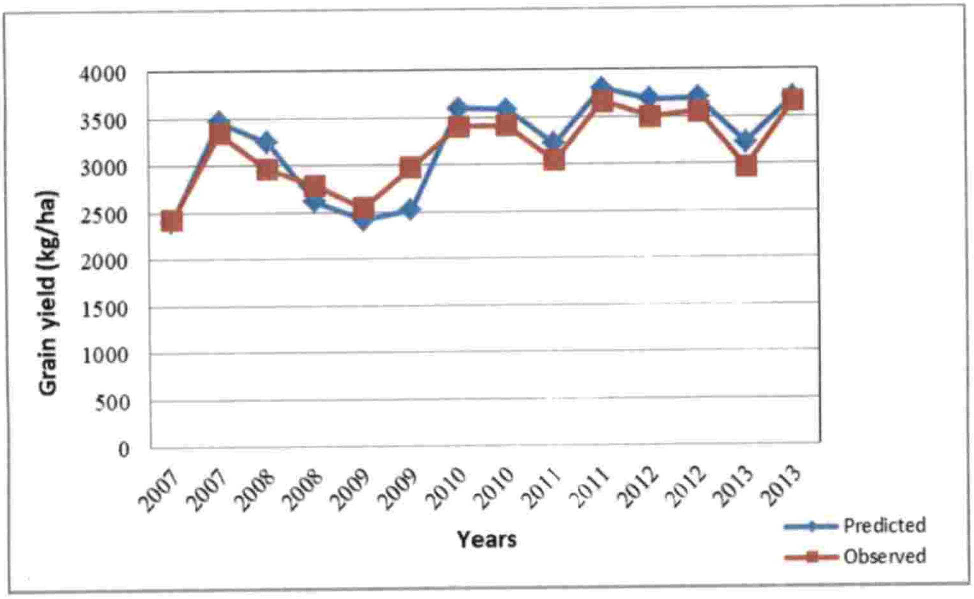

Fig.22. Observed and simulated yields of Treatment 9 using DSSAT model

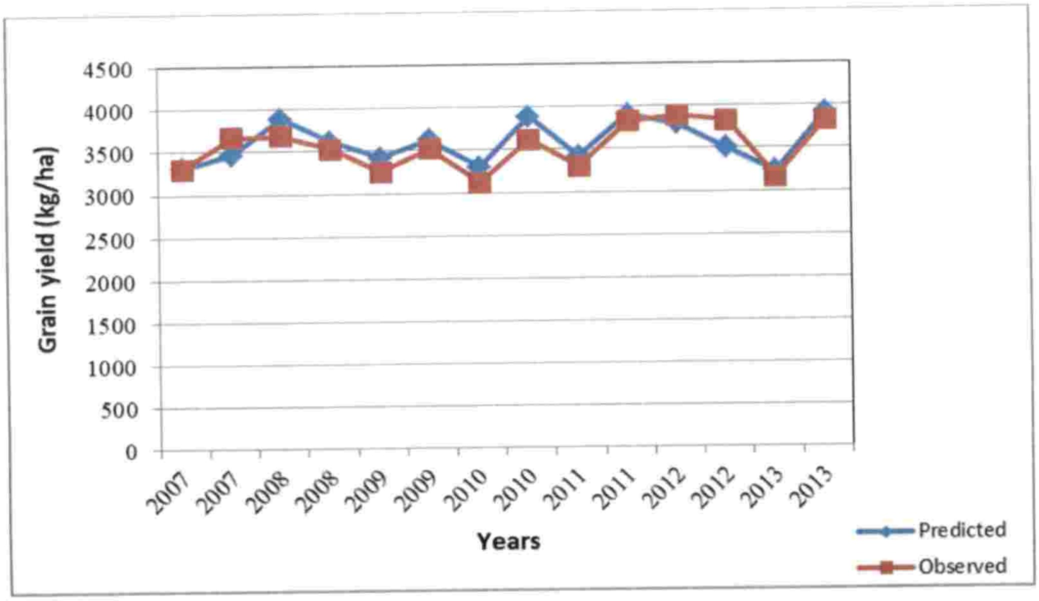

Fig.23. Observed and simulated yields of Treatment 10 using DSSAT model

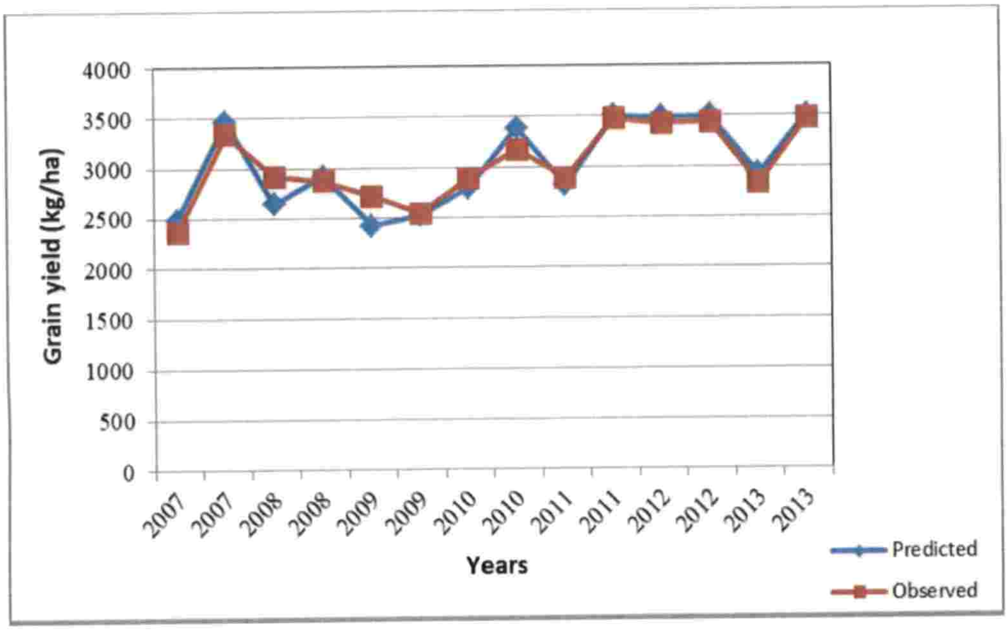

Fig.24. Observed and simulated yields of Treatment 11 using DSSAT model

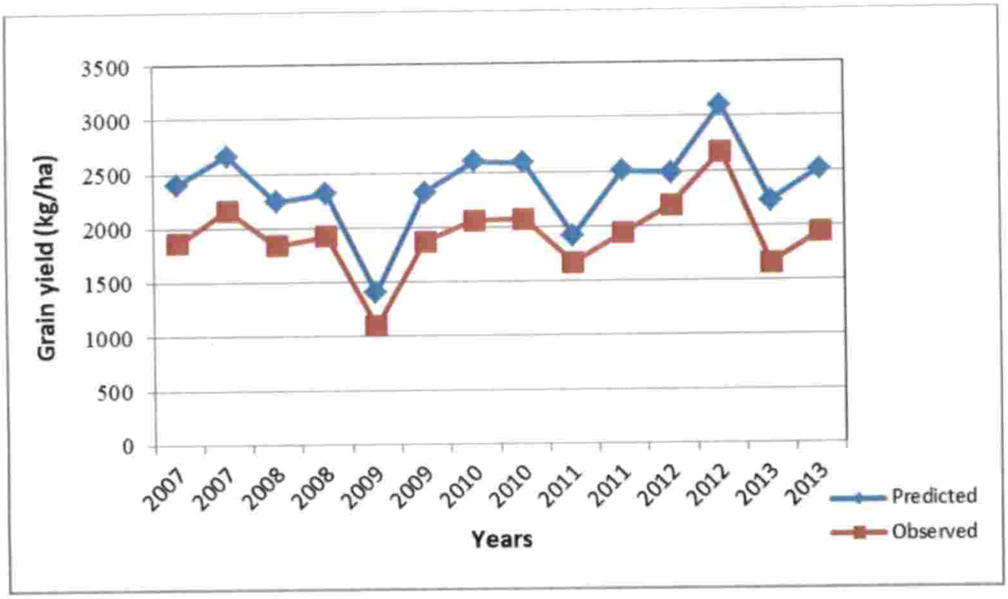

Fig.25. Observed and simulated yields of Treatment 12 using DSSAT model

4.5. DISCUSSION

The results of LTFE provide ample information on the effect of organic manure and inorganic fertilizer on sustaining productivity. The outcomes from our experiment prevalence the superiority of INM over sole application of chemical fertilizers. The positive effect of INM can be attributed to the effect of organic manures on improvement of physical, chemical and biological properties of the soil and hence the nutrient use efficiency (NUE) of the crop.

Ram and Saha (1999) reported that the highest grain and straw yields of rice were observed in the treatments where organic manures like FYM or *Sesbania* green manure and chemical nitrogen fertilizer were applied in 50:50 combination and comparatively lower yield when N fertilizer was applied as urea alone. The results are in conformity with the findings of Kumar *et al*., 2014 and Kurumthottical (1982) in rice.

Our results clearly show that the trends in soil organic carbon depend on the long term nutrient management regime. The carbon sequestration rate had a positive relation with the carbon inputs into the soil. Several studies could not establish general relationship between carbon inputs and carbon sequestration (Gulde *et al.*, 2008; Stewart *et al.*, 2009; Chung *et al.*, 2009). There are studies could establish a linear or logarithmic relation between carbon sequestration rate and carbon inputs (McLauchlan, 2006; Zhang *et al.*, 2012; Yan *et al.*, 2013). In the present study we could obtain a clear linear relationship between the annual carbon inputs and SOC sequestration rate which was similar to the findings in upland paddy soils (Zhang *et al.*, 2012; Kong *et al.*, 2005).

Zhang *et al.*, (2010) reported a mean carbon sequestration efficiency of 6.8 per cent for alluvial soils and Hue *et al.*, (2014) reported 16 per cent for vertisol. We could see that that the carbon sequestration efficiency of the organic manures decreased as the fertilizers recommended along with the manures were reduced to half. This can be attributed to the reduced microbial activity in the soil indicated by the lower microbial biomass carbon and dehydrogenase activity reported in the experimental soils (Sumayya, 2017).

Many factors have been suggested to affect the humification process. The factors include the type of input material, soil type, climate factors, soil nutrient status etc. (Lin and Wen, 1987; Galantini *et al.*, 1992). However the quality of the organic amendments is the dominant driver determining carbon sequestration efficiencies of organic amendments (Maillard and Angers, 2014). In the present study FYM had better efficiency of sequestration of carbon in soil compared to daincha. The FYM include the resistant or stabilized components of carbon thus leading to more efficiency of sequestration of carbon in soil. Therefore application of FYM seems to be a preferred strategy for enhancing SOC sequestration in lateritic soils due to its higher carbon sequestration efficiency.

In the present correlation studies, a positive correlation was observed between grain yield and maximum temperature. This is in conformity with other findings. Sreedharan (1975) reported that the temperature required for accelerating shoot and root growth is 26° C and low temperature weakens the rate

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of germination. The presence of high temperature accelerates the floral initiation in rice (Vergara *et al.*, 1972).

In the present study, a negative correlation was observed between grain yield and rainfall. Vijayakumar (1996) reported that when rain occurred continuously for three days rice flowering was affected. Due to continuous rain coupled with strong wind at flowering in wet season low yield was obtained (Pradhan and Dixit, 1989). Narayanan (2004) found that a positive non-significant correlation between grain yield and total rainfall; whereas total rainfall was negatively correlated with straw yield in non-significant manner.

Viswambaran *et al.,* (1989) noted a negative correlation between yield and number of rainy days during maturity phase. Total rainfall during this stage was negatively correlated with grain and straw yield in a non-significant manner (Narayanan, 2004).

The impact of morning relative humidity was more predominant in determining grain yield of the LTFE. Sunil (2000) reported that during active tillering increase in relative humidity can increase the number of panicles per hill. At high relative humidity, high solar radiation positively influenced the number of leaves per plant and low relative humidity shortened the days taken from transplanting to panicle initiation.

Kamalam *et al*., (1988) mentioned that wind velocity at tillering stage had a positive significant correlation with grain yield. Lenka (2000) found that wind during flowering stage in *kharif* season resulted in 63 per cent panicle grain sterility and heavy loss in grain yield. The LTFE studies also indicated a negative impact of wind speed during transplanting to tillering on grain yield.

Sreenivasan (1985) reported that at the time of the flower opening strong winds may induce sterility and increase the number of abortive endosperms. During flowering high wind speed had caused pollen dehydration and consequent spikelet sterility in rice (Rao, 2003)

SUMMARY

5. SUMMARY

The present study entitled 'Carbon sequestration and crop weather relations in long term fertilizer experiment at Pattambi' was formulated with the objectives of studying the effect of long term application of fertilizers and manures on soil carbon sequestration pattern and crop weather relations under long term fertilizer experiments with rice-rice cropping sequence. AICRP on Long Term Fertilizer Experiments (LTFE) at RARS, Pattambi formed the study material. The results of the detailed investigations carried out, in field and in laboratory are summarized below:

Growth and yield

- Regarding grain yield, during the year 2017-18, integrated nutrient management practice T_8 (100 Per cent NPK + FYM) had higher values which are on par with T_3 (150 percent NPK) and T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeate*). The plots which received nitrogen alone (T_7) registered the lowest grain yields which is on par with T_{12} (Absolute control).
- Straw yield (2017-18) was the highest in the treatment T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) which is statistically on par with T_3 (150 per cent NPK) and T_{10} (100 per cent NPK + in situ growing of *Sesbaniaaculeata* (for Virippu crop only)). The treatment T_{12} (Absolute control) recorded the lowest straw yield.
- In general, effect of long term application of different nutrient management practices on rice growth parameters corroborated the trends in grain and straw yields.
- Regarding the pooled grain yield from 1997 to 2018 (41season), the treatment T_8 (100 per cent NPK + FYM @ 5 t ha^{-1}) recorded the highest value followed by T_{10} (100 per cent NPK + in situ growing of *Sesbania*

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aculeata). The treatment T_{12} (Absolute control) recorded the lowest mean grain yield.

- The pooled straw yield was higher in the treatment T_8 (100 per cent NPK + FYM @ 5 t ha^{-1}) followed by T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata*). The treatment T_{12} (Absolute control) recorded the lowest mean value of straw yield.

Carbon sequestration pattern

- The stubble biomass carbon and assimilated carbon inputs were the highest in the plot which received 100 per cent NPK along with FYM (T_8) and is on par with that in T_{10}.
- The highest weed biomass was recorded by the treatment T_{12} (Absolute control). The treatment T_{10} (100 per cent NPK + *in situ* green manure) recorded the lowest biomass of weed.
- The average annual total carbon inputs including organic amendments was the highest in the plots which received 100 per cent NPK along with *in situ* green manured daincha. Though the inputs excluding organic amendments was the highest in T_8 (100 per cent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only)) the higher biomass of daincha being produced and incorporated under *in situ* green manuaring, increased the total carbon inputs in T_{10} andT_{11}.
- The carbon input contribution from FYM and daincha are 2.25 and 2.74 tons $ha^{-1}year^{-1}$ respectively.
- The soil organic carbon decreased with increase in soil depth. The SOC up to 30 cm depth from surface was the highest in treatment T_8. However, the treatments did not differ significantly with respect to SOC at higher depths ie, >30 cm from surface.
- The organic carbon in top soil increased from initial value of 0.935 per cent at different rates over years of experimentation in the twelve treatments. However the rate of increase was higher in the initial ten years

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regardless of the treatments. The highest soil organic carbon in top soil was recorded in T_8 (100 per cent NPK + FYM).

- Soil carbon sequestration rate (SSR) was highest in soil which received 100 per cent NPK and FYM and the lowest in control.
- The long term incorporation of 100 per cent NPK along with FYM sequester 785 kg of carbon per ha per year in top soil

Carbon sequestration efficiency

- A significant positive linear relationship exists between carbon inputs and rate of carbon sequestration in top soil. The mean carbon sequestration efficiency in top soil was 8.4%.
- The average sequestration efficiency for FYM and daincha were 12.18 and 8.58 per cent respectively.
- The decrease in dose of fertilizers incorporated along with organic manures decreased the carbon sequestration efficiency of the organic amendments.

Crop- weather relations

- Maximum temperature had a positive impact on grain yield in both seasons Virippu and Mundakan, while the effect of minimum temperature was not significant. In general the rainfall and wind speed had negative impact on grain yield.
- A perfect concurrence has been obtained between observed yield and predicted yield using CERES-Rice in all the treatments of LTFE

CONCLUSIONS

- Integrated nutrient management practice T_8 (100 Per cent NPK + FYM) recorded higher values for pooled grain yield and growth related parameters followed by T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata*) and T_3 (150 per cent NPK)

- The soil which received 100 per cent NPK+FYM (T_8) had higher mass of total organic carbon in top soil followed by T_{10}.
- A significant positive linear relationship exists between carbon inputs and rate of carbon sequestration. The mean carbon efficiency was 8.4%.
- The average sequestration efficiency for FYM and daincha were 12.18 and 8.58% respectively
- The decrease in dose of fertilizers incorporated along with organic manures decreased the carbon sequestration efficiency of the organic amendments
- Maximum temperature had a positive impact on grain yield in both seasons Virippu and Mundakan, while the effect of minimum temperature was not significant. In general the rainfall and wind speed had negative impact on grain yield.

FUTURE LINES OF WORK

- ➢ Chemical and physical stability of carbon
- ➢ Threshold carbon concept in soils of Kerala
- ➢ The impact of nutrient management practice on crop-weather relations in rice under LTFE.

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APPENDIX

APPENDIX I

The results of the CERES-Rice model prediction and observed yields over a period from 2007 to 2013

Treatment	2007		2008		2009		2010		2011		2012		2013	
	Virippu	Mundakan	Virippu	Mundakan	Virippu	Mundakan	Virippu	Mundakan	Virippu	Mundakan	Virippu	Mundakan	Virippu	Mundakan
T□ Predicted	2290	3365	2604	2633	2411	2756	3095	3119	2537	2850	2709	3057	2507	2915
T□ Observed	2153	3265	2305	2366	2139	2398	2853.8	3090.5	2104	2801	2445	2939	2062	2801
T□ Predicted	2290	2465	2604	2633	2411	2756	3095	3119	2537	2850	2709	3057	2507	2915
T□ Observed	2128	2196	2390	2616	2408	2669	2878.5	2920	2523	2645	2552	2928	2467	2677
T□ Predicted	2816	3467	3157	3375	2631	3113	3095	3880	2773	3596	3689	3576	3179	3467
T□ Observed	2399	3474	2905	3250	2531	3024	2941	3448.5	2743	3227	3434	3431	2750	3227

T□ Predicted	2214	3467	3157	3344	2631	3113	3095	3743	2912	3516	3593	3576	3179	3467
T□ Observed	2313	3485	2801	2854	2558	3056	2841	3287.3	2892	3150	3180	3237	2784	3150
T□ Predicted	2122	3467	3157	3344	2631	3113	3095	3743	2912	3516	3593	3576	3179	3467
T□ Observed	2423	3483	2722	2931	2563	3250	2874.3	3126	2758	3026	3186	3121	2685	3026
T□ Predicted	2406	3467	2446	2618	2421	2521	2799	3386	2721	2702	3486	3501	2529	2711
T□ Observed	2380	3230	2295	2420	2029	2518	2549.3	2994.3	2295	2700	2891	2921	2167	2700
T□ Predicted	2406	3467	2446	2618	2421	2521	2799	3221	2721	2702	2700	2795	2412	2348
T□ Observed	2249	3098	2120	2117	1879	2328	2453.3	2470.3	1828	1955	2374	2715	1750	1955
T□ Predicted	3333	3867	3846	4018	3421	3821	3899	4021	3521	4202	4080	4054	3512	4284

T□ Observed	3410	3731	3706	3900	3270	3606	3572.3	3853	3290	4069	3990	3922	3333	4069
T□ Predicted	2406	3467	3246	2618	2421	2521	3599	3586	3221	3802	3686	3701	3229	3711
T□ Observed	2434	3347	2958	2788	2549	2973	3409.75	3416	3046	3669	3501	3554	2967	3669
T□□ Predicted	3306	3467	3886	3618	3421	3621	2799	3886	3421	3902	3486	3501	2529	3911
T□□ Observed	3298	3667	3682	3525	3256	3516	3122	3618.5	3300	3817	3890	3828	3167	3817
T□□ Predicted	2488	3467	2446	2618	2421	2521	2799	3386	2721	2702	3486	3501	2529	2711
T□□ Observed	2368	3342	2922	2875	2715	2544	2895.5	3171.5	2894	3474	3426	3441	2833	3474
T□□ Predicted	2406	2667	2246	2318	1406	2321	2599	2586	1921	2502	2486	3101	2229	2511
T□□ Observed	1863	2165	1842	1922	1096	1870	2062	2072.5	1672	1939	2192	2676	1661	1937

APPENDIX □

Change in weather parameters during the period from 1998-2016

Years	T Max (^oC)	T Min (^oC)	Rain fall (mm)	Sunshine (hrs)	RH_1, Max (%)	RH_2, Min (%)	Wind speed (km ha^{-1})
1998	32.10	23.58	223.97	6.39	90.47	60.24	4.17
1999	31.91	22.72	196.68	6.55	88.95	57.30	4.30
2000	32.36	23.46	169.97	6.65	88.45	57.25	3.54
2001	31.93	22.76	224.53	6.69	90.79	59.73	3.71
2002	32.54	22.99	175.67	6.66	89.79	57.83	3.87
2003	32.29	22.98	129.82	6.62	90.24	58.04	3.44
2004	32.50	23.02	196.48	6.88	88.83	55.13	4.49
2005	32.35	22.86	224.40	6.53	91.31	59.27	3.30
2006	32.22	23.05	251.29	6.71	89.84	57.40	4.75
2007	32.30	22.89	309.53	6.17	90.37	57.22	4.48
2008	32.13	23.55	157.68	6.60	89.56	55.86	4.27
2009	32.59	23.11	192.75	6.76	89.95	57.16	4.12
2010	32.30	23.26	190.20	6.30	89.52	58.12	3.46
2011	32.97	22.91	211.62	6.10	90.50	57.74	3.29
2012	32.57	23.22	160.80	6.32	90.14	55.03	3.01
2013	32.11	23.25	239.02	5.79	88.38	55.67	3.74
2014	32.51	23.41	210.29	5.96	88.51	59.03	3.33
2015	32.64	22.67	192.66	4.47	90.21	50.99	2.21
2016	32.84	23.57	110.68	6.36	88.78	57.38	3.16

CARBON SEQUESTRATION AND CROP WEATHER RELATIONS IN LONG TERM FERTILIZER EXPERIMENTS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study entitled "Carbon sequestration and crop weather relations in long term fertilizer experiment was formulated with the objectives of studying the effect of long term application of fertilizers and manures on soil carbon sequestration pattern and crop weather relations under long term fertilizer experiments with rice-rice cropping sequence maintained at Pattambi. The objectives were set out to study the carbon sequestration pattern in long term fertilizer experiment (LTFE), estimation of the SOC sequestration efficiency of different organic manures and to analyze and establish crop weather relations in LTFE.

The LTFE consist of 12 treatments *viz.* T_1:50 percent NPK, T_2: 100 per cent NPK, T_3:150 per cent NPK, T_4: 100 per cent NPK + lime $CaCO_3$ @ 600 kg ha^{-1}, T_5: 100 per cent NPK, T_6: 100 per cent NP, T_7: 100 per cent N, T_8: 100 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only), T_9: 50 percent NPK + FYM @ 5 t ha^{-1} (to Virippu crop only), T_{10}: 100 percent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only) ,T_{11}: 50 percent NPK + *in situ* growing of *Sesbania aculeata* (for Virippu crop only), T_{12}: Absolute control (No fertilizers/ manures). The grain yield, straw yield, stubbles left after harvest and unincorporated weed biomass were quantified for calculating the carbon inputs into soil. The soil organic carbon distribution pattern was analysed in different depths. The total carbon inputs and soil organic carbon sequestration rate were plotted to establish the relationship. Crop weather relations were studied through correlation studies and DSSAT modelling.

Integrated nutrient management practice T_8 (100 Per cent NPK + FYM) recorded higher values for grain yield and growth related parameters followed by T_{10} (100 per cent NPK + *in situ* growing of *Sesbania aculeata*) and T_3 (150 per cent NPK).The soil which received 100 per cent NPK+FYM (T_8) had higher mass of total organic carbon in top soil followed by T_{10}. A significant positive linear relationship exists between carbon inputs and rate of carbon sequestration. The mean carbon sequestration efficiency was 8.4% in top soil. The average sequestration efficiency for FYM and daincha were 12.18 and 8.58% respectively.

The decrease in dose of fertilizers incorporated along with organic manures decreased the carbon sequestration efficiency of the organic amendments. Therefore application of FYM seems to be a preferred strategy for enhancing SOC sequestration in lateritic soils due to its higher carbon sequestration efficiency.

Maximum temperature had a positive impact on grain yield in both seasons Virippu and Mundakan, while the effect of minimum temperature was not significant. In general the rainfall and wind speed had negative impact on grain yield.

Furthermore, crop weather relations in rice are established by using available long term data using DSSAT. There is perfect concurrence between observed and predicted grain yield of the experiment. So this study will help in planning better and judicious carbon management strategies and recommendations for these soils for sustainable health and crop production.