

# Effect of different cropping systems on energy budgeting and carbon footprint



THESIS SUBMITTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE DEGREE OF  
**Master of Science (Agriculture)**

in  
**Agronomy**

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I certify that the entire scheme of investigation reported herein was planned and carried out solely by the candidate under my guidance and supervision. The data presented in the thesis, to the best of my knowledge and belief, are genuine and have not been utilized for the award of other degree or dissertation.

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Forwarded by

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**Effect of different cropping systems on energy budgeting and carbon footprint**



by  
*Rajkumar Khare*

Thesis submitted in partial fulfillment of  
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**Date:** - - 2021

**Place:** Varanasi

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## LIST OF ABBREVIATIONS

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%	:	Percent	MSL	:	Mean Sea Level
°C	:	Degree centigrade	N	:	Nitrogen
dSm	:	deci Siemen per meter	NAR	:	Net assimilation rate
ha	:	per hectare	NE	:	Net energy
@	:	at the rate of	No.	:	Number
₹	:	Rupees	NS	:	Non-significant
C	:	Carbon	OC	:	Organic carbon
CC	:	Carbon credit	P	:	Phosphorus
CD	:	Critical difference	ppm	:	Part per million
CE	:	Carbon efficiency	S	:	Sulphur
CF	:	Carbon footprint	SCS	:	Soil Carbon Stock
Cm	:	Centimeter	SE	:	Specific energy
CO <sub>2</sub>	:	Carbon dioxide	SEM <sub>±</sub>	:	Standard error of mean
DAS	:	Days after sowing	SOC	:	Soil Organic Carbon
DMA	:	Dry matter accumulation	SOM	:	Soil Organic Matter
e.g.,	:	for example( <i>exempli gratia</i> )	Spp.	:	Species
EC	:	Electrical conductivity	t	:	Tonnes
EP	:	Energy productivity	t/ha	:	Tones per hectare
<i>et al.</i>	:	and others ( <i>et alibi</i> )	Viz.	:	Namely ( <i>videlicet</i> )
<i>etc.</i>	:	and so fourth ( <i>et cetera</i> )	MSL	:	Mean Sea Level
EUE	:	Energy use efficiency	N	:	Nitrogen
EUE	:	Energy Use Efficiency	NAR	:	Net assimilation rate
G	:	Gram	NE	:	Net energy
GDP	:	Gross Domestic Products	No.	:	Number
H.I.	:	Harvest index	NS	:	Non-significant
Ha	:	Hectare	OC	:	Organic carbon
i.e.,	:	That is ( <i>idest</i> )	P	:	Phosphorus
K	:	Potassium	ppm	:	Part per million
K W/h	:	Kilo watt per hour	S	:	Sulphur
Kg	:	Kilogram			
kg/MJ	:	Kilogram per mega joule			
kg/plot	:	Kilogram per plot			
M <sup>3</sup> /ha	:	Cubic meter per hectare			
Mg/ha	:	Mega gram per hectare			
mha	:	Million hectares			
MJ/ha	:	Mega joule per hectare			
MJ/kg	:	Mega joule per kilogram			
MJ/unit	:	Megajoule per unit			
mm	:	Millimeter			
Kg	:	Kilogram			

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## **INTRODUCTION**

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Climate change and land-use systems are widely acknowledged as major environmental issues on the earth (Pielke, 2005). Agriculture has been identified as major land use, connected with the social, economic, and cultural activity that provides a wide range of ecosystem services globally (Howden et al., 2007). Agricultural systems, namely croplands and pastures, are contributing by 40% to global land cover (Ramankutty et al., 2008). Global CO<sub>2</sub> concentrations are significantly influenced by land-use change over the long term (Houghton and Goodale, 2004). Currently, agricultural activities are contributing from 12-14% to global anthropogenic greenhouse gas emissions to global CO<sub>2</sub> emissions, not including land clearing (Power, 2010). However, the exact magnitude of land-use change's impact on CO<sub>2</sub> emissions is not known (IPCC, 2007).

CO<sub>2</sub> is one of the essential components of the atmosphere. Natural processes such as respiration and volcanic eruptions, as well as human activities such as deforestation, land-use changes, and fossil fuel combustion, are responsible for the emission. As a result of our industrial revolution, the CO<sub>2</sub> levels in the atmosphere have risen by 48 percent. One of the most important long-lived "forces" of climate change, Anthropogenic sources of CO<sub>2</sub> emissions include fossil fuel emissions and net emissions from land-use change and land management, such as forestry and other land use, as well as emissions from carbonates during cement production (IPCC 2021). In the period 2009–2018, deforestation, changes in land cover, land use, and management methods accounted for around 14% of anthropogenic CO<sub>2</sub> emissions (Bastos et al., 2021).

Carbon emissions from land-use conversions, land management, and changes therein (Pomerantz et al., 2018) make up the global CO<sub>2</sub> emission from land-use change and land management, which is equivalent to the land-use, land-use change (LULUC) fluxes from agriculture, forestry, and other land-use sectors (Jia et al., 2019). It thus consists of gross emissions (loss of biomass and soil carbon in clearing

or logging, harvested product decay, emissions from peat drainage and burning, degradation) and gross removals (CO<sub>2</sub> uptake in natural vegetation regrowing after harvesting or agricultural abandonment, afforestation). LULUC fluxes refer to direct human involvement with terrestrial vegetation, as opposed to natural carbon fluxes that occur as a result of interannual variability or trends in environmental variables (particularly climate, CO<sub>2</sub> and nutrient deposition) (Houghton, 2013).

Modern agriculture entails the long-term utilization of soil resources because soil quality may readily decline in a short period. The soil nutrients and related soil processes, such as erosion, oxidation, mineralization, and leaching, are influenced by the land use pattern for different crops and soil management strategies (Celik, 2005; Liu et al., 2010). However, using a specific cropping system on the same piece of land for a long time might cause soil fertility to deteriorate. In India's Indo-Gangetic Plains (IGP), continuous cereal-cereal rotations have resulted in nutritional imbalances, soil deterioration, and increased insect-pest stress (Ladha et al., 2003; Chauhan et al., 2012). Long-term incorporation of pulses in maize-wheat rotations boosted soil fertility, which boosted crop nutrient uptake and production (Venkatesh et al., 2017). Due to incompatible agricultural techniques and land uses, a considerable reduction in soil health has been seen worldwide during the last several decades (Arshad and Martin, 2002). Excessive use of imbalanced inorganic chemicals, improper tillage, nutrient mining, and a variety of other anthropogenic activities are the main causes of soil deterioration (Xiubin et al., 2002).

From both an eccentric and anthropocentric perspective, the soil is a highly complex ecosystem and a highly important resource. Due to its many critical functions, such as (i) provision of food, fiber, and fuel; (ii) decomposition of organic matter (e.g., dead plant and animal material); (iii) Recycling of important nutrients; (iv) Organic contaminant detoxification; (v) CO<sub>2</sub> sequestration; (vi) water quality and supply control; (vii) Soil is most essential and crucial resources for habitat formation. Unfortunately, as a result of a variety of invasive anthropic activities in intensive agriculture, soil deterioration has been and continues to be rapid on a global scale,

with negative consequences for human and ecosystem health. As a finite natural resource, soil cannot be replenished indefinitely (i.e., Neither soil loss nor degradation can be recovered within a human lifetime).

Since the beginning of intensive agriculture, a significant portion of SOC stock has been lost from agricultural soils. The loss of SOC stock is between 60 and 75% in tropical and temperate ecosystems (Lal et al., 2007; Ghimire et al., 2015). A long history of native soil cultivation in South Asia contributes to soil C levels that range from 8 to 10 grams per kilogram a year, resulting from soil erosion, intensive tillage, erosion, and the removal of residues (Lal, 2004a). It is estimated that 162 mg of carbon per hectare was removed from Bangladesh's soil between 1967 and 1995 due to agricultural practices (Lal, 2004a. Johnson et al., (2006) and Wilhelm et al., (2007) found that one of the most important factors to sustain or increase soil organic carbon levels is conservation tillage, particularly for corn cultivation systems in the United States. Pikul et al., (2008) and Varvel (2006) demonstrated that long-term conventionally tilled cropping system experiments still showed the same SOC levels even with increased cropping system diversity.

SOC in the agriculture context is essential because of its impact on the global carbon cycle and agricultural production. In the terrestrial ecosystem on a global scale, the soil is a large carbon (C) reservoir in the global terrestrial ecosystem, containing about 1505 Pg (1 Pg = 10<sup>15</sup>g C = 1 Gt = 1 billion tones) of SOC (Lal, 2018), more or less three times that stored in flora, which is roughly double that stored in the atmosphere (Yang et al., 2016). So, the SOC and its fractions have an impact on the global C cycle, as well as altering the chemistry of the atmosphere due to greenhouse gas emissions (GHGs) (Ladha et al., 2016). Therefore, a minor increase in SOC and its components in the soil might affect the amount of carbon in the atmosphere (Mi et al., 2016). Moreover, SOC and its fractions, in particular, have a big impact on the agroecosystem's long-term productivity because they play a big role in soil quality and influence the physical, chemical, and biological properties of the soil (Kumar et al., 2018). Also, SOC build-up is a method of carbon sequestration that enhances the ability of agroecosystems to absorb CO<sub>2</sub> from the atmosphere and store

it in soils. Consequently, rotating various crops after rice on the same piece of land and its impact on SOC dynamics are critical considerations when considering the impact on soil quality and global climate change. Various agricultural activities have contributed considerably to the increase in GHGs concentrations in the atmosphere. (Lal, 2004) and have been shown to have an impact on soil C sequestration (Jaiarree et al., 2011). Agricultural soils may become an effective C sink, balancing C inputs from plant production and outputs through decomposition and regulation of SOC accumulation in soil, with the implementation of various management practices (Minasny et al., 2017). C input and soil C loss are influenced by certain land use and management practices (Paustian et al., 2016). Reduced tillage, crop rotation, and fertilization practices maintained SOC at optimum level (Gong et al., 2009), enhanced grain production, maintained soil quality, produced a sustainable agroecosystem (Zhou et al., 2015), and improved the carbon reserve to mitigate current global climate change (Paustian et al., 2016).

Agronomic practices that influence yield and, therefore, affect the proportion of crop residues returned to the soil, are likely to influence C levels in agricultural soils. Therefore, the inclusion of legumes and cover crops (Kuo et al., 2012), the addition of manure and fertilizer (Hartwig and Ammon, 2002), and the reduction in fallow frequency (Rasmussen et al., 1980) linearly increase SOC levels. Nevertheless, Campbell et al., (1991) found no effect of varying C inputs on SOC levels for a high organic matter soil at Melfort, Saskatchewan (Canada), thereby suggesting that these soils may be C saturated (Six et al., 2002). Carbon saturation implies that once the capacity for soil to stabilize C is reached, additional C inputs will not be stabilized as SOC (Six et al., 2002). Therefore, determining the C status of soil relative to C saturation is important to gauge the potential for C sequestration.

Banjara et al., (2021), RWCS is one of the world's biggest agricultural production systems, covering 26 million hectares (M ha) across South Asia's Indo-Gangetic Plains (Timsina and Connor, 2001). RWCS is the most common in India, covering about 12.0 million hectares and generating around 23% of the country's total food grains. In the winter (Rabi) season, 95 percent of rice land is replaced with wheat

in Punjab, Haryana, and Uttar Pradesh, the main Indian states. RWCS's increased productivity and stability gave abundant job and income generating possibilities for rural populations, as well as assuring food security for not only India but the whole IGP area. Due to massive damage to natural resources, declining soil fertility, depletion of groundwater, rising salinity and alkalinity problems, and increasing weeds, insect-pest, and disease problems. The RWCS is essential for India's food security. The system's long-term sustainability, on the other hand, is frequently questioned due to several issues with this cropping system. A possible solution is to diversify the RWCS with appropriate crops.

Rice (*Oryza sativa L.*) and maize (*Zea mays L.*) are cultivated on 3.5 million hectares in Asia, including 1.5 million hectares in South Asia (Timsina et al., 2010). Maize (*Zea mays L.*), cotton (*Gossypium spp*) (Das et al., 2014), and pigeon pea (*Cajanus cajan L.*) (Singh et al., 2005) are all viable alternatives to rice during the Kharif (Rainy) season. Maize is the third most significant food crop in India, after rice and wheat, and is cultivated on 9.5 million hectares with a yield of 24.5 million tonnes per year (USDA, 2017). Rice, maize, and wheat are the most important cereals in South Asia, contributing to food security and revenue. In South Asia's tropical and sub-tropical climates, these crops like rice, maize, and wheat are cultivated as monocultures or in rotations. Rice-Rice (R-R), Rice-Wheat (R-W), and Rice-Maize (R-M) are the most common cropping systems in irrigated and rainfed low land areas. (R-R) is widely grown in tropical climates with distinct dry and rainy seasons, such as in South India, and in subtropical climates with moderate, cold winters, such as Bangladesh and Eastern India.

Loss of SOC from rice-based cropping systems, however, has not been widely accepted and the long-term trend of SOC with alternative agricultural management practices has not been extensively studied. Puddled rice agroecosystems are historically recognized as a cropping system being used for centuries without declining soil fertility (Lal et al., 2007). Rice planted under flooded conditions has lower SOC loss due to reduced decomposition of SOM in soils flooded during the summer and autumn seasons (Kukul et al., 2009). Major processes influencing SOC

dynamics in the water-logged soil environment of rice fields include changes in redox potential, soil pH, reduction of C, N, and sulphur (S) (Fageria et al., 2011). For example, SOC is lost as CO<sub>2</sub> and CH<sub>4</sub> emissions from anaerobic soils via sequential oxidation-reduction reactions mediated by diverse microbial groups (Faulkner 2004).

Cropping systems have an impact on soil organic matter, which has a significant influence on soil properties. Cultivation methods and the application of organic residues all affect soil properties. Tillage systems have long been studied as a way to enhance agricultural systems and soil physical qualities (Ashworth et al., 2020). Soil organic matter is depleted in different cropping practices and the slow or stable fraction of organic matter, which accounted for almost half of the current amount of organic matter. Changing tillage techniques or crop rotations can help increase SOC build-up. Organic manures have been demonstrated to improve SOM content when used as part of cropping systems (Assefa et al., 2020). Keeping facts in the mind present study entitled ***“Effect of different cropping systems on energy budgeting and carbon footprint”*** was conducted to analyse the energy and SOC status in different cropping systems. The following objectives were presented in this investigation:

1. To evaluate the effect of different cropping systems on soil and crop yield.
2. To evaluate the energy budgeting under different cropping systems.
3. To study the role of different cropping systems on SOC stocks.

## REVIEW OF LITERATURE

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### 1.1 Rice- wheat-green gram

#### 1.1.1 Soil physiochemical properties

Bajpai et al., (2006) analysed the soil after twelve years of long-term manuring and fertilizer under a rice-wheat cropping system at Raipur (C.G.) and concluded that the bulk density of surface soil (0-7 cm) after harvest of wheat decreased significantly in 100% RDF to both crops ( $1.50 \text{ Mg/m}^3$ ) and 50% NPK + 50% N (FYM) ( $1.45 \text{ Mg/m}^3$ ) and 50% NPK +50% N(GM) to rice ( $1.43 \text{ Mg/m}^3$ ) and or in 100% NPK to wheat crop as compared to control ( $1.56 \text{ Mg/m}^3$ ). The use of only fertilizers increased the bulk density, which might be due to the deterioration of soil by inorganic fertilizer. Mandal et al., (2003) conducted a field experiment at the experimental farm of the Indian Agricultural Research Institute (IARI) New Delhi, India. Green manuring treated plots had higher organic matter and total soil nitrogen concentrations than summer fallow plots. During the growth of rice and wheat, the magnitude of the decrease in bulk density because of green manuring over fallow bulk density was  $0.03\text{--}0.07 \text{ Mg/m}^3$  in the 0–15 cm soil layer and  $0.05\text{--}0.09 \text{ Mg/m}^3$  in the 15–30 cm soil layer. Green manuring improved the soil physical environment, as evidenced by increased mean weight diameter and saturated hydraulic conductivity values compared to fallow. Nandan et al., (2019) conducted a field experiment for six years to assess the impact of four tillage based crop establishment treatments [puddled transplant rice followed by conventional tillage in wheat/maize (CTTPR–CT), non–puddled transplant rice followed by zero–tillage in wheat/maize (NPTPR–ZT), zero-till transplant rice followed by zero–tillage in wheat/maize (ZTTPR–ZT), zero–tillage direct-seeded rice followed by zero–tillage in wheat/maize (ZTDSR–ZT)], two residue management treatments [residue removal, residue retention (~33%)], and two cropping systems [rice–wheat, rice–maize] found that residual retention treatment increased the amount of coarse macro-aggregate and meso-

aggregate when compared to residual removal treatment. The coarse macro-aggregate and meso-aggregate content of the ZT-based crop establishment treatments (ZTTPR-ZT and ZTDSR-ZT) were greater than the CTTPR-CT.

Brar et al., (2013) experimented and studied C sequestration after nine year's rice (*Oryza sativa L.*)–wheat (*Triticum aestivum L.*) cropping under an ongoing experiment at Punjab Agricultural University, Ludhiana, Punjab (India). This study was based on five treatments (100%N, 100%NP, 100%NPK, 100%NPK + FYM, and the control). In the surface soil layer (0–15 cm), soil organic carbon (SOC) increased from the initial status of 2.42 to 3.26 g kg<sup>-1</sup> in the control, which significantly increased with the application of 100%NPK (4.11 g kg<sup>-1</sup>) and 100%NPK + FYM (4.55 g kg<sup>-1</sup>). Singh et al., (2011) conducted a long-term field experiment that was initiated during 2000–01 on sandy loam soil at Banaras Hindu University, Varanasi, India. to assess 10 rice-based cropping sequences – rice-wheat, rice-chickpea, rice-wheat-green gram, rice-wheat-Sesbania (green manure), rice-mustard-green gram, rice-lentil-cowpea (fodder), rice-pea, rice-lentil þ mustard (3:1)-cowpea (fodder), rice-maize (cob) þ vegetable pea (1:1)-cowpea (fodder) and rice-potato-green gram in randomized block design with four replications. the organic carbon content in surface soil (0–15 cm) was improved than the initial value by 14.7% in rice-wheat-Sesbania (GM), by 11.8% in rice-mustard-green gram, rice-lentil + mustard (3:1)-cowpea (F), and rice-maize (cob) + veg. pea (1:1)-cowpea (F) sequences and by 8.8% in rice-wheat- green gram, rice-lentil-cowpea (F) and rice-potato-green gram sequences. In the sequences having 200% intensity, the inclusion of pulses in the place of wheat led to an increase in soil organic carbon to 5.9% in rice-chickpea and 2.9% in rice-pea rotation. The organic carbon content in the rice-wheat cropping system remained unchanged during the four years of the experiment. Vyas et al., (2013) studied that the soil physical, chemical, and biochemical properties and productivity of soybean and wheat in Malwa region of Central India were studied under a long-term field trial involving four soybean-based crop rotations (soybean-wheat, soybean-wheat-maize-wheat, soybean-wheat-soybean-wheat-maize wheat, and soybean+ maize-wheat) and three tillage systems (conventional-conventional, conventional-reduced and reduced-reduced) being continuously maintained since, 2001. After completing six cropping

seasons, the reduced-reduced (R-R) tillage system considerably increased the bulk density, porosity, and water-filled pore space (WFPS) at wheat harvest during 2007-08. The R-R and conventional-reduced (C-R) tillage systems had significantly higher available P and K content in the surface soil. The R-R tillage system significantly increased soil organic carbon (SOC), particulate organic carbon (POC), and light fraction carbon (LFC) contents as compared to C-C and C-R systems. There was no significant influence of crop rotation on bulk density, porosity, and WFPS at wheat harvest.

Bandyopadhyay et al., (2011) A long-term field experiment was established in 1986 with a rice-wheat cropping system on an Inceptisol located at the University Teaching Farm, Bidhan Chandra Krishi Vishwavidyalaya, West Bengal, India carried out a long-term rice-wheat cultivation with fertilizer nitrogen-phosphorus-potassium (NPK) or added organics [farmyard manure (FYM), paddy straw (PS), green manure (GM)] and a permanent fallow on bulk density (BD), saturated hydraulic conductivity (SHC), available water capacity (AWC), maximum water-holding capacity (MWHC), aggregation, and soil organic carbon (SOC) dynamics on an Inceptisol of humid subtropics of eastern India. Cropping for a long time resulted in a net decrease in SOC content. In terms of structural and hydrophysical qualities, undisturbed fallow was equivalent to soils amended with FYM, PS, and GM. FYM had the highest WHC and AWC values, followed by PS, GM, fallow, NPK, and control. FYM > PS > GM was the relative efficacy of the organics for physical build-up, which raised structural indices.

Porpavai et al., (2011) experimented were carried out at the Soil and Water Management Research Institute at Kattuthottam, Thanjavur, throughout the year. The soil was a sandy clay loam with a pH of 6.5, a low available nitrogen level (217 kg ha<sup>-1</sup>), a high available phosphorus content (265 kg/ha), and a medium available potassium level (153 kg ha<sup>-1</sup>), as well as a 0.390 percent organic carbon content. Ten rice-based cropping systems were tested, including rice (*O. Sativa*)– rice – black gram (*Vigna mungo*), rice – rice – sesame (*Sesamum indicum*), rice – rice – bhindi (*Abelmoschus esculentus*), lab-lab (*Dolichos lablab*) – rice – maize, onion (*Allium*

*cepa*)– rice – black gram, rice – rice. At the end of the fourth year, these cropping systems resulted in a 0.04 percent increase in organic carbon content. This organic carbon content increase was shown to be superior to that of other cropping systems. Over four years, the organic carbon content of rice – rice – sesame (0.006%), rice – rice – onion (0.001%), bhindi – rice – radish (0.008%), and rice-rice-onion (0.005%) cropping systems increased the least. Nandan et al., (2019) conducted research. The field experiment took place at the Indian Council of Agricultural Research–Research Complex for Eastern Region (ICAR–RCER) in Patna, Bihar, from 2009 to 2015. a field experiment was conducted for six years to assess the impact of four tillage based crop establishment treatments [puddled transplant rice followed by conventional tillage in wheat/maize (CTTPR–CT), non–puddled transplant rice followed by zero–tillage in wheat/maize (NPTPR–ZT), zero-till transplant rice followed by zero–tillage in wheat/maize (ZTTPR–ZT), zero–tillage direct-seeded rice followed by zero–tillage in wheat/maize (ZTDSR–ZT)], two residue management treatments [residue removal, residue retention (~33%)], and two cropping systems [rice–wheat, rice–maize] Zero-till crop establishment treatments (ZTTPR–ZT and ZTDSR–ZT) showed greater total organic carbon (TOC) in the top 0.2 m of soil depth after six years of rotation than conventional tillage treatment (CTTPR–CT). Zero–till crop establishment treatments raised the very–labile C fraction ( $C^{\text{frac1}}$ ) by 21%, the labile fraction ( $C^{\text{frac2}}$ ) by 16%, the non–labile fraction ( $C^{\text{frac4}}$ ) by 13%, and the less–labile fraction ( $C^{\text{frac3}}$ ) by 7%. Prakash et al., (2008) investigated the effects of pulses on soil fertility and rice yield sustainability in the Cauvery command area's paddy-pulses cropping system. When compared to the rice-rice cropping system (0.32 percent, 9.60 cmol/kg, 26.50 percent, 21.20 percent, and 1.67 g/cc, respectively), the rice-pulses cropping system improved organic carbon (0.54-0.56 percent), CEC (10.10 to 10.50 cmol/kg) porosity (29.80 to 35.30 percent), and maximum water holding capacity (28.90 to 30.90 percent), and drastically reduced bulk density (1.35 g/cc).

Purakayastha et al., (2007) studied the effects of different land uses and soil managements (agroforestry plantation, vegetable field, tube-well irrigated rice-wheat, sewage-irrigated rice-wheat, and uncultivated soils) on soil pH, bulk density, soil organic C (SOC), particulate organic C (POC), microbial biomass C (MBC), C

mineralization ( $C_{sub>min}$ ), microbial quotient. The pH of sewage-irrigated rice-wheat soil was lowest in the 0-0.05 and 0.10-0.20 m soil layers. Agroforestry plantations had the highest SOC regardless of soil depth, followed by sewage-irrigated rice-wheat soil. Nonetheless, in the 0-0.20 m soil layer, agroforestry soil had the maximum stock of SOC ( $33.7 \text{ Mg ha}^{-1}$ ), POC ( $3.58 \text{ Mg}^{-1}$ ), and MBC ( $0.81 \text{ Mg ha}^{-1}$ ). Purakayastha et al., (2007) also studied the effect of different land uses (agroforestry plantation, at Indian agriculture research institute, New Delhi on the vegetable field, tube-well irrigated rice-wheat, sewage-irrigated rice-wheat, and uncultivated soils) in this Agroforestry soil had the lowest bulk density ( $1.29 \text{ mg/m}^3$ ) at 0-0.05 m, whereas uncultivated soil (jointly with vegetable field soil) had the highest bulk density ( $1.48 \text{ mg/m}^3$ ).

### **1.1.2 Yield**

According to Sharma et al., (2009), field research was conducted at the Indian Agricultural Research Institute in New Delhi, India, to determine the impact of different cropping systems on soil physical, chemical, and biological properties. Rice-potato mung bean cropping system had 59–89% higher productivity, 30–46% higher protein yield, 18–38% higher energy output, 7–16% higher available P, 60% higher fungi population, 15% higher actinomycetes population, 14% higher microbial biomass, and 3% higher CO<sub>2</sub> evolution in soil than rice-wheat cropping system. Rice-rapeseed -mung bean cropping system had 12–15 percent higher productivity, 19–26 percent higher protein yield, 11–18 percent higher available P, 65 percent higher fungi population, 22 percent higher actinomycetes population, 12 percent higher microbial biomass, and 2% higher CO<sub>2</sub> evolution in soil than rice-wheat cropping system. However, in terms of productivity, protein production, and energy production, the rice- -potato-mung bean cropping system outperformed the rice-rapeseed mung bean cropping system and is thus suggested as an alternative to rice-wheat cropping. Sarwar et al., (2008) did a study, The experiment was started with rice crops and followed by wheat. Compost was incorporated one month before transplanting rice seedlings in the field. The yield of rice is reported to be  $2.0 \text{ t ha}^{-1}$  while that of wheat is  $2.4 \text{ t ha}^{-1}$  (Anon., 2003). Kumar and Yadav (2003),

experimented and find that the highest rate of yield reduction in rice and wheat was reported when just N was treated at  $120 \text{ kg ha}^{-1}$ , but the rate of yield reduction was lower when NPK was treated at  $40\text{-}35\text{-}33 \text{ kg ha}^{-1}$ . According to them, such a decline was likely caused by a deficiency of other nutrients or an imbalance of one or more soil nutrients, with no appreciable change in available N and K in the soil due to continuous application of N and K fertilizers, but a significant increase in available P due to regular P fertilizer dressing. However, using  $12\text{-}15 \text{ t ha}^{-1}$  of farmyard manure to rice might contribute approximately  $60 \text{ kg N ha}^{-1}$ , while using 40–60 days old *Sesbania* as green manure might contribute  $50 \text{ kg N ha}^{-1}$ . They found that when mineral fertilizers were combined with FYM and *Sesbania* green manure, the available N and P content of the soil increased higher than when mineral fertilizers or organics were used alone. Mineral fertilizer plots had higher depletion of micronutrients in the soil (Fe, Cu, Zn, Mn) than plots with combined mineral and organic sources.

### **1.1.3 Nutrient dynamics**

Singh et al., (1999) investigated rice-wheat rotation using different combinations of N, P, K, Zn, and FYM (farmyard manure). Except in the plots receiving mono superphosphate and FYM, organic matter content reduced significantly. They determined that after ten years of rice-wheat farming, the amounts of accessible P, K, and DTPA-Zn in plots that did not get these nutrients directly or through FYM had decreased. However, in the plots treated with single superphosphate and FYM, there was a general rise in the DTPA extractable Cu, Mn, Fe, and accessible B and Mo over time. The combined effect of Zn shortage, Fe, Mn, Cu, and B toxicity, as well as imbalances caused by antagonisms between primarily P-Zn, Fe-Zn, B-Cu, Cu-Zn, and S-Zn, seemed to be responsible for the loss of rice and wheat production during 10 years in some treatments.

The available N content of the soil after completion of the four-year trial followed more or less a similar trend as the organic carbon content in the surface soil. As compared to the initial value, soil available N in the rice-wheat system declined by 3%; whereas, in the rest of the sequences, it improved. The rice-wheat-*Sesbania*

sequence recorded the maximum available N of 13.9% closely followed by rice- lentil þ mustard (3:1)-cowpea fodder (12.7%). However, the rice-pea sequence registered the lowest improvement of 4.1%. As compared with the initial value, the available P content of soil improved under all the sequences. In the standard rice-wheat cropping system, the availability of P was increased by 1.4% as compared with the initial value of 21.4 kg/ ha. The extent of P increase ranged between 2.8% in rice-pea to 15.4% in the rice-chickpea sequences. In contrast, available K was depleted under all the crop rotations after four crop cycles with the greatest depletion of 13.3% in the standard rice-wheat system.

Kumar et al., (2001) studied the introduction of leguminous crops that resulted in the highest organic carbon build-up. Rice – rice – black gram, onion – rice – black gram, groundnut – rice – black gram, and rice – rice – green gram cropping sequences had greater organic carbon content in the first, second, third, and fourth years, respectively, among the 10 cropping systems studied. The addition of leguminous crops to the system enhanced the organic carbon, accessible nitrogen, phosphorous, potassium, and sulphur content of the soil, according to Kumar *et al.*, (2001). This might be owing to the addition of nutrients from these crops' biological N fixation. Over four years, the organic carbon content of rice – rice – sesame (0.006 percent), rice – rice – onion (0.001 percent), bhindi – rice – radish (0.008 percent), and rice rice-onion (0.005 percent) cropping systems showed the least increase in organic carbon content.

## **1.2 Rice -barley cropping system**

### **1.2.1 Soil physiochemical properties**

Zhangliu et al., (2009) experimented and in this cropping system crops consists of Barley (*Hordeum vulgare*), early rice, and late rice (*Oryza sativa*), cropping system, based on a long-term field experiment, the goal of this study was to evaluate changes in soil physical characteristics as a result of mineral fertilizer, crop residues, and manure application. Manure reduced bulk density, increased SOC concentration, soil aggregation, transmission and storage porosity, and water retention

capacity, according to the findings. Crop residue and mineral fertilizer applied together enhanced soil physical characteristics as well, whereas mineral fertilizer alone had minimal effect. Yang et al., (2007) experimented with this cropping system of rice- barley. After the application of barley straw, the soil physical properties improved, with lowering soil hardness, bulk density, and rising soil porosity, notably in the increase of porosity, gaseous phase, and with decreasing soil hardness, bulk density of subsurface soil in the DRI+WRI plot (dry rotary I+ water rotary I). Kang et al., (2018) experimented, in this experiment straw of biochar is applied into the soil, and biochar is also applied with a combination of inorganic fertilizer (IF). A control (Cn) treatment area was used to segregate the barley straw biochar (BC, applied at 10 ton/ha), inorganic fertilizer (IF, applied at N-P-K = 320–78–198 kg ha<sup>-1</sup>), and BC + IF treatment areas. The soils treated with BC and BC + IF exhibited lower bulk density and greater porosity than those treated with Cn. the addition of biochar, soil chemical properties (pH, available P<sub>2</sub> O<sub>5</sub>, and CEC) improved. In comparison to Cn and IF regions, soil pH and CEC associated with crop nutrient availability were considerably higher in BC areas. Wang et al., (2005) experimented, and in this experiment After 23 years of recurrent organic and chemical fertilizer amendments, an experiment was undertaken to investigate a problem in rice–barley system in eastern China. Unfertilized control (CK), pig manure (M), chemical fertilizers NPK (NPK), and pig manure mixed with NPK were the fertilization treatments (MNPK). M, NPK, and MNPK considerably enhanced 25, 13, and 30% of SOC content as compared to CK, according to the results. M, NPK, and MNPK increased 11, 1, and 16 percent of SOC storage, respectively, as compared to the original SOC stock at 0–20 cm depth (41.2 Mg C ha<sup>-1</sup>), but CK decreased 9 percent of the SOC pool.

### **1.2.2 Nutrient dynamics**

Singh et al., (2017) experimented and study the effect of the organic and inorganic sources of nutrients in the cropping system of rice- barley. Only inorganic (N, P, and K) did not achieve the targeted yield in both barley and rice, but the integration of inorganic with organic (FYM) assured the achievement of target yield in both barley and rice. It appears that providing balanced nutrition to the soil through the integration of both organic and chemical nutrient sources is critical. It provides

sufficient nutrients for crop absorption, promoting barley and rice growth and, as a result, the development of yield characteristics, resulting in higher yields.

### 1.2.3 Yield

Abera et al., (2018) experimented to study the effect of integrated inorganic and organic fertilizer. The application of solo recommended NP (nitrogen, phosphorus) and the combined use of 50:50 % vermicompost and conventional compost with recommended NP resulted in significantly better grain yield and biomass yield of barley. Application of 50:50 percent conventional compost and vermicompost based on N equivalency with prescribed NP fertilizer rate resulted in mean grain yields of 2567 and 2549 kg ha<sup>-1</sup> barley, respectively, which significantly reduced the cost of chemical NP fertilizer required for barley production.

## 1.3 Rice -mustard cropping system

### 1.3.1 Soil physiochemical properties

Rajpoot et al., (2021) experimented with the six most prevalent cropping systems, Rice-wheat (RW), rice-chickpea (RC), rice-field pea (RP), rice-mustard (RM), rice-linseed (RL), and rice-fallow (RL) were identified as the six “most prevalent cropping sequences” (RF). BD was greater in the RW cropping system than in the RC, RP, and RL cropping systems. Other soil physical characteristics, such as porosity, AWHC (available water holding capacity), SMC (soil moisture content), and MWD (mean weight diameter), were higher in soils under the rice-legume (RC and RP) cropping systems than in soils under the RW, RM, and RF cropping systems. Kuotsu et al., (2014) to studied the effect of land configuration, tillage, and residue management on soil characteristics in rainfed groundnut–rapeseed cropping system The treatments were: (i) farmers' practice (FP) (flatbed – residue removal, 3–4 times ploughing); (ii) broad bed and furrow (BBF) with in situ residue incorporation; (iii) BBF with in situ residues + hedge leaves incorporation (white hoary pea, *Tephrosia candida*) DC); (iv) BBF with in situ residues + hedge leaves mulching (no-till, NT); (v) raised bed (RB) with in situ residue incorporation; (vi) RB with in situ residues + hedge leaves incorporation; (vii) RB with in situ residues + hedge leaves

mulching (NT). Under residue retention/incorporation and altered land configuration, the moisture content of the soil profile was greater than under FP. After two cropping cycles, water infiltration rate (11.2 mm/h) and hydraulic conductivity (6.98 mm/h) in soil were significantly higher in RB with residue + hedge leaves mulching (NT) than in FP (7.65 mm/h and 3.35 mm/h). Nayak et al., (2020) experimented with a rice-mustard cropping system in that Application of 50% RDF with BF to mustard recorded higher soil organic carbon and pH than RDF and control. The decrease in bulk density was more in the plots applied with 50% RDF+10t FYM to Kharif rice (1.38 Mg m<sup>-3</sup>) and 50% RDF + BF to rabi mustard (1.41 Mg m<sup>-3</sup>). Das et al., (2020) study was conducted in 2010-2011 at ICAR – Indian agriculture research institute, new Delhi in this study they concluded that when the non-CA based cropping system compared to the traditional TPR-CTM rice-mustard system, this CA-based rice-mustard system produced considerably greater very labile (50.6%) and labile (47.7%) carbon concentrations at the 0–5 cm depth of soil. Yadav et al., (2019) experimented in the HER (Eastern Himalayan regions), India, for four years in a row. During the first two years of the research (2012-13 to 2013-14), the rice (*Oryza sativa*)–rapeseed (*Brassica campestris* var. rapeseed) cropping system was practiced, and the rice–rapeseed–cowpea (*Vigna unguiculata*) system was practiced during the following two years (2014-15 to 2015-16). The tillage system consisted : 1) CT-RI: conventional tillage (CT) with 100% residue incorporation (RI) and 2) NT-RR: no-till (NT) with 100% residue retention (RR). Under the NT-RR (no till-residue retention) system, the quantity of total biomass (above and below ground) and C added into the soil was higher than under the CT-RI system (conventional tillage- residue retention ). At 0–30 cm, the NT-RR had greater SOC concentration, pool (29.9 vs. 29.1 Mg/ha), sequestration rate (450 vs. 265 kg/ha/yr.), and C retention efficiency (7.7 vs. 4.6%) than the CT-RI after four cropping system.

### 1.3.1 Yield

Das et al., (2020) study was conducted in 2010-2011 at ICAR – Indian agriculture research institute, new Delhi and find that, in all five years, the traditional transplanting puddled rice (TPR) – conventional till mustard (CTM) (TPR-CTM) rotation produced significantly greater rice grain production than the zero-till direct-seeded rice (ZTDSR) – conventional till mustard (CTM) system with no crop residue.

Nayak et al., (2020) a study was conducted at the regional research and technology transfer station of Orissa university of agriculture and technology, Bhawani Patna, Kalahandi during the year 2013-14 and 2014-15 with the rice-mustard cropping system in that system application of 100 percent RDF + FYM 5 t ha<sup>-1</sup> to rice resulted in significantly higher grain (7545 kg ha<sup>-1</sup>) and straw yield (7241 kg ha<sup>-1</sup>) of rice, as well as significantly higher seed yield (806 kg ha<sup>-1</sup>), stover yield (1423 kg ha<sup>-1</sup>), harvest index (36.3 percent) of subsequent mustard crop, and system rice equivalent yield (9629 kg ha<sup>-1</sup>)

### **1.3.2 Nutrient dynamics**

Nayak et al., (2020) experimented and concluded that in the rice-mustard cropping system, in this application of 50 percent RDF + BF to mustard, the available N, P, and K content of soil rose to 237.6, 17.1, and 374.9 kg ha<sup>-1</sup>, respectively, from its initial value of 148.2, 12.7, and 352.4 kg ha<sup>-1</sup> at the end of the second year. Paul et al., (2017) Two field experiments were conducted in succession Comparative Study of Organic Matter (Kharif followed by rabi) at Sub-divisional Adaptive Research Farm, Kandi, Murshidabad, India and they found that the Effect of FYM @ 5.0- and 2.5-ton ha<sup>-1</sup> and commercial and extracted humic acid @ 0.5 and 0.25 kg ha<sup>-1</sup> on paddy followed by mustard, respectively. the content of the available phosphate is gradually increasing in the treatments that are applied with the extracted humic acid and FYM. the effect was on the content and uptake of P during the cultivation of paddy followed by mustard was increased.

## **1.4 Bottle gourd-cabbage-sponge gourd cropping system**

### **1.4.1 Soil physicochemical properties**

Verma et al., (2017) experimented at Vegetable Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, and the findings revealed that both P. fluorescens and humic acid have a substantial impact on cabbage productivity and soil physicochemical characteristics. When the plants were treated with humic acid in the presence of P. fluorescens, the greatest values of physicochemical parameters such as pH, EC, organic carbon, and accessible NPK were found. Verma et al ., (2020) experimented and in this study involved four

cropping systems (CS) comprising direct-seeded basmati rice (DSBR)–wheat (CS<sub>1</sub>), DSBR–wheat–green gram (CS<sub>2</sub>), DSBR–cabbage–green gram (CS<sub>3</sub>) and DSBR–cabbage–onion (CS<sub>4</sub>) under different nutrient management strategies (NMS) comprising of control (NS<sub>0</sub>), 100% recommended dose of N, P and K fertilizers (RDF-NPK) (NS<sub>1</sub>), 50% RDF + 25% recommended dose of nitrogen (RDN) through leaf compost (LC) + biofertilizer (NS<sub>2</sub>), 50% RDF + 25% RDN through vermicompost (VC) + biofertilizer (NS<sub>3</sub>) and was carried out for two consecutive years. At the end of the study, soil carbon fractions, bulk density, and water-stable aggregates were significantly higher under integrated NMS as compared to control and RDF alone. Soil biological parameters such as dehydrogenase, alkaline phosphatase, and microbial biomass carbon increased significantly in all three seasons (rainy, winter and summer) under integrated NMS (NS<sub>2</sub> and NS<sub>3</sub>) plots, as compared to NS<sub>0</sub> and NS<sub>1</sub>.

#### **1.4.2 Yield**

Prasad et al., (2016) During the summer seasons (January to April) in 2009 and 2010, a field experiment was carried out in Vanivihar, Department of Botany, Utkal University, Bhubaneswar, India. When compared to the traditional N-P-K fertilizer control, integrated nutrient management can provide enough nutrients to enhance bottle gourd productivity. Integrated application of cow manure at 10 Mt·ha<sup>-1</sup> + half the Recommended rate of N-P-K fertilizer (N: P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O; 25:30:25 kg. ha<sup>-1</sup>) was at least as good as the control (recommended rate of N-P-K fertilizer) since it had similar fruit yield, fruit length, fruit diameter, node producing the first female flower, days to first harvest, number of branches per plant, and water use efficiency.

### **1.5 Sudan chari-berseem- Sudan chari cropping system**

#### **1.5.1 Soil physiochemical properties**

Serme et al., (2015) experimented Nadion is in the South Sudan zone of Burkina Faso. Results revealed that the application of sorghum straw leftovers increased the amount of water in the soil by 20%. The conventional method of tillage

used in the past resulted in a reduction in the surface soil bulk density (0-10 cm). Srivastava et al., (2016) experimented at Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana. They found that the sorghum-berseem cropping system had the lowest soil pH (8.14), followed by the cowpea-cauliflower-potato cropping system (8.35). In comparison to other cropping systems, the sorghum-berseem cropping system considerably increased soil fertility in terms of available nitrogen (221.1 kg/ha) and soil organic carbon (0.59 percent). Moreover, the sorghum-berseem fodder system had a greater Mn content (6.37 mg/kg) than the other cropping systems.

### **1.5.2 Yield**

Aulakh et al., (2012) Field research were done in Ludhiana on sandy loam soil to investigate the effect of nutrient sources on green fodder production of various fodders in the cropping system. The maize-berseem-pearl millet fodder cropping system produced the greatest maize equivalent green fodder production (83.3 t/ha), which was substantially greater than the sorghum-berseem cropping system. Relative to the integrated and chemical fertilizer system, organic nutrient management generated considerably greater overall system green fodder productivity (125.8 t/ha) and maize equivalent green fodder output (85.4 t/ha).

Serme et al., (2015) experimented Nadiou is in the South Sudan zone of Burkina Faso. The result of this experiment showed that the Compost + NPK + Urea treatment improved sorghum grain yield by 74% over the control, whereas NPK + urea and compost increased sorghum grain yield by 50% and 29%, respectively, above the control (no soil amendment). After two years of experimentation, conventional tillage resulted in a lower yield than zero tillage. Regardless of the fertility management options, zero tillage coupled with compost, NPK, and urea improved sorghum production by 28% compared to tied-ridging.

## **MATERIALS AND METHODS**

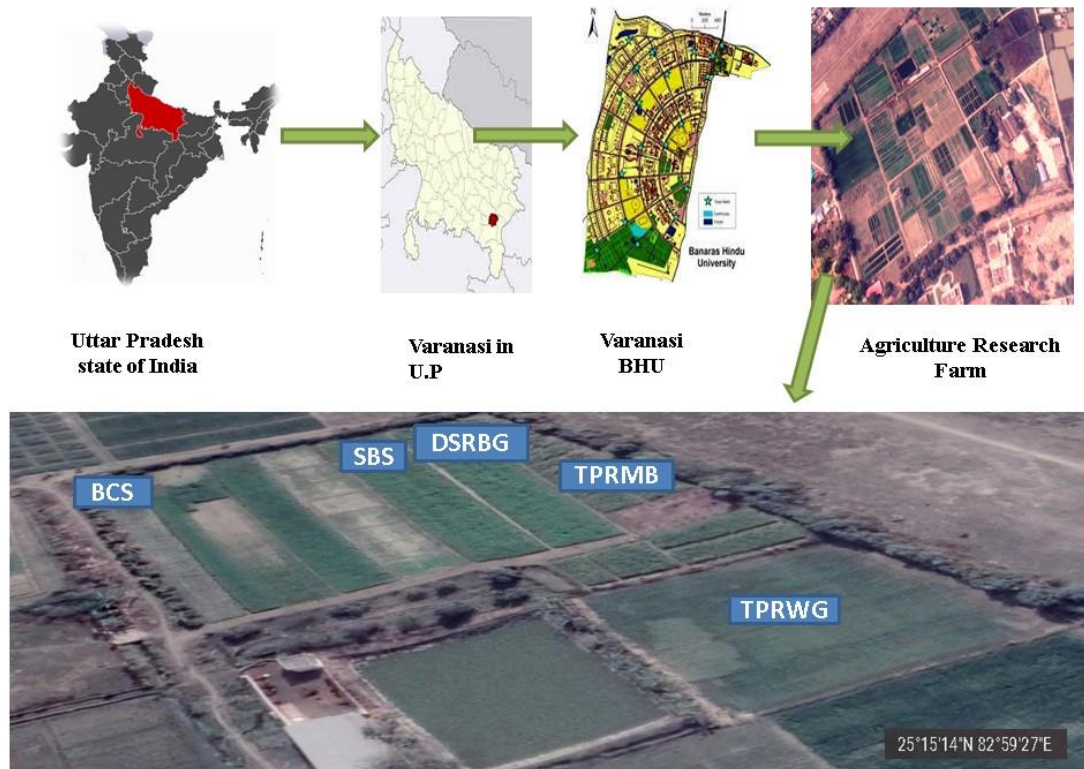
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The current study's title is “**Effect of different cropping systems on energy consumption and carbon footprint**” conducted at Banaras Hindu University's Agricultural Research Farm, followed by laboratory analysis of soil samples at Banaras Hindu University's Department of Agronomy and Institutes of Agricultural Sciences in Varanasi. This chapter contains a thorough description of the materials utilized and the experimental techniques performed throughout the research.

### **3.1 Description of the experimental site**

#### **3.1.1 Physiographic situation**

The Agricultural Research Farm of the Banaras Hindu University is located at a distance of about 10 km from Varanasi Railway station in the South-East part of Varanasi city, which lies in the North-East plain zone of Eastern Uttar Pradesh (Fig1). Varanasi is situated between 25°18' North latitude, 83°30' East longitude, and at an altitude of 76.22 meters from the mean sea level. The experimental site was homogenous fertile and uniform textural make-up and was well connected to a tube-well through a cemented irrigation channel for frequent and timely irrigations. A proper drainage facility was also provided to remove the excess water if any, during the experimental period.



**Fig 3.3** *Layout of experimental site*

### **3.1.2 Climate and weather**

Varanasi is located in the eastern part of Uttar Pradesh with a sub-tropical climate and is subjected to extremes of weather conditions i.e., extremely hot summer and cold winter having semi-arid to sub-humid climate type of climate with moisture deficit index between 20-40. Generally, the normal period of onset of the monsoon of this region is the 3<sup>rd</sup> week of June which lasts up to the end of September or sometimes extends up to the first week of October. The area also experiences winter showers due to cyclonic rains from December to February. The annual rainfall of this region is about 1100 mm. May and June are the hottest months with maximum temperatures ranging from 37 to 40°C. The cold period of this region lies between November to January with minimum temperature varying between 6-12°C. The mean relative humidity is about 68% which rises to 82% during the wet season and goes down to 30% during the dry season.

### **3.2 Climate and weather during the crop growth period**

The details of the observation on maximum and minimum temperature, morning and evening relative humidity, rainfall, and sunshine during the years of investigation 2011-2020 were recorded from the meteorological observatory at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, and are given in tables.

#### **3.2.1 Temperature**

The monthly mean maximum temperature ranged from 20.28 to 39.75<sup>0</sup>C with an average of 31.21<sup>0</sup>C and the monthly mean minimum temperature ranged from 8.3 to 27.56 <sup>0</sup>C with an average of 19.62 <sup>0</sup>C during the crop growing period 2011 to 2020.

#### **3.2.2 Rainfall**

The total rainfall of 9801.7 mm was received with an average of 980.17 mm during the entire period of 10 years (2011-2020).

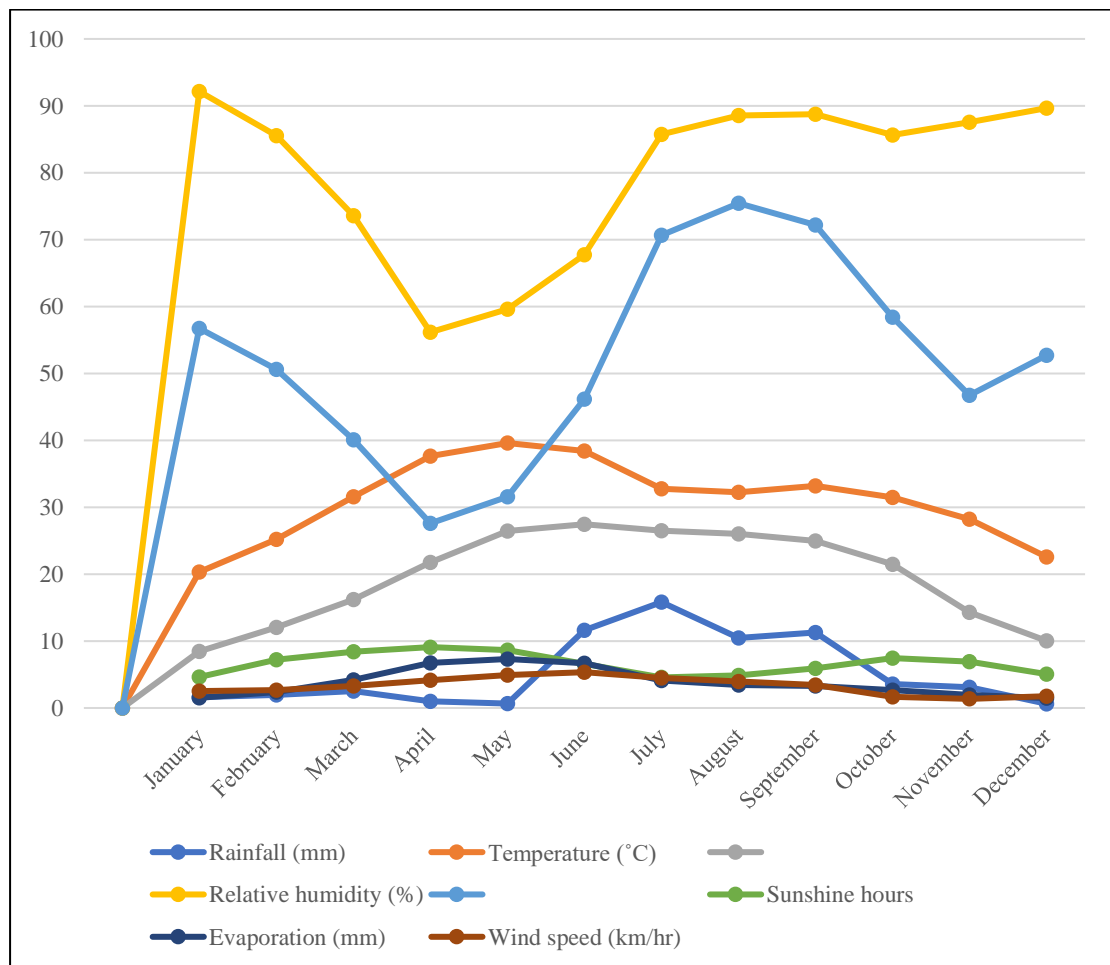
### **3.2.3 Relative Humidity (%)**

The monthly mean relative humidity in the morning ranged from 54.89 to 92.59 percent with an average of 79.42 percent and the monthly mean relative humidity in the evening ranged from 26.83 to 75.07 percent with an average of 51.58 percent during the years from 2011 to 2020.

**Table 3.1 (a) Months wise meteorological data of 10 years average (2011-2020)**

Months	Rainfall (mm)	Temperature (°C)		Relative humidity (%)		Sunshine hours	Evaporation (mm)	Wind speed (km/hr)
		Max	Min	Morning	Evening			
January	1.60	20.33	8.48	92.15	56.75	4.63	1.53	2.54
February	1.95	25.22	12.07	85.56	50.61	7.20	2.40	2.66
March	2.51	31.55	16.20	73.56	40.10	8.41	4.19	3.29
April	1.01	37.67	21.78	56.18	27.61	9.10	6.72	4.16
May	0.64	39.60	26.44	59.60	31.58	8.63	7.32	4.93
June	11.62	38.40	27.46	67.72	46.15	6.58	6.71	5.35
July	15.82	32.79	26.52	85.75	70.64	4.57	4.10	4.50
August	10.47	32.22	26.04	88.57	75.44	4.89	3.42	3.95
September	11.28	33.18	24.98	88.73	72.19	5.91	3.31	3.42
October	3.60	31.49	21.46	85.62	58.41	7.44	2.68	1.69
November	3.12	28.21	14.30	87.54	46.75	6.92	1.94	1.36
December	0.63	22.59	10.04	89.64	52.71	5.06	1.48	1.78

**Note:** Meteorological Observations Data Recorded at the Meteorological Observatory of the Dept. of Agro., Inst. of Agri. Sci., BHU, Varanasi

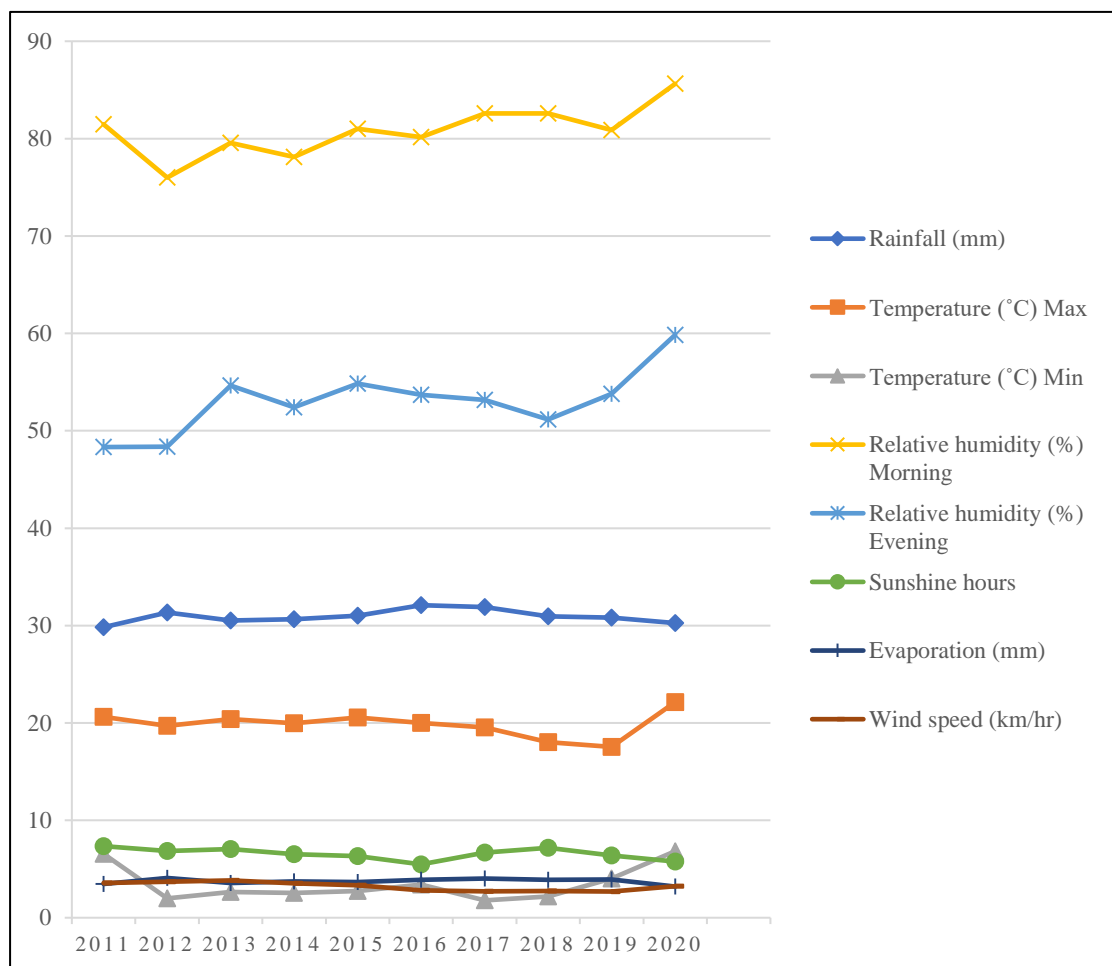


**Fig. 3.1 (a) Month-wise meteorological data of 10 years average (2011-2020)**

**Table 3.1 (b) Years-wise meteorological data of 10 years average (2011-2020)**

Months	Rainfall (mm)	Temperature (°C)		Relative humidity (%)		Sunshine hours	Evaporation (mm)	Wind speed (km/hr)
		Max	Min	Morning	Evening			
2011	29.83	20.64	6.54	81.47	48.33	7.35	3.46	3.58
2012	31.33	19.72	1.99	76	48.38	6.86	4.08	3.68
2013	30.53	20.38	2.63	79.55	54.66	7.06	3.57	3.83
2014	30.64	19.98	2.53	78.13	52.42	6.52	3.73	3.53
2015	31	20.55	2.74	81	54.86	6.33	3.67	3.35
2016	32.09	19.99	3.4	80.14	53.7	5.48	3.88	2.82
2017	31.89	19.54	1.78	82.59	53.18	6.68	4.02	2.72
2018	30.94	18.03	2.19	82.6	51.15	7.19	3.9	2.73
2019	30.83	17.54	4.04	80.89	53.79	6.39	3.93	2.69
2020	30.25	22.14	6.83	85.63	59.85	5.77	3.20	3.23

**Note:** Meteorological Observations Data Recorded at the Meteorological Observatory of the Dept. of Agro., Ins. of Agri. Sci., B.H.U., Varanasi



**Fig. 3.1 (b) Years wise meteorological data of 10 years average (2011-2020)**

**3.2.4 Sun-shine duration (hours)**

The monthly mean sun-shine duration varied from 2.98 to 9.05 hours with an average of 6.69 hours during the crop growing period from 2011 to 2020. The minimum sun-shine hours were found in January whereas, the maximum was found in May.

### **3.2.5 Evaporation**

The monthly mean variation of evaporation ranged from 1.27 to 6.32 mm with an average of 3.87 mm during the years 2011 to 2020.

### **3.2.6 Wind speed (km/hours)**

The monthly mean variation of wind velocity ranged from 1.35 km/hrs. in November to 5.00 km/hrs. in June with an average of 3.3 km/hrs. during the years 2011-2020.

### **3.3 Experiment details**

This study is basically on long-term experiments (LTE) based on the field trials which were already established at Agricultural Research Farm, BHU. This study was done to know about the effect of long-term cropping systems practices on soil properties and crop productivity.

#### **Treatment details**

<b>T-1</b>	<b>Rice-wheat-green gram</b>	<b>TPRWG</b>
<b>T-2</b>	<b>Rice -barley-green gram</b>	<b>DSRBG</b>
<b>T-3</b>	<b>Rice-mustard-black gram</b>	<b>TPRMB</b>
<b>T-4</b>	<b>Bottle gourd -cabbage -sponge gourd</b>	<b>BCS</b>
<b>T-5</b>	<b>Sudan chari-berseem-Sudan chari</b>	<b>SBS</b>

### 3.2.4 Sun-shine duration (hours)

The monthly mean sun-shine duration varied from 2.98 to 9.05 hours with an average of 6.69 hours during the crop growing period from 2011 to 2020. The minimum sun-shine hours were found in January whereas, the maximum was found in May.

### 3.4 Cropping practices of the experimental site

The production potential and soil quality of the experimental field can be judged from the cropping practices. The details of cropping practices of the experimental field are presented in Table 3.2

**Table 3.2: Cropping practices of the experimental field**

Cropping systems					
Practices	Rice-wheat-green gram	Rice-barley-green gram	Rice-mustard-black gram	Bottle gourd-cabbage-sponge gourd	Sudan chari-berseem-Sudan chari
Tillage	Conventional	Conventional	Conventional	Conventional	Conventional
Crop rotation	Rice-wheat-green gram	Rice-barley-green gram	Rice-mustard-black gram	Bottle gourd-cabbage-sponge gourd	Sudan chari-berseem-Sudan chari
Soil type	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Design	RBD	RBD	RBD	RBD	RBD
Replication	4	4	4	4	4

### 3.5 Soil sampling and processing

It is the process of collecting a small portion of soil up to the desired depth (0-15 and 15-30 cm) from the field by the means of suitable sampling tools from well-distributed spots moving in a zigzag manner from each sampling site. Soil samples were collected using soil cores with (0-15 and 15-30 cm) soil depth from each plot. Sampling was randomly at four places from each plot and blended to make a

composite sample by mixing all the collected small portions of soil moving in a zigzag manner from each sampling site after scrapping off the surface litter without removing soil. From the fields having standing crops in a row, draw samples in between the rows. Soil samples were taken during the crop period in March 2019, taking all the possible precautions prescribed for soil sampling (Black et al. 1965). The collected composite samples were air-dried at room temperature (25°C), soil clods were broken with the help of mortar and pestle, and foreign material was also removed, and sieved with a 2 mm sieve. The processed soil samples were stored in airtight plastic bags for lab analysis.

### **3.6 Observation to be recorded**

#### **3.6.1 Soil analysis**

An attempt was made to assess the physicochemical properties of soil of the experimental field. Soil samples were taken after the experiment was conducted. The processed samples were brought to the laboratory and subjected to appropriate mechanical, physical, and chemical analysis.

#### **3.6.2 Soil physical properties**

#### **3.6.3 Soil bulk density (B.D)**

Soil bulk density was determined by the core method (Blake and Hartge, 1986). The soil sample was taken from the field at depth of 0-15 cm and 15-30 cm with the help of the soil core. The sample was filled tightly in an aluminum moisture box and kept in an oven at 105°C temperature till the constant weight was obtained. Then, measure the weight of dry soil along with the moisture box and measure the weight of the moisture box alone. The weight of dry soil was obtained by subtracting the weight of the moisture box + soil from the moisture box.

### **Observation**

Weight of moisture box = x g

Weight of moisture box + soil = y g

Weight of dry soil = y-x g=z g

Bulk density ( $\text{Mg m}^{-3}$ ) =  $\frac{\text{weight of soil (y-x)g}}{\text{volume of core}}$

### **3.6.4 Chemical properties of soil**

#### **3.6.5 Soil pH**

A soil-water suspension was prepared in the ratio of 1:2.5 (10 g soil with 20 mL of distilled water) and pH was measured with the help of a pH meter (Sparks, 1996).

#### **3.6.6 Electrical conductivity (EC dS/m)**

The soil water suspension prepared for the determination of pH was used to estimate the electrical conductivity of the soil. The soil suspension was allowed to settle till the supernatant become clear. Electrical conductivity was measured with the help of an EC meter and expressed as  $\text{dSm}^{-1}$  (Sparks, 1996).

#### **3.6.7 Organic carbon (OC%)**

The Soil Organic Carbon (SOC) content of samples was determined by the wet oxidation method (Walkley and Black method (1934)).

### **Procedure**

1 g of soil was taken in 500 mL of the conical flask. Add 10 mL of 1N  $\text{K}_2\text{Cr}_2\text{O}_7$  solution was added and mixed. Then 20mL of conc.  $\text{H}_2\text{SO}_2$  was added, the flask was swirled 2-3 times and allowed to stand for 30 minutes on an asbestos sheet for the reaction to occur. The suspension was diluted with 200 mL of distilled water. Add 10 mL of 85%  $\text{H}_3\text{PO}_4$  and 1 mL of diphenylamine indicator were added and

titrated against the solution of 0.5N Ferrous Ammonium Sulphate till color changed from violet to bright green. A blank titration was also carried out.

**Observation**

$$\% \text{ organic 'C' in soil} = \frac{(B-S) \times 0.003 \times 100}{\text{weight of soil (1 g)}}$$

**Here,**

Strength of used = 1N

The volume of  $K_2Cr_2O_7$  taken = 10 ml

B= volume of 0.5 N FAS solution used for the blank titration

T= volume of 0.5 N FAS solution used for sample titration

**3.6.8 Available nitrogen (N kg/ha)**

Available Nitrogen content in soil was determined using Kjeltac Semi-Auto Nitrogen Analyzer by Alkaline Potassium permanganate method as proposed by Subbiah and Asija (1956). The method has been widely adopted to get a reliable index of nitrogen availability in soil due to its rapidity and reproductively.

**Procedure**

5g of soil sample was weighed and transferred in a Kjeldahl tube. The sample was moistened with 5mL distilled water, washing down the soil adhering to the neck of the flask. 25 ml 0.32%  $KMnO_4$  was added to it and the distillation tube was set to the instrument. In a 250 ml conical flask, 20 mL of 2% boric acid mixed indicator was taken and placed under the receiver tube. Tap water was run continuously in the condenser. 25 mL of 2.5 % NaOH was sucked and added to the tube. Then it was put on distillation for 9 minutes. During this process, the N released in the form of ammonia is trapped in the boric acid, which develops green color. The flask

containing the distilled was removed. The distilled was then titrated against 0.02 N H<sub>2</sub>SO<sub>4</sub> until pink color developed.

### **Calculation**

$$\text{Available Nitrogen (kg/ha)} = \frac{(S-B) \times 0.002 \times 14 \times 10 \times 2.24}{1000 \times 5}$$

$$\text{Available Nitrogen (kg/ha)} = S-B \times 125.44$$

Where,

S = sample titration reading

B = blank titration reading

### **3.6.9 Available phosphorus (P<sub>2</sub>O<sub>5</sub> kg/ha)**

Available phosphorus content of the soil was determined by (Olsen's et al. 1954). Firstly reagent "A" was prepared by using ammonium molybdate, antimony potassium tetrates, and H<sub>2</sub>SO<sub>4</sub>. Then reagent "B" was prepared with help of reagent A. 2 g of soil was taken in 150 mL of the conical flask, a pinch of Darco G-60, and 40 mL of Olsen's reagent (0.5 M NaHCO<sub>3</sub>) was added to it. It was then shaken for 30 minutes on the mechanical shaker and the suspension was filtered through Whatman No. 1 filter paper. 5 mL of filtrate was transferred in a 25 mL volumetric flask and was acidified with 2.5M H<sub>2</sub>SO<sub>4</sub> to pH 5 and 20 mL distilled water was added followed by 4 mL of reagent "B". After waiting for 10 minutes the intensity of the blue color was measured on a spectrophotometer at 760 nm. Simultaneously a blank was also run. The first standard reading was taken followed by a sample reading.

### **Calculation**

2 g of soil sample was diluted in 40 ml of 0.5M NaHCO<sub>3</sub> solution

$$\text{Hence, dilution factor} = \frac{40}{2} = 20 \text{ times}$$

5 ml aliquot is taken in 25 ml volumetric flask

Hence, Dilution factor =  $\frac{25}{5} = 5$  times

Therefore, total dilution factor (DF) =  $20 \times 5 = 100$  times

Transmittance (%) of the test solution = T

T = A ppm, A = standard mean  $\times$  sample reading

Hence, concentration of P (ppm) = A  $\times$  100

Available P (kg/ha) in soil = A  $\times$  100  $\times$  2.24

Available P<sub>2</sub>O<sub>5</sub> (kg/ha) in soil = A  $\times$  100  $\times$  2.24  $\times$  2.29

### **3.6.10 Available potassium (K<sub>2</sub>O kg/ha)**

The available potassium content of the soil was determined by the flame photometer (1N ammonium acetate extract) method (Hanway and Heidel 1952). 5 gram soil was transferred in a 100 mL conical flask and 25 mL of 1N ammonium acetate solutions was added and it was shaken for 5 minutes. The suspension was then filtered through Whatman No. 1 filter paper and potassium concentration in the filtrate was measured using a flame photometer. The first standard reading was taken followed by a sample reading.

#### **Calculation**

Dilution factor =  $25/5 = 5$  times

The concentration of K in the sample from the standard curve against the reading R=C

Available K (kg/ha) = C  $\times$  dilution factor  $\times$  2.24

= C  $\times$  5  $\times$  2.24

= C  $\times$  11.2

#### **4.1 Statistical analysis**

The experiment was laid out in Randomized Blok Design (RBD). The data obtained from various characters under study were analyzed by the method of analysis of variance as described by Gomez and Gomez (1984). To compare the mean value of treatment, standard error and critical values were calculated. The following formula was used for standard error, critical differences, and coefficient of variance estimations.

- a)  $\text{Sem} \pm \text{EMS}/r$
- b)  $\text{C.D} = \text{S. Em} \pm$
- c)  $\text{C.V}(\%) \text{ EMS}/\text{GM}$

## EXPERIMENTAL FINDINGS

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A cropping system refers to the type and sequence of crops grown and practices used for growing them. It encompasses all cropping sequences practiced over space and time based on the available technologies of crop production. Cropping systems have been traditionally structured to maximize crop yields. Now, there is a strong need to design cropping systems that take into consideration the emerging social, economic, and ecological or environmental concerns. Conserving soil and water and maintaining long-term soil productivity which ultimately provides food security to the rapidly increasing population. However, to meet all these goals depend largely on the management of cropping systems. Crop diversification is an important option in sustainable agricultural systems. Management of cropping systems implies management of tillage, crop residue, nutrients, pests, and practices for soil conservation. For example, excessive use of chemicals (e.g., fertilizers) for growing crops, particularly in developed countries, has raised concerns over increased risks of non-point source pollution which enhance water pollution, soil pollution, and environmental pollution. Choice of appropriate cropping systems is useful strategies to minimize all types of pollutions. Cereal crops are rotated by legumes improved soil nitrogen by biological nitrogen fixation process of legume that increases the yield of proceeding crop (via, cereals). Cultivation of Legume crops is also considered a natural mini-nitrogen manufacturing factory in the field. A brief review of available literature pertains to the present investigation entitled *“Effect of different cropping systems on energy budgeting and carbon footprint”* has been presented in the chapter under different sub-headings.

### **4.1 Effect of seasons on biological yield of different cropping systems**

#### **4.1.1 Biological yield**

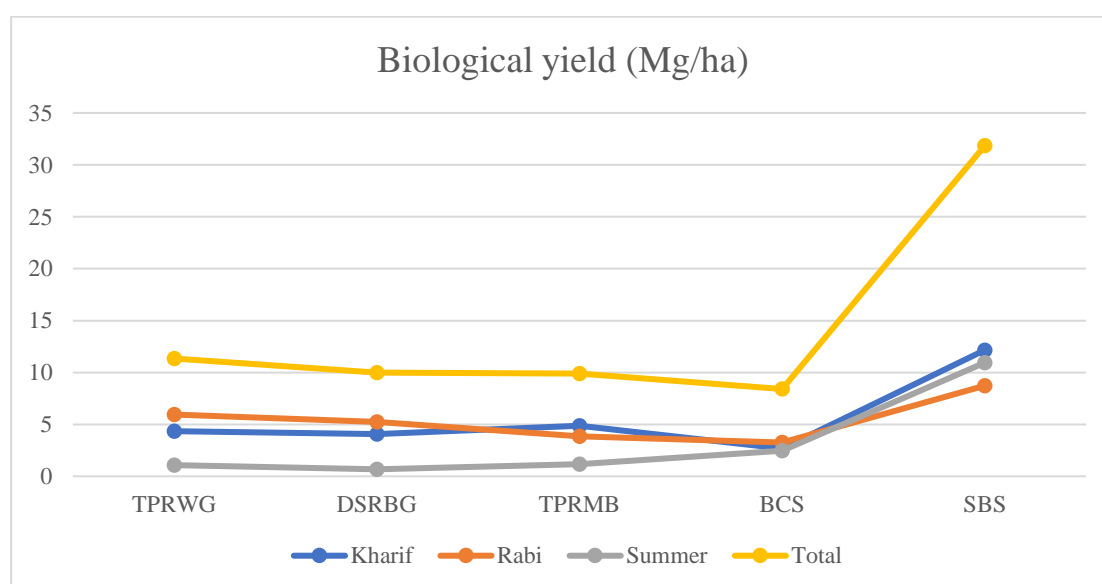
A significant variation in biological yield was seen in all cropping systems during *Khariif*, rabi, and summer seasons, according to the data presented in table 4.1

and Fig 4.1. A range of biological yields of 0.68- 12.16 Mg/ha was recorded during all the seasons in cropping systems. The lowest to highest 2.68-12.16, 3.26-8.73, 2.47-10.95, and 8.41- 31.84Mg/ ha biological yield was recorded in SBS and BCS during all seasons viz; *Kharif*, rabi, summer, and a total of the year, respectively except summer season. Moreover, a range of biological yields of 8.41- 31.84 Mg/ha was recorded based on the total biological yield of the system in a year. While the TTPRWG, DSRBG, and TPRMB were statistically at par with each other based on the total biological yield of the year.

**Table 4.1 Effect of seasons on biological yield of different cropping systems**

Treatments	Mg/ha			
	Kharif	Rabi	Summer	Total
<b>TTPRWG</b>	4.35	5.94	1.07	11.36
<b>DSRBG</b>	4.07	5.24	0.98	10.29
<b>TPRMB</b>	4.88	3.84	1.18	9.90
<b>BCS</b>	2.87	3.26	2.47	8.60
<b>SBS</b>	12.16	8.73	10.95	31.84
<b>SEm±</b>	0.41	0.41	0.36	0.35
<b>CD(p=0.05)</b>	1.19	1.18	1.04	1.02

TTPRWG: Rice-wheat-green gram; DSRBG: Rice-barley-green gram; TPRMB: Rice-Mustard-Green gram; BCS: Bottle gourd-cabbage-sponge gourd; SBS: Sudan chari -berseem-Sudan chari



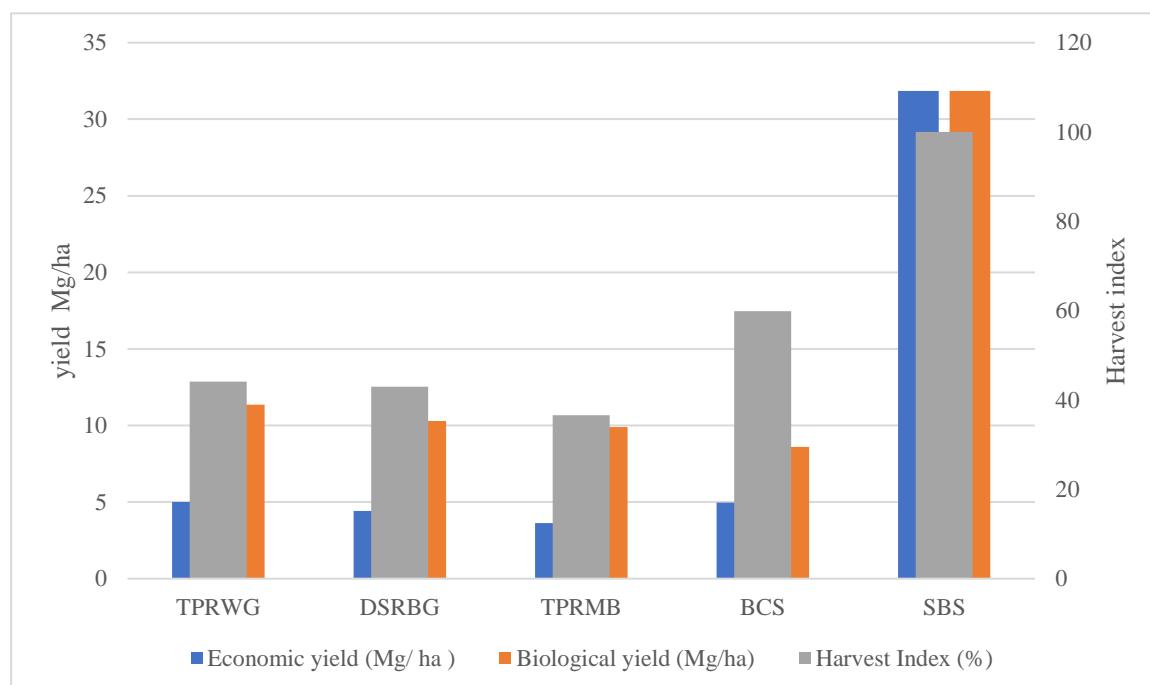
**Fig 4.1 Effect of seasons on biological yield (Mg/ha) of different cropping systems**

#### 4.1.2 Economic yield and harvest index

The data presented in the table 4.2 and fig 4.2 is given that the economic yield, biological yield, harvest is considerably affected by the different cropping systems. The highest economic yield was recorded under the SBS cropping system, while lowest economic yield was recorded under TPRMB cropping system. Harvest index of different cropping is greatly affected by different cropping system.

**Table 4.2 Effect of cropping sequences on economic yield, biological yield, and harvest index of different cropping systems**

Treatments	Economic yield (Mg ha <sup>-1</sup> )	Biological yield (Mg/ha)	Harvest Index (%)
TPRWG	5.01	11.36	44.1
DSRBG	4.43	10.29	43.0
TPRMB	3.63	9.90	36.6
BCS	4.96	8.60	59.9
SBS	31.84	31.84	100.0
SEm±	0.31	0.35	0.55
CD (p=0.05)	0.90	1.02	1.60



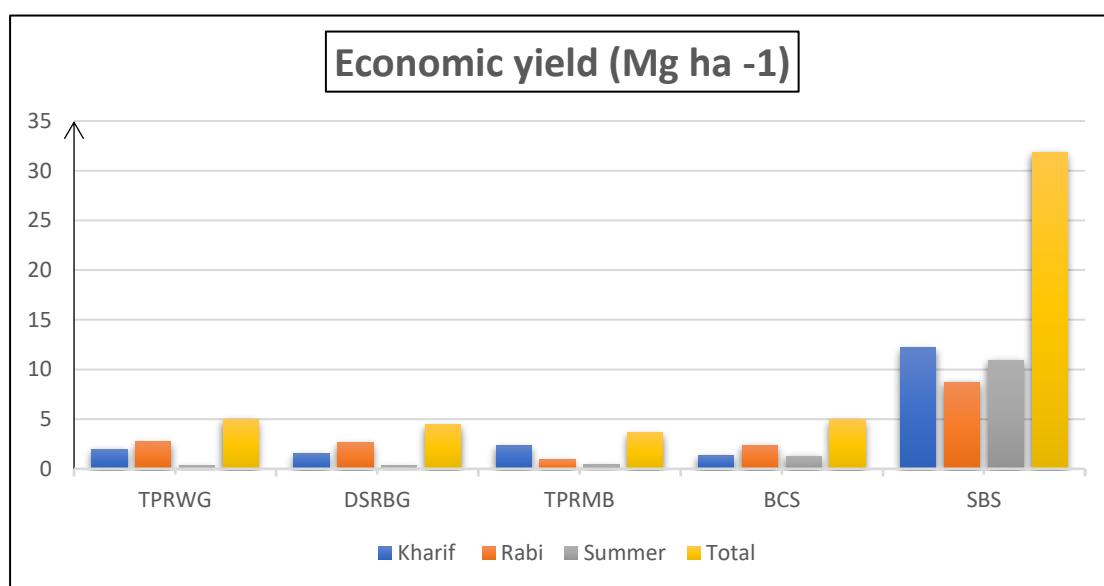
**Fig 4.2 Effect of cropping sequences on economic yield, biological yield, and harvest index of different cropping systems**

### 4.1.3 Economic yield (Mg ha<sup>-1</sup>)

A significant variation in economic yield was seen in all cropping systems during *Kharif*, rabi, and summer seasons, according to the data presented in table 4.3 and Fig 4.3. A range of economic yield of 0.32 - 12.16 Mg/ha was recorded during all the seasons in cropping systems. The lowest to highest 1.33-12.16, 0.90-8.73, 0.30 - 10.95, and 3.63- 31.84Mg/ ha economic yield was recorded in BCS and SBS during all seasons *viz*; *Kharif*, rabi, summer, and a total of the year, respectively except summer season. Moreover, a range of economic yield of 3.63 - 31.84 Mg/ha was recorded based on the total economic yield of the system in a year. While the TPRWG, DSRBG, and TPRMB were statistically at par with each other based on the total biological yield of the year.

**Table 4.3 Economic produce on a dry weight basis**

Treatments	Economic yield (Mg ha <sup>-1</sup> )			
	Kharif	Rabi	Summer	Total
<b>TPRWG</b>	1.95	2.73	0.32	5.01
<b>DSRBG</b>	1.51	2.62	0.30	4.43
<b>TPRMB</b>	2.33	0.90	0.40	3.63
<b>BCS</b>	1.33	2.36	1.27	4.96
<b>SBS</b>	12.16	8.73	10.95	31.84
<b>SEm±</b>	0.32	0.23	0.27	0.82
<b>CD (p=0.05)</b>	0.93	0.67	0.78	2.38



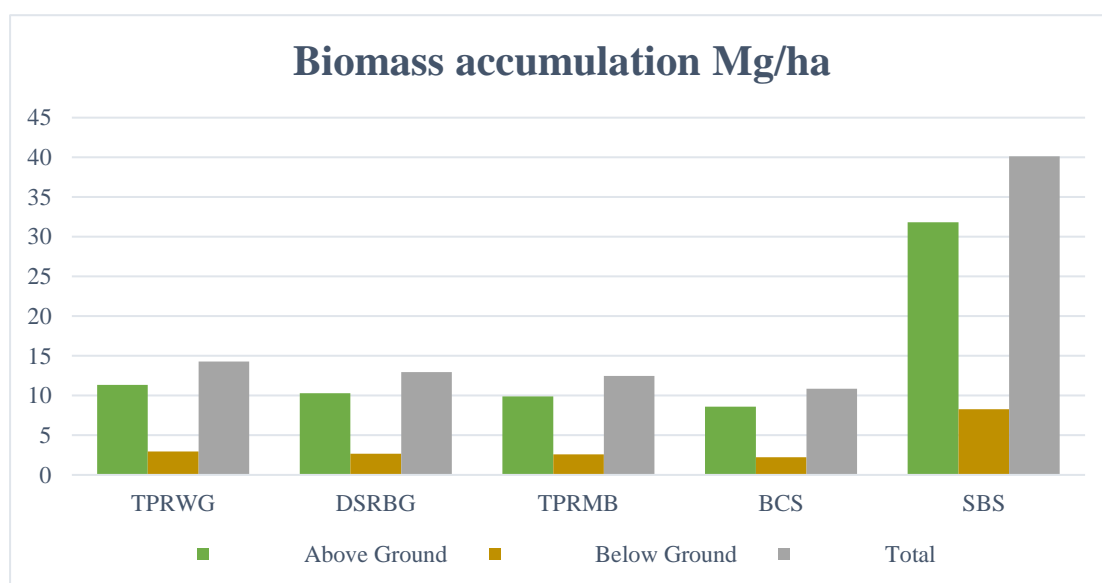
**Fig 4.3 Economic produce on a dry weight basis**

**4.1.4 Biomass accumulation (Mg/ha)**

A significant variation in biomass accumulation was seen in all cropping systems of above ground and below ground biomass according to the data presented in table 4.4 and Fig 4.4. A range of biomass accumulation of 8.61-31.84 and 2.24-8.28 Mg/ha above ground and below ground biomass respectively was recorded during all systems. Moreover, the maximum biomass accumulation was recorded based on total biomass accumulation of the system in a year in SBS cropping system and followed by TPRWG. While the lowest biomass accumulation was recorded under BCS, which was statistically at par with TPRMB, DSRBG total biomass accumulation of the year, and found statistically at par with each other.

**Table 4.4 Above and below biomass accumulation of different cropping systems**

Treatments	Biomass accumulation (Mg/ha)		
	Above Ground	Below ground	Total
<b>TPRWG</b>	11.36	2.95	14.32
<b>DSRBG</b>	10.29	2.67	12.96
<b>TPRMB</b>	9.90	2.57	12.47
<b>BCS</b>	8.60	2.24	10.84
<b>SBS</b>	31.84	8.28	40.12
<b>SEm±</b>	0.35	0.09	0.44
<b>CD (p=0.05)</b>	1.02	0.26	1.28



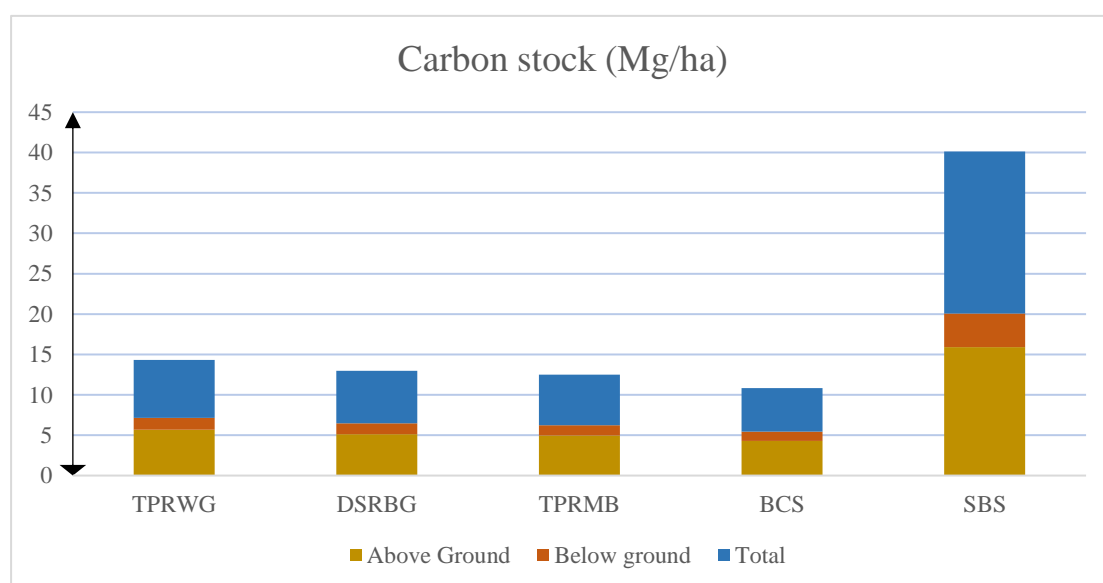
**Fig 4.4 Above and below biomass accumulation of different cropping systems**

**4.1.5 Above and below carbon stock (Mg/ha)**

A significant variation on carbon stock was seen in all cropping systems of above ground and below ground carbon stock according to the data presented in table 4.5. and Fig 4.5. A range of carbon stock of 4.31-15.92 and 1.12-4.14 Mg/ha above ground and below ground carbon stock respectively was recorded during all systems. Moreover, the maximum carbon stock was recorded based on the total carbon stock of the system in a year in SBS cropping system and followed by TPRWG. While the lowest biomass accumulation was recorded under BCS, which was statistically at par with DSRBG, TPRMB total biological accumulation of the year, and found statistically at par with each other

**Table 4.5 Above and below Carbon stock of different cropping systems**

Treatments	Carbon stock (Mg/ha)		
	Above Ground	Below ground	Total
TPRWG	5.68	1.48	7.16
DSRBG	5.15	1.34	6.48
TPRMB	4.95	1.29	6.24
BCS	4.30	1.12	5.42
SBS	15.92	4.14	20.06
SEm±	0.04	0.01	0.05
CD (p=0.05)	0.11	0.03	0.14



**Fig 4.5 Above and below carbon stock of different cropping systems**

**4.1.6 CO<sub>2</sub> sequestration (Mg/ha) and carbon credit**

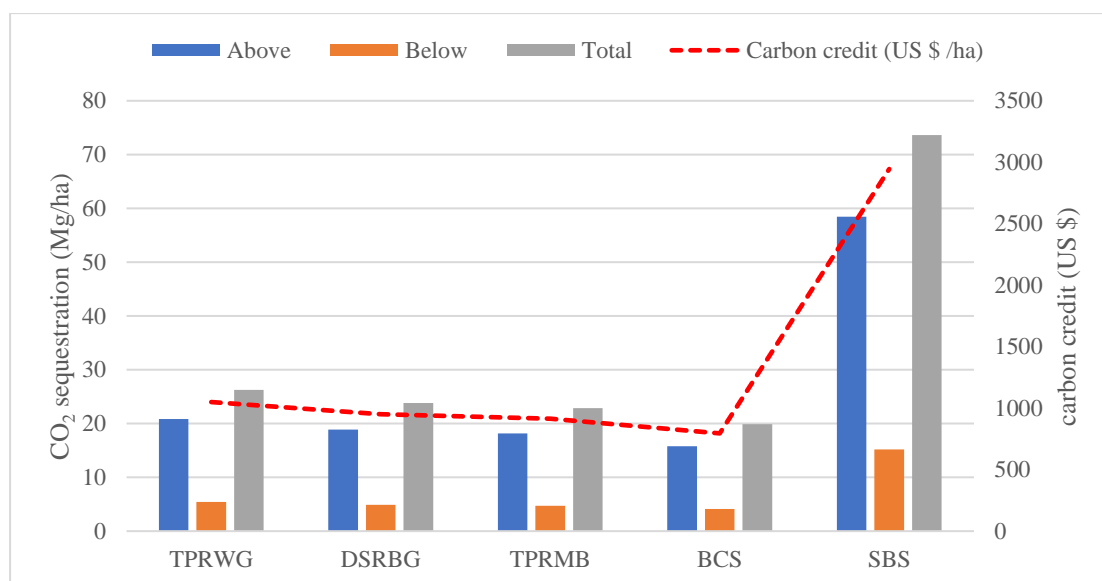
A significant variation in CO<sub>2</sub> sequestration was seen in all cropping systems of above ground and below ground according to the data presented in table 4.6. and Fig 4.6. A range of CO<sub>2</sub> sequestration of 15.80-31.84 and 4.11-15.19 Mg/ha above ground and below ground CO<sub>2</sub> sequestration respectively was recorded during all systems. Moreover, the maximum CO<sub>2</sub> sequestration was recorded based on total CO<sub>2</sub> sequestration of the system in a year in SBS cropping system and followed by TPRWG. While the lowest CO<sub>2</sub> sequestration was recorded under BCS, which was statistically at par with DSRBG, TPRMB total biological accumulation of the year, and found statistically at par with each other.

**Carbon credit (Rs. /ha/yr.**

The information in the table and fig is given that the carbon credit was greatly affected by the different cropping systems. carbon credit was higher under the SBS (21378 Rs. /ha/yr.) cropping system and followed by TPRWG cropping system. carbon credit was lower under the BCS cropping system

**Table 4.6 CO<sub>2</sub> sequestration and carbon credit of different cropping systems**

Treatments	CO <sub>2</sub> sequestration (Mg/ha)			Carbon credit (US \$ /ha)	Carbon credit (Rs. /ha)
	Above Ground	Below ground	Total		
<b>TPRWG</b>	20.85	5.42	26.27	1050.8	76288
<b>DSRBG</b>	18.88	4.91	23.79	951.6	69086
<b>TPRMB</b>	18.17	4.72	22.89	915.6	66473
<b>BCS</b>	15.78	4.10	19.88	795.2	57732
<b>SBS</b>	58.43	15.19	73.62	2944.8	213792
<b>SEm±</b>	0.13	0.03	0.16	6.4	465
<b>CD(p=0.05)</b>	0.39	0.10	0.49	19.6	1423



**Fig 4.6 CO<sub>2</sub> sequestration and carbon credit of different cropping systems**

## 4.2 Effect of different cropping system on physic-chemical properties of soil

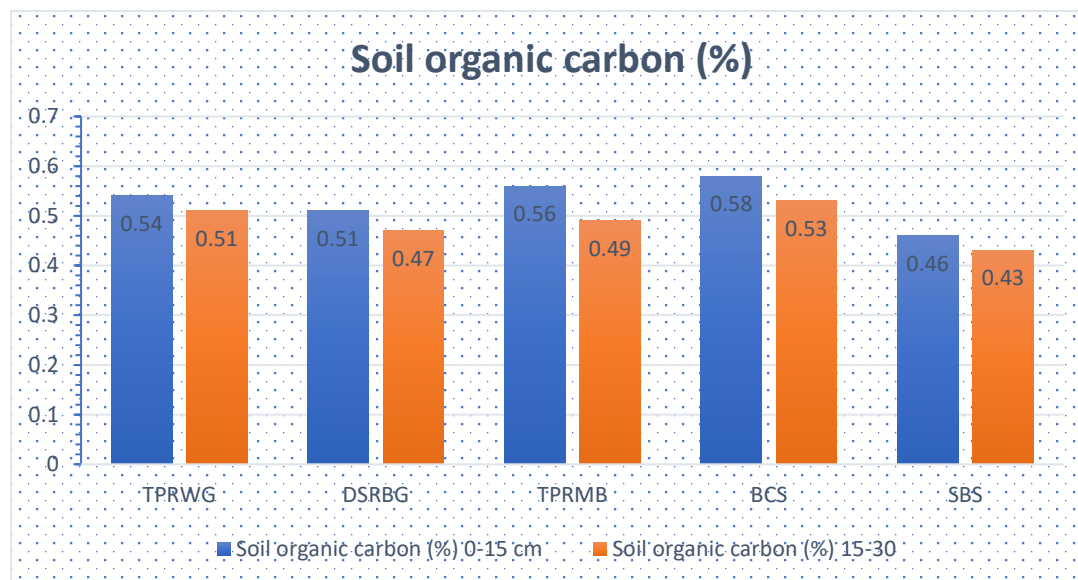
### 4.2.1 Soil organic carbon (%)

A significant variation in soil organic carbon (SOC) was seen in all cropping systems, according to the data presented in table 4.7 and Fig 4.7. The maximum soil organic carbon 0.58 and 0.53 were recorded in BCS cropping system at 0-15 and 15-30 cm, respectively which was at par with both TPRMB and TPRWG cropping system. the lowest soil organic carbon 0.46,0.43 were recorded in SBS cropping system at 0-15 and 15-30 cm, respectively which was at par with DSRBG cropping system.

**Table 4.7 The impact of various cropping systems on soil organic carbon (%)**

Treatments	Soil organic carbon (%)	
	Soil depth(cm)	
	0-15	15-30
TPRWG	0.54	0.51
DSRBG	0.51	0.47
TPRMB	0.56	0.49
BCS	0.58	0.53
SBS	0.46	0.43
SEm±	0.01	0.02
CD (p=0.05)	0.04	0.06

TPRWG: Rice-wheat-green gram; DSRBG: Rice-barley-green gram; TPRMB: Rice-Mustard-Green gram; BCS: Bottle gourd-cabbage-sponge gourd; SBS: Sudan chari -berseem-Sudan chari



**Fig 4.7 The impact of various cropping systems on soil organic carbon (%)**

#### 4.2.2 Bulk density(g/cc)

The data presented in the table 4.8 and fig 4.8 is given that the bulk density of the soil is considerably affected by the different cropping systems. Among the different cropping systems, the highest bulk density was recorded at 0-15 and 15-30 cm depth under the SBS cropping system and followed by DSRBG cropping system which was at par with TPRMB cropping system. However, the lowest bulk density was recorded in TPRMB cropping system which was at par with the TPRWG cropping system.

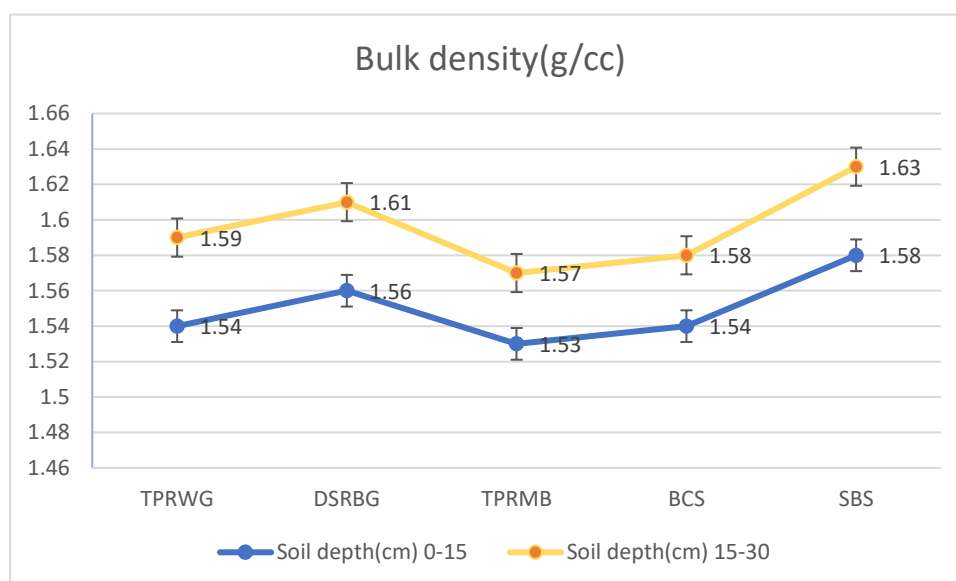
**Table 4.8 The impact of various cropping systems on soil bulk density**

Treatments	Bulk density(g/cc)	
	Soil depth(cm)	
	0-15	15-30
TPRWG	1.54	1.59
DSRBG	1.56	1.61
TPRMB	1.53	1.57
BCS	1.54	1.58
SBS	1.58	1.63
SEm±	0.02	0.01

CD (p=0.05)

0.05

0.04



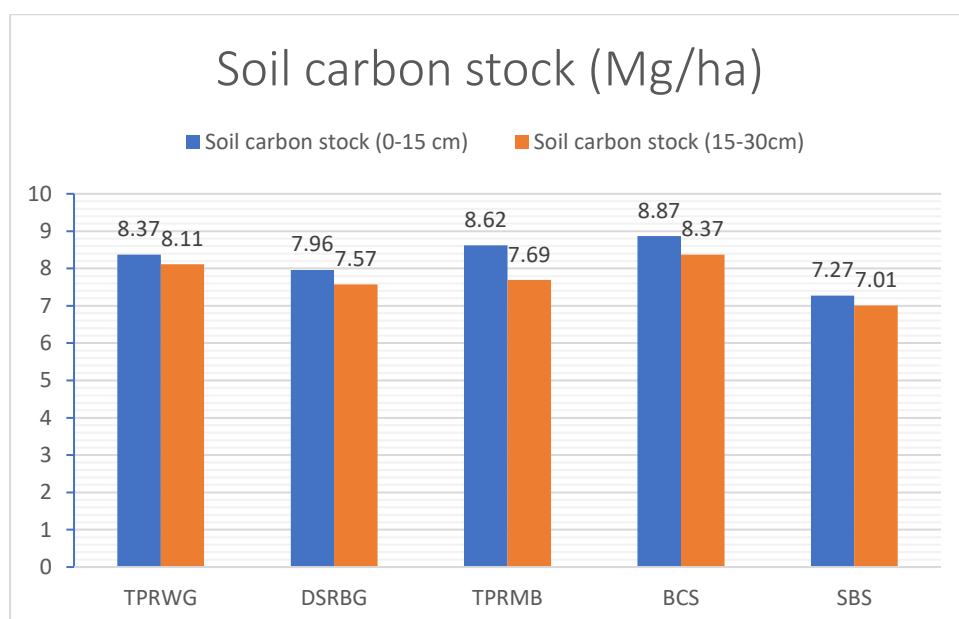
**Fig 4.8 The impact of various cropping systems on soil bulk density**

#### 4.2.3 Soil carbon stock (Mg/ha)

The information in the table 4.9 and fig 4.9 is given that the soil carbon stock (SCS) was greatly affected by the different cropping systems. The highest soil SCS was recorded in BCS cropping system at 0-15 and 15-30 depth followed by the TPRMB cropping system which was at par with TPRWG cropping system. However, the lowest SCS was observed under the SBS cropping system at 0-15,15-30 depth which was at par with cropping system DSRBG cropping system.

**Table 4.9 The impact of various cropping systems on soil carbon stocks**

Treatments	Soil carbon stock (Mg/ha)	
	Soil depth(cm)	
	0-15	15-30
TPRWG	12.56	12.16
DSRBG	11.93	11.35
TPRMB	12.94	11.54
BCS	13.31	12.56
SBS	10.90	10.51
SEm±	0.15	0.23
CD (p=0.05)	0.44	0.68



**Fig 4.9 The impact of various cropping systems on soil carbon stocks**

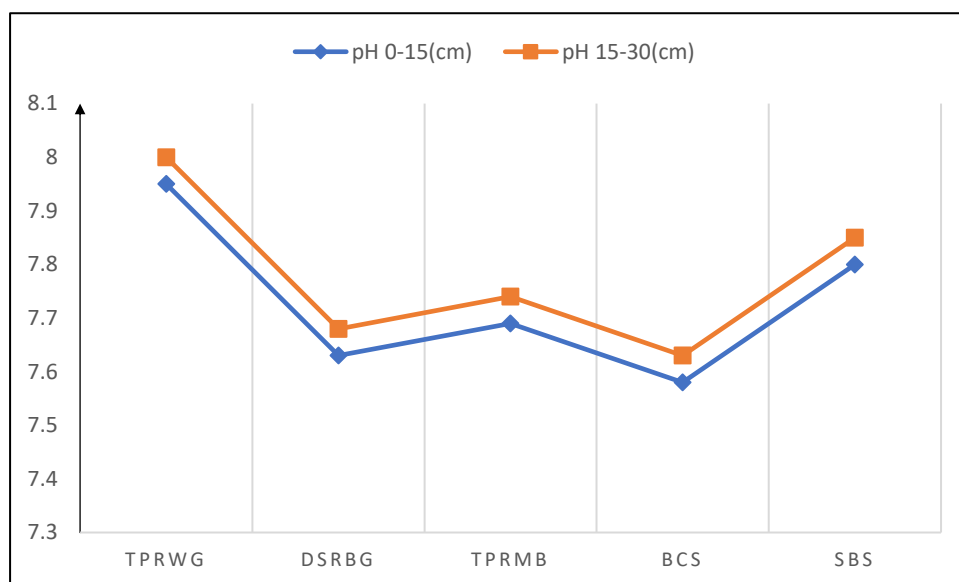
#### 4.2.4 pH

The results concerning available pH are shown in the table 4.10 and fig 4.10 that the pH is considerably affected by different cropping systems. The marked variations in pH in this study, considerably affected by different cropping systems. Among the different cropping systems, the highest pH was recorded at 0-15 and 15-30 cm depth under the TPRWG cropping system and followed by SBS cropping system which was at par with TPRMB, BCS, DSRBG cropping system. However, the lowest pH was recorded in BCS cropping system which was at par with the DSRBG cropping.

**Table 4.10 The impact of various cropping systems on pH of soil**

Treatments	pH	
	Soil depth(cm)	
	0-15	15-30
TPRWG	7.95	8.00
DSRBG	7.63	7.68
TPRMB	7.69	7.74
BCS	7.58	7.63

<b>SBS</b>	7.80	7.85
<b>SEm±</b>	0.29	0.26
<b>CD (p=0.05)</b>	0.85	0.75



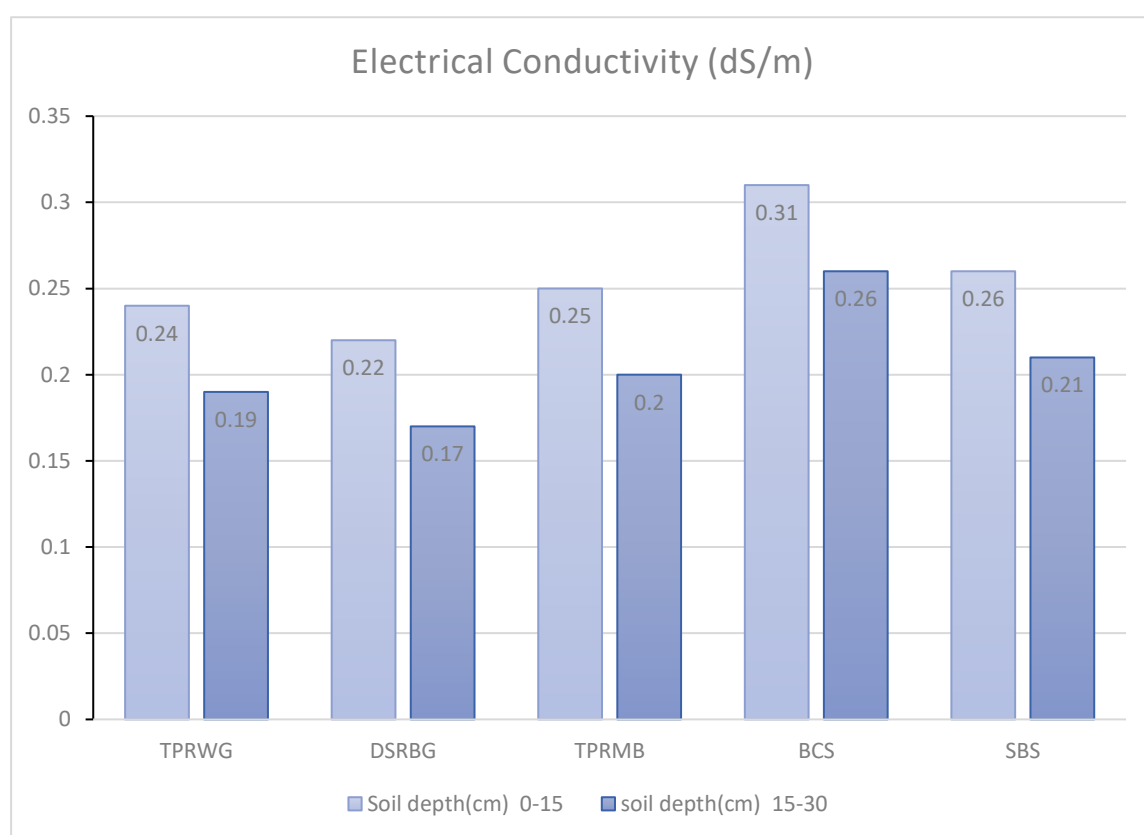
**Fig 4.10** The impact of various cropping systems on pH of soil

#### 4.2.5 Electrical conductivity(dS/m)

The data of electrical conductivity is shown in the table 4.11 and fig 4.11 reveals that the electrical conductivity in different cropping systems. The marked variations in electrical conductivity in this study, considerably affected by different cropping systems. Among the different cropping systems, the highest electrical conductivity was recorded at 0-15 and 15-30 cm depth under the BCS cropping system and followed by SBS cropping system which was at par with TPRMB and TPRWG cropping system. However, the lowest electrical conductivity was recorded in DSRBG cropping system which was at par with the DSRBG cropping system.

**Table 4.11** The impact of various cropping systems on electrical conductivity of soil

Treatments	EC (dS/m)	
	Soil depth(cm)	
	0-15	15-30
<b>TPRWG</b>	0.24	0.19
<b>DSRBG</b>	0.22	0.17
<b>TPRMB</b>	0.25	0.20
<b>BCS</b>	0.31	0.26
<b>SBS</b>	0.26	0.21
<b>SEm±</b>	0.01	0.01
<b>CD (p=0.05)</b>	0.02	0.02



**Fig 4.11** The impact of various cropping systems on electrical conductivity of soil

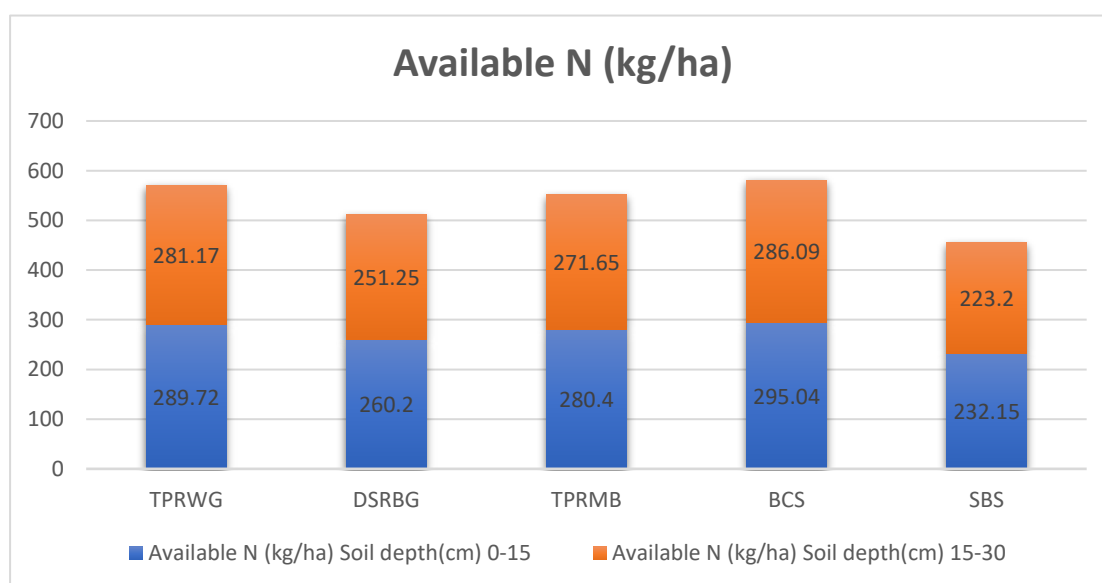
#### 4.2.6 Available N (kg/ha)

The result on available nitrogen content under different cropping systems is indicated in the table 4.12 and fig 4.12. The marked variations in available nitrogen in this study, considerably affected by different cropping systems. Among the

different cropping systems, the highest available nitrogen was recorded at 0-15 and 15-30 cm depth under the BCS cropping system and followed by TPRMB cropping system which was at par with TPRWG cropping system. However, the lowest available nitrogen was recorded in SBS cropping system which was at par with the DSRBG cropping system.

**Table 4.12 The impact of various cropping systems on available nitrogen soil**

Treatments	Available N (kg/ha)	
	Soil depth(cm)	
	0-15	15-30
<b>TPRWG</b>	289.72	281.17
<b>DSRBG</b>	260.20	251.25
<b>TPRMB</b>	280.40	271.65
<b>BCS</b>	295.04	286.09
<b>SBS</b>	232.15	223.20
<b>SEm±</b>	0.36	0.54
<b>CD (p=0.05)</b>	1.04	1.59



**Fig 4.12 The impact of various cropping systems on available nitrogen soil**

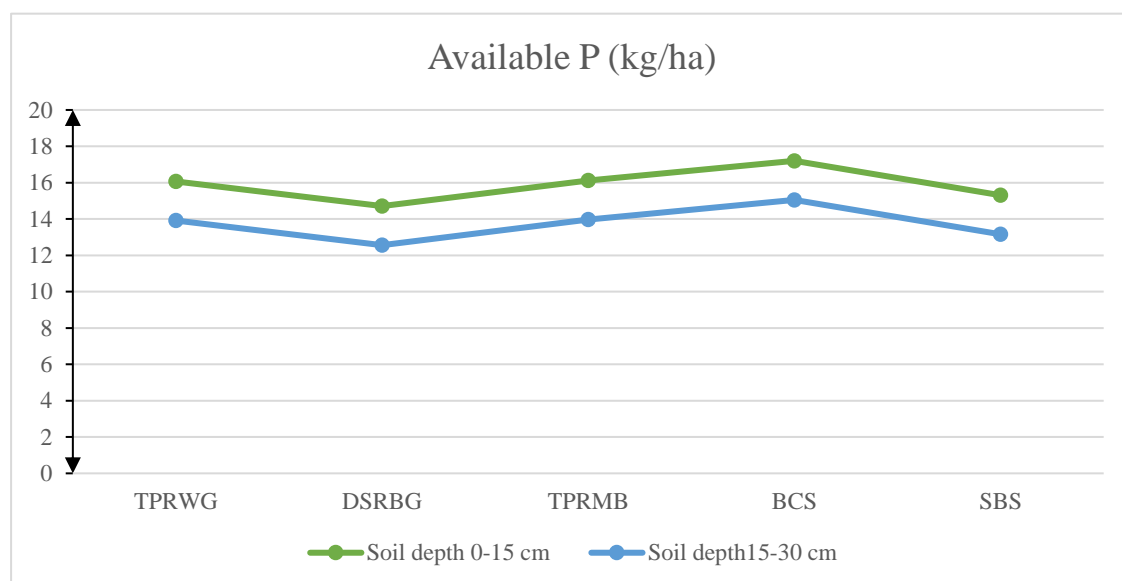
#### 4.2.7 Available P<sub>2</sub>O<sub>5</sub> (kg/ha)

The results concerning available phosphorus are shown in table 4.13 and fig 4.13. affected by different cropping systems. Among the different cropping systems,

the highest available phosphorus was recorded at 0-15 and 15-30 cm depth under the BCS cropping system and followed by TPRMB cropping system which was at par with DSRBG cropping system. while the lowest available phosphorus was recorded in DSRBG cropping system which was at par with SBS cropping system.

**Table 4.13 The impact of various cropping systems on available phosphorus of soil**

Treatments	Available P <sub>2</sub> O <sub>5</sub> (kg/ha)	
	Soil depth(cm)	
	0-15	15-30
TPRWG	16.06	13.91
DSRBG	14.71	12.56
TPRMB	16.11	13.96
BCS	17.20	15.05
SBS	15.30	13.15
SEm±	0.13	0.06
CD (p=0.05)	0.38	0.18



**Fig 4.13 The impact of various cropping systems on available phosphorus of soil**

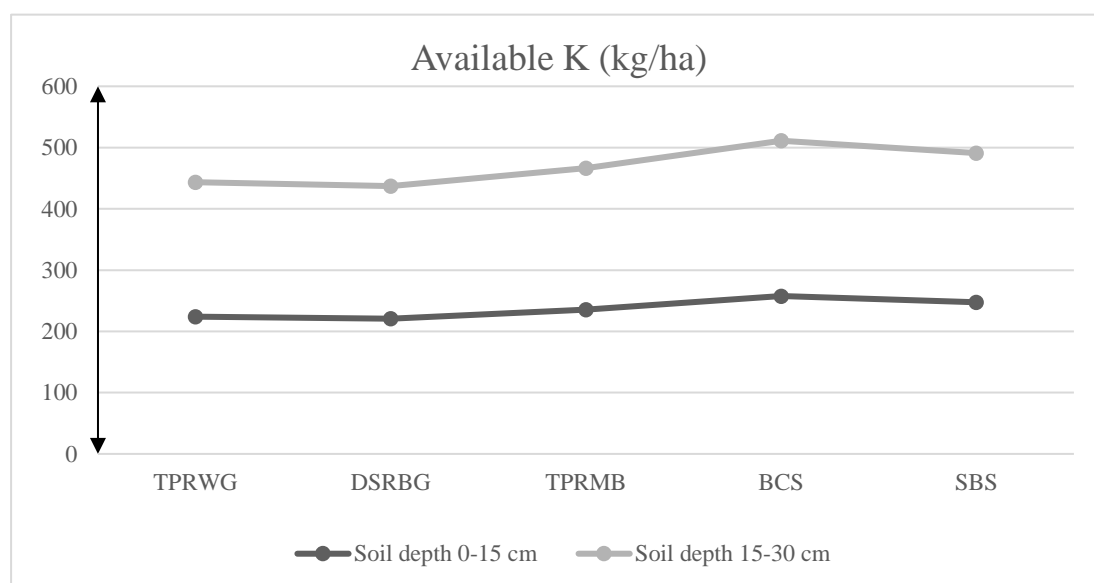
#### 4.2.8 Available K<sub>2</sub>O (kg/ha)

The data of available potassium is shown in the table 4.14 and fig 4.14 reveals that the available potassium in different cropping systems. The marked variations in available potassium in this study, considerably affected by different

cropping system. Among the different cropping system, the highest available potassium was recorded at 0-15,15-30 cm depth under the BCS cropping system and followed by SBS cropping system. while the lowest available phosphorus was recorded in DSRBG cropping system and which is statistically at par with TPRWG and TPRMB and statistically found at par with each other.

**Table 4.14 The impact of various cropping systems on available potassium of soil**

Treatments	Available K <sub>2</sub> O (kg/ha)	
	Soil depth(cm)	
	0-15	15-30
TPRWG	223.86	219.63
DSRBG	220.70	216.47
TPRMB	235.32	231.09
BCS	257.69	253.46
SBS	247.68	243.45
SEm±	1.05	0.16
CD (p=0.05)	3.07	0.46



**Fig 4.14 The impact of various cropping systems on available potassium of soil**

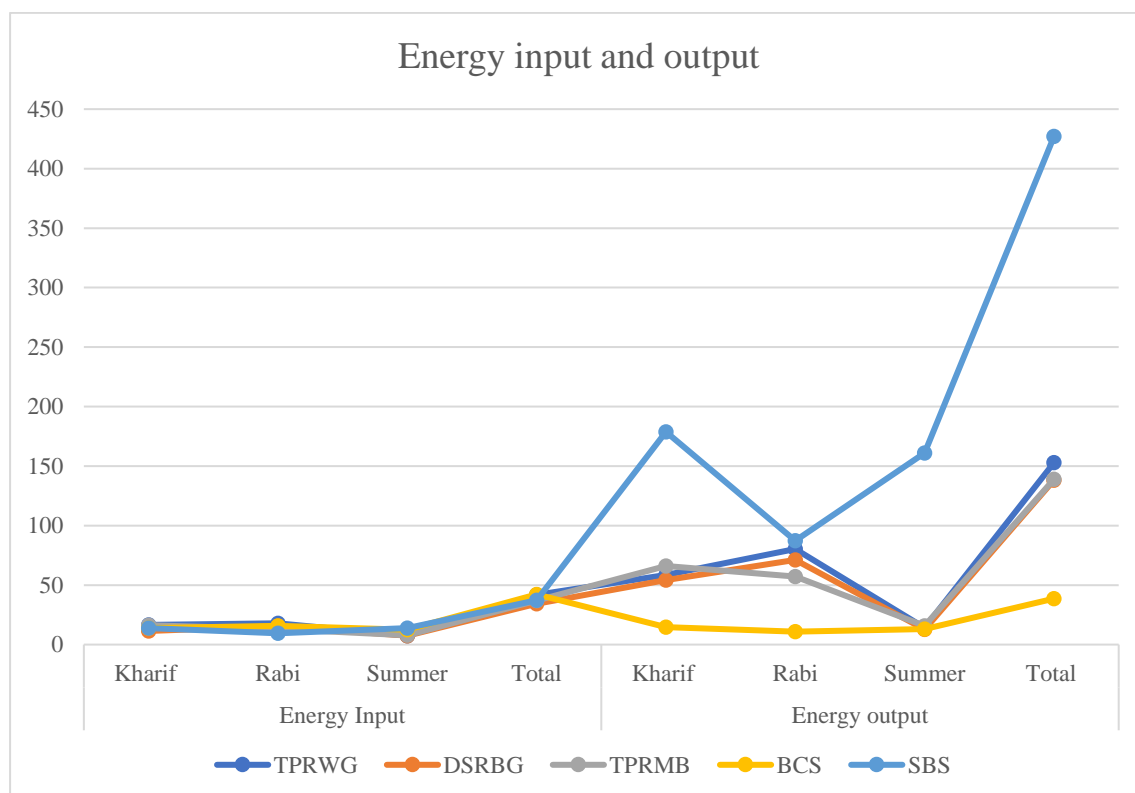
### 4.3 Effect of different cropping sequences on energy input and output in different season

#### 4.3.1 Energy input and output of different cropping system

**Table 4.15** Effect of different cropping sequences on energy input and output in different season

Treatments	Energy Input (MJ ha <sup>-1</sup> × 10 <sup>3</sup> )				Energy output (MJ ha <sup>-1</sup> × 10 <sup>3</sup> )			
	Kharif	Rabi	Summer	Total	Kharif	Rabi	Summer	Total
TPRWG	16.43	17.89	7.50	41.72	58.62	80.23	14.02	152.87
DSRBG	11.45	15.46	7.50	34.41	54.14	71.22	12.90	138.26
TPRMB	16.23	13.01	7.81	36.94	66.10	57.22	15.63	138.94
BCS	13.89	15.82	12.46	42.17	14.74	10.89	13.02	38.64
SBS	13.85	9.49	13.85	37.19	178.82	87.32	160.91	427.05
SEm±	0.06	0.05	0.09	0.2	0.20	0.85	0.27	3.94
CD(p=0.05)	0.16	0.14	0.27	0.57	0.57	2.49	0.80	11.49

TPRWG: Rice-wheat-green gram; DSRBG: Rice-barley-green gram; TPRMB: Rice-Mustard-Green gram; BCS: Bottle gourd-cabbage-sponge gourd; SBS: Sudan chari -berseem-Sudan chari



**Fig 4.15** Effect of different cropping sequences on energy input and output in different season

The data presented in Table 4.15 and table 4.15 indicate that the energy inputs of different cropping systems were significantly influenced by different cropping system. The highest input energy was recorded under the TPRWG cropping system in Kharif season. while the lowest energy input was recorded under SBS cropping system which was at par with BCS, TPRMB, DSRBG. In rabi season the highest input energy was recorded under the SBS cropping system while in summer season it was recorded under BCS cropping system. In summer season highest energy input was recorded under SBS cropping system. Total energy input was recorded under BCS cropping system. Energy output of different cropping system in Kharif, rabi summer season the highest output was recorded under SBS cropping system. While the lowest energy output was recorded under BCS cropping system which was at par with TPRWG, DSRBG, TPRMB

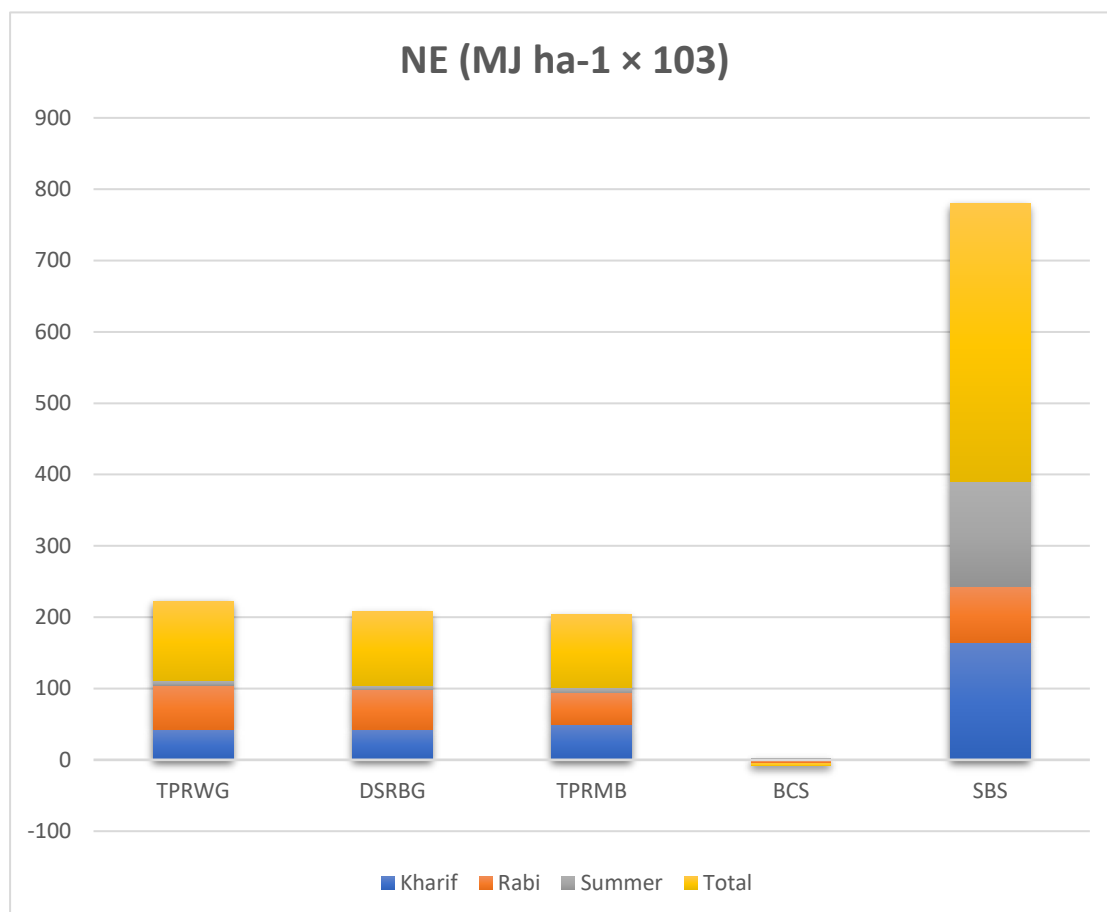
#### 4.3.2 Net energy (MJ ha<sup>-1</sup> × 10<sup>3</sup>)

A significant variation in net energy was seen in all cropping systems during *Kharif*, rabi, and summer seasons, according to the data presented in table 4.16. and Fig 4.16. A range of net energy -4.93 to 164.97 MJ/ha was recorded during all the seasons in cropping systems. The lowest to highest 0.85 to 164.97, -4.93 to 77.83, 0.56 to 147.06 MJ/ ha net energy was recorded in BCS and SBS during all seasons *viz*; *Kharif*, rabi, and summer. Moreover, a range of Net energy and -3.53 to 389.86 MJ/ha was recorded based on the total biological yield of the system in a year. While the TPRWG, DSRBG, and TPRMB were statistically at par with each other based on the total biological yield of the year

**Table 4.16 Effect of seasons on net energy of different cropping systems**

Treatments	NE (MJ ha <sup>-1</sup> × 10 <sup>3</sup> )			
	Kharif	Rabi	Summer	Total
<b>TPRWG</b>	42.19	62.44	6.52	111.15
<b>DSRBG</b>	42.69	55.76	5.40	103.85
<b>TPRMB</b>	49.67	44.21	7.82	101.69
<b>BCS</b>	0.85	-4.93	0.56	-3.53
<b>SBS</b>	164.97	77.83	147.06	389.86

<b>SEm±</b>	0.28	0.36	0.26	0.9
<b>CD (p=0.05)</b>	0.82	1.04	0.77	2.63



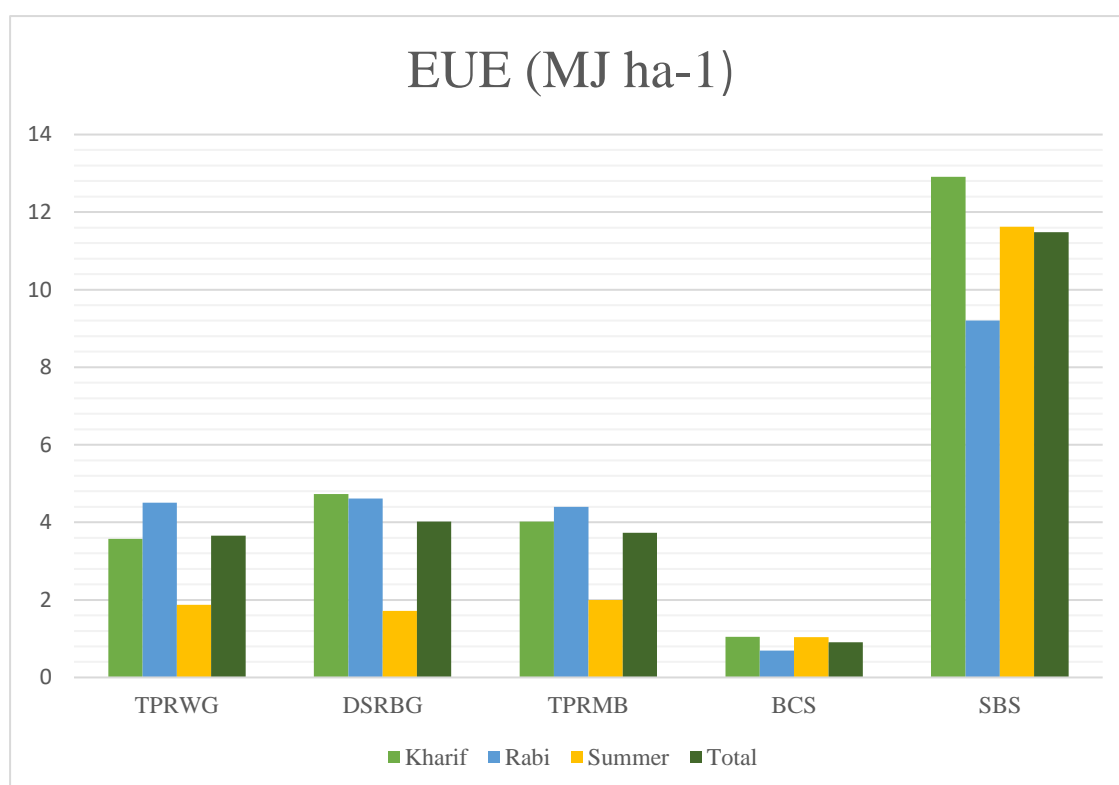
**Fig 4.16 Effect of seasons on net energy of different cropping systems**

### 4.3.3 Energy use efficiency

A significant variation in energy use efficiency was seen in all cropping systems during *Kharif*, rabi, and summer seasons, according to the data presented in table 4.17. and Fig 4.17. A range of Energy use efficiency 0.69 to 12.91 MJ/ha was recorded during all the seasons in cropping systems. The lowest to highest 1.05 to 12.91, 0.69 to 9.20, 1.04 to 11.62 MJ/ ha energy use efficiency was recorded in BCS and SBS during all seasons *viz*; *Kharif*, rabi, and summer. Moreover, a range of Energy use efficiency of 0.91 to 11.48 MJ/ha was recorded based on the total energy use efficiency of the system in a year. While the TPRWG, DSRBG, and TPRMB were statistically at par with each other based on the total biological yield of the year.

**Table 4.17** Effect of seasons on energy use efficiency of different cropping systems

Treatments	EUE (MJ ha <sup>-1</sup> )			
	Kharif	Rabi	Summer	Total
TPRWG	3.57	4.51	1.87	3.66
DSRBG	4.73	4.61	1.72	4.02
TPRMB	4.02	4.40	2.00	3.73
BCS	1.05	0.69	1.04	0.91
SBS	12.91	9.20	11.62	11.48
SEm±	0.24	0.29	0.28	0.81
CD (p=0.05)	0.69	0.84	0.83	2.36



**Fig 4.17** Effect of seasons on energy use efficiency of different cropping systems

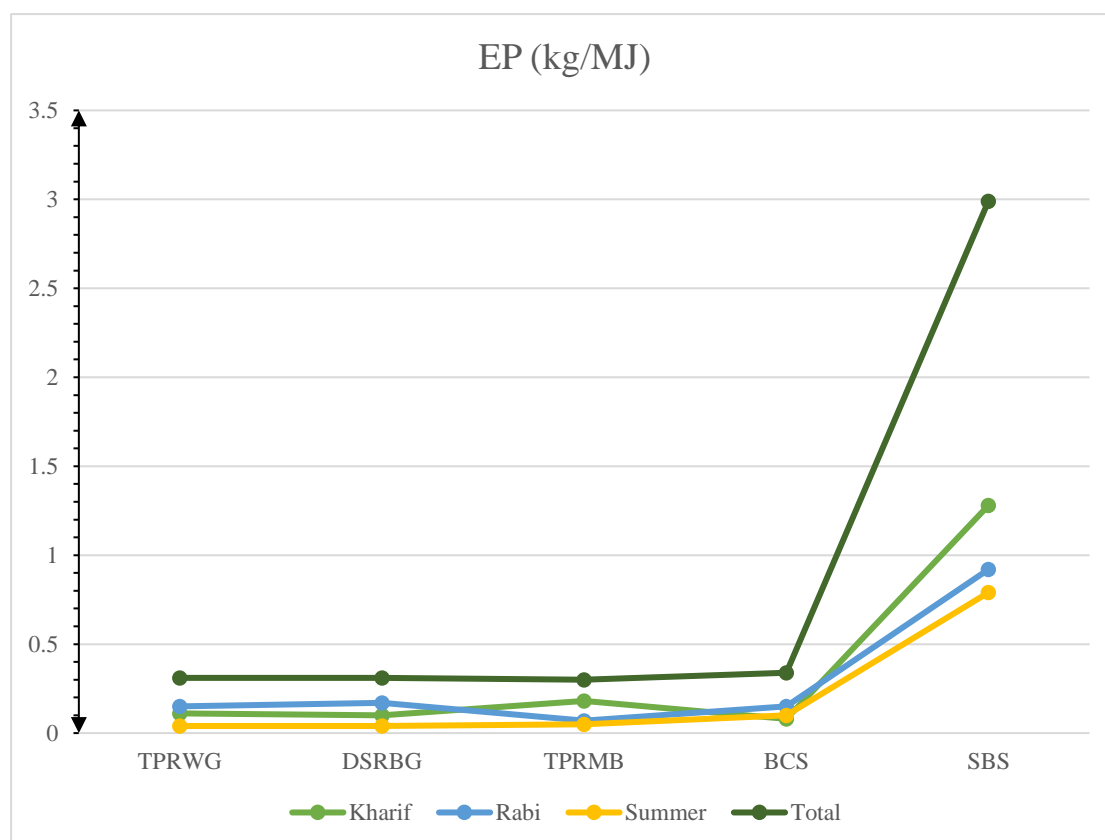
#### 4.3.4 Energy productivity (kg/MJ)

A significant variation in energy productivity was seen in all cropping systems during *Kharif*, *rabi*, and *summer* seasons, according to the data presented in table 4.18 and Fig 4.18. A range of energy productivity 0.04 to 1.28 Mg/MJ ha was recorded during all the seasons in cropping systems. The lowest to highest 0.08 to 1.28, 0.04

to 0.92, 0.04 to 0.79 Mg/MJ energy productivity was recorded in BCS and SBS during all seasons viz; *Kharif*, rabi, and summer. Moreover, a range of Energy productivity of 0.10 to 0.86 Mg/MJ was recorded based on the total energy production of the system in a year. While the TPRWG, DSRBG, and TPRMB were statistically at par with each other based on total energy productivity of the year.

**Table 4.18 Effect of seasons on energy productivity of different cropping systems**

Treatments	EP (kg/MJ)			
	Kharif	Rabi	Summer	Total
TPRWG	0.11	0.15	0.04	0.31
DSRBG	0.10	0.17	0.04	0.31
TPRMB	0.18	0.07	0.05	0.30
BCS	0.08	0.15	0.10	0.34
SBS	1.28	0.92	0.79	2.99
SEm±	0.02	0.01	0.01	0.04
CD (p=0.05)	0.07	0.04	0.04	0.15



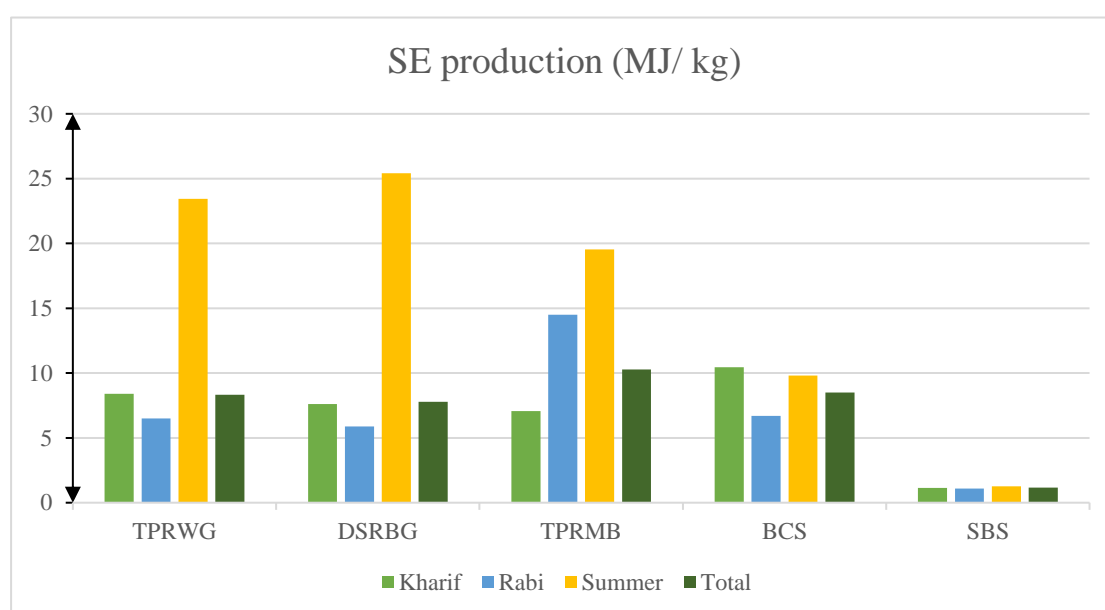
**Fig 4.18 Effect of seasons on energy productivity of different cropping systems**

### 4.3.5 Specific energy production SE (MJ/ kg)

A significant variation in specific energy was seen in all cropping systems during *Kharif*, rabi, and summer seasons, according to the data presented in table 4.19 and Fig 4.19. A range of specific energy 1.09 to 23.44 MJ/Mg ha was recorded during all the seasons in cropping systems. The lowest to highest 1.14 to 10.45, 1.09 to 14.49, 1.27 to 23.44 MJ/ Mg specific energy was recorded in all the cropping systems in all seasons viz; *Kharif*, rabi, and summer. Moreover, a range of specific energy of 1.17 to 10.27 MJ/ Mg was recorded based on the total specific energy of the system in a year. While the TPRWG, DSRBG, and BCS were statistically at par with each other based on the total specific energy of the year.

**Table 4.19** Effect of seasons on specific energy of different cropping systems

Treatments	Specific energy production SE (MJ/ kg)			
	Kharif	Rabi	Summer	Total
<b>TPRWG</b>	8.41	6.51	23.44	8.33
<b>DSRBG</b>	7.60	5.89	25.42	7.78
<b>TPRMB</b>	7.06	14.49	19.53	10.27
<b>BCS</b>	10.45	6.70	9.81	8.50
<b>SBS</b>	1.14	1.09	1.27	1.17
<b>SEm±</b>	0.28	0.33	0.28	0.84
<b>CD (p=0.05)</b>	0.81	0.97	0.83	2.47



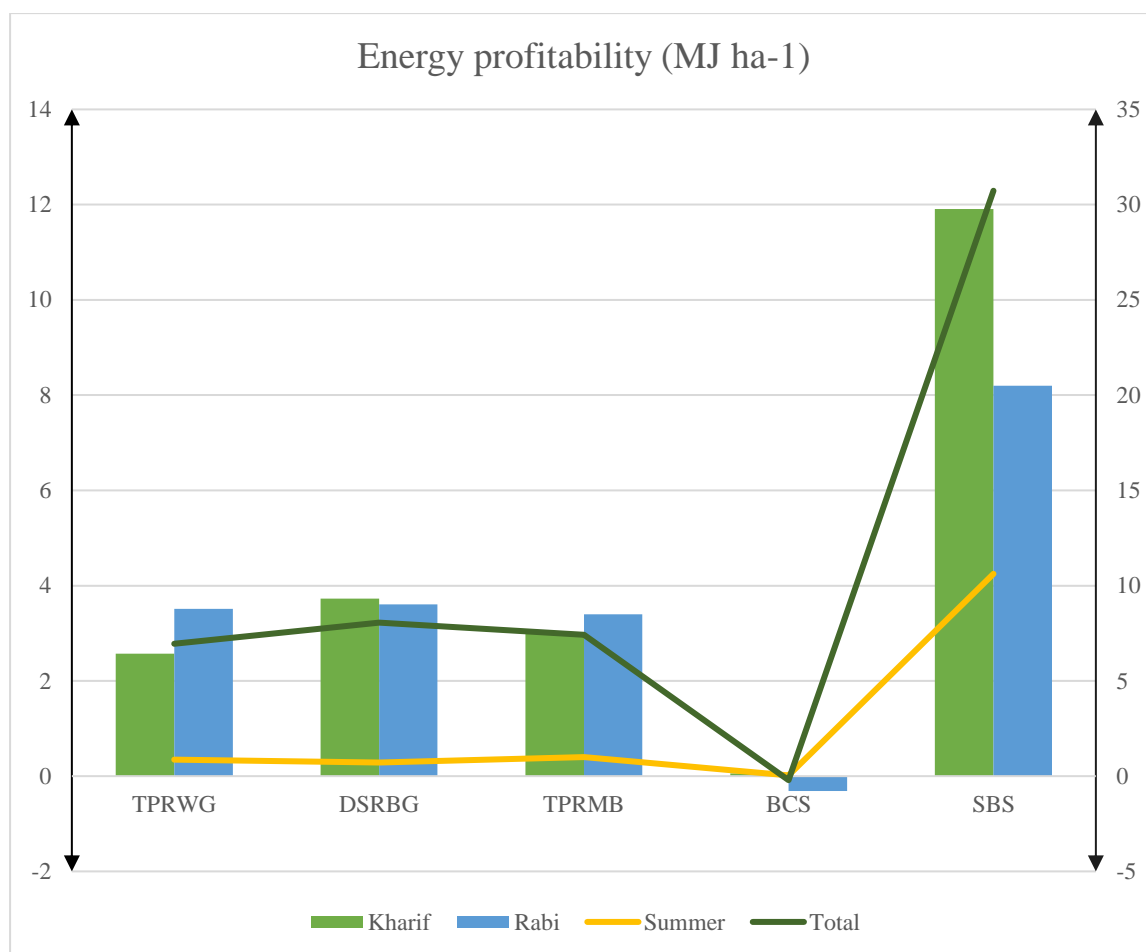
**Fig 4.19 Effect of seasons on Specific energy of different cropping systems**

#### 4.3.6 Energy profitability (MJ ha<sup>-1</sup>)

A significant variation in energy profitability was seen in all cropping systems during *Kharif*, rabi, and summer seasons, according to the data presented in table 4.20 and Fig 4.20. A range of energy profitability -0.31 to 11.91 MJ/Mg/ha was recorded during all the seasons in cropping systems. The lowest to highest 0.06 to 11.91, -0.31 to 8.20, 0.04 to 10.62 MJ/ha energy profitability was recorded in BCS and SBS during all seasons viz; *Kharif*, rabi, and summer. Moreover, a range of energy profitability -0.21 to 30.73 MJ/ha was recorded based on the total energy profitability of the system in a year. While the TPRWG, DSRBG, and TPRMB were statistically at par with each other based on total energy profitability of the year.

**Table 4.20 Effect of seasons on energy profitability of different cropping systems**

Treatments	Energy profitability (MJ ha <sup>-1</sup> )			
	Kharif	Rabi	Summer	Total
<b>TPRWG</b>	2.57	3.51	0.87	6.95
<b>DSRBG</b>	3.73	3.61	0.72	8.06
<b>TPRMB</b>	3.02	3.40	1.00	7.42
<b>BCS</b>	0.06	-0.31	0.04	-0.21
<b>SBS</b>	11.91	8.20	10.62	30.73
<b>SEm±</b>	0.27	0.26	0.31	0.84
<b>CD (p=0.05)</b>	0.80	0.75	0.92	2.47



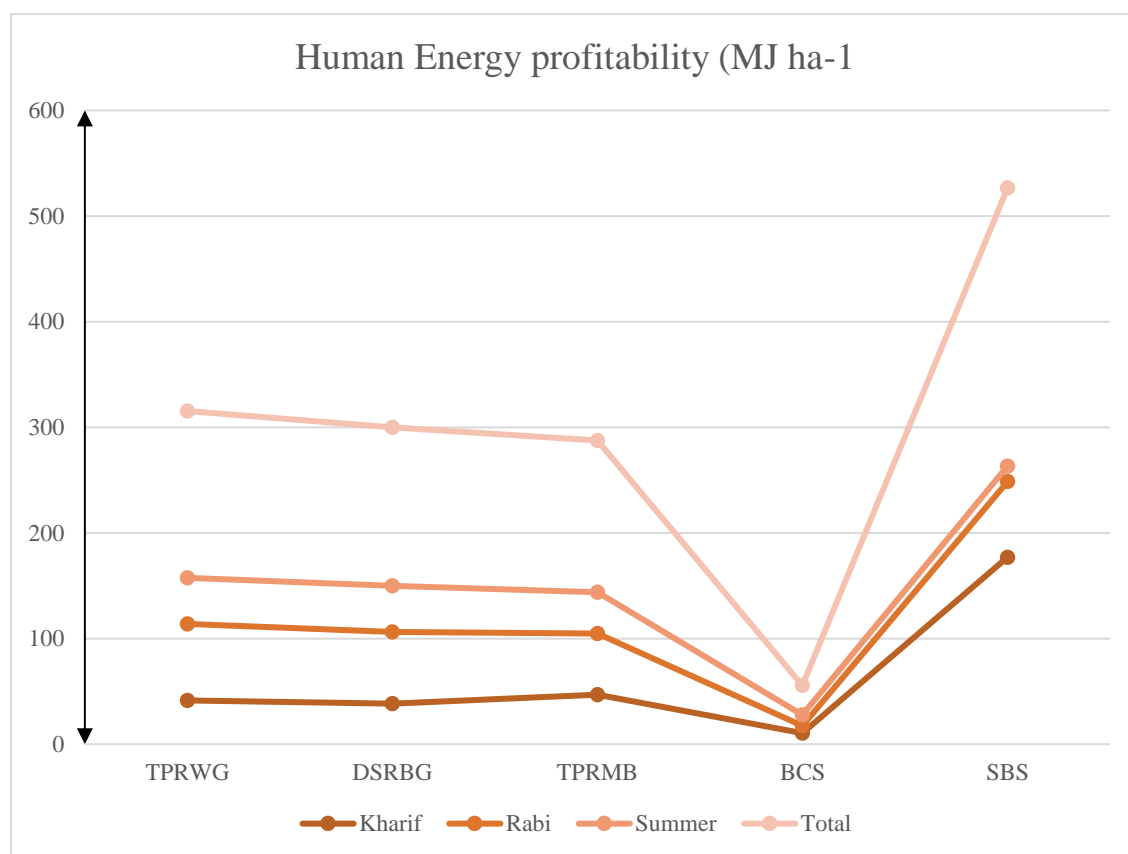
**Fig 4.20 Effect of seasons on energy profitability of different cropping systems**

#### 4.3.7 Human energy profitability (MJ ha<sup>-1</sup>)

A significant variation in human energy profitability was seen in all cropping systems during *Kharif*, rabi, and summer seasons, according to the data presented in table 4.21 and Fig 4.21. A range of human energy profitability 0.69 to 12.91 Mg/MJ ha was recorded during all the seasons in cropping systems. The lowest to highest 1.05 to 12.91, 0.69 to 9.20, 1.04 to 11.62 MJ/ ha human energy profitability was recorded in BCS and SBS during all seasons viz; *Kharif*, rabi, and summer. Moreover, a range of human energy profitability of 0.91 to 11.48 MJ/ha was recorded based on the total human energy profitability of the system in a year. While the TPRWG, DSRBG, and TPRMB were statistically at par with each other based on total human energy profitability of the year.

**Table 4.21** Effect of seasons on human energy profitability of different cropping systems

Treatments	Human energy profitability (MJ ha <sup>-1</sup> )			
	Kharif	Rabi	Summer	Total
<b>TPRWG</b>	41.58	72.28	43.80	157.66
<b>DSRBG</b>	38.40	67.83	43.73	149.95
<b>TPRMB</b>	46.88	57.79	39.08	143.75
<b>BCS</b>	10.53	7.03	10.25	27.80
<b>SBS</b>	177.05	71.57	14.70	263.32
<b>SEm±</b>	0.27	0.26	0.31	0.84
<b>CD (p=0.05)</b>	0.80	0.75	0.92	2.47



**Fig 4.21** Effect of seasons on human energy profitability of different cropping systems

### 4.3 Effect of different cropping system on nitrous oxide emission, total carbon sequestration in soil, net CO<sub>2</sub> emission and carbon footprint of different cropping system

#### 4.3.1 Nitrous oxide emission, carbon sequestration, carbon footprint

As per the data recorded on nitrous oxide emission, total carbon sequestration in soil, net CO<sub>2</sub> emission, and carbon footprint (Table 4.22). Revealed that the highest nitrous oxide emission was recorded under TPRWG cropping system also in terms of CO<sub>2</sub> equivalent. Whereas highest carbon sequestration was recorded under BCS cropping system followed by DSRBG, TPRMB, TPRWG, and SBS. However, net CO<sub>2</sub> emission was recorded under SBS, DSRBG, TPRWG, TPRMB, and BCS. The carbon footprint was highly recorded under DSRBG cropping system followed by TPRMB, TPRWG, BCS, and SBS.

**Table 4.22** Effect of different cropping system on nitrous oxide emission, total carbon sequestration in soil, net CO<sub>2</sub> emission and carbon footprint of different cropping system

Treatments	N <sub>2</sub> O emission kg CO <sub>2</sub> eq ha <sup>-1</sup>	Total CO <sub>2</sub> -eq (Kg ha <sup>-1</sup> )	Carbon sequestration in soil (CO <sub>2</sub> -eq kg ha <sup>-1</sup> )	Net CO <sub>2</sub> - eq emission (kg ha <sup>-1</sup> )	Carbon footprint (Kg CO <sub>2</sub> eq Mg <sup>-1</sup> )
<b>TPRWG</b>	2630	5595	1916	3679	735
<b>DSRBG</b>	2450	5338	1498	3840	868
<b>TPRMB</b>	2089	4757	1944	2813	776
<b>BCS</b>	2168	4455	2304	2151	434
<b>SBS</b>	1504	4182	908	3274	103
<b>SEm±</b>	42.23	50.38	8.84	58.48	20.96
<b>CD (p=0.05)</b>	123.27	147.06	25.80	170.70	61.18

#### 4.3.2 Carbon accumulation carbon sequestration rate

Among the different cropping systems (Table 4.23) highest carbon accumulation at both the depth at 0-15 was recorded under BCS followed by TPRMB, TPRWG, DSRBG, and SBS. Whereas, at 15-30 cm highest recorded under BCS, TPRWG, TPRMB, TPRWG, and SBS. Whereas the highest carbon sequestration at both the depth 0-15 and 15-30 cm was recorded under BCS cropping system followed by TPRMB, TPRWG, DSRBG, BCS, and SBS. Whereas at 15-30 cm highest carbon

sequestration was recorded under BCS, TPRWG, TPRMB, DSRBG, and SBS cropping systems.

**Table 4.23 Effect of different cropping systems on carbon accumulation and rate of carbon sequestration**

Treatment	Carbon accumulation (Mg/ha)		Carbon sequestration rate (Mg/ha. yr.)	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm
<b>TPRWG</b>	3.10	3.22	0.34	0.36
<b>DSRBG</b>	2.48	2.40	0.28	0.27
<b>TPRMB</b>	3.48	2.59	0.39	0.29
<b>BCS</b>	3.86	3.62	0.43	0.40
<b>SBS</b>	1.45	1.57	0.16	0.17
<b>SEm±</b>	0.27	0.30	0.01	0.01
<b>CD (p=0.05)</b>	0.79	0.87	0.02	0.02

#### 4.3.3 Carbon pool index

After carefully examined the data Table 4.24 revealed that at both the depth significantly higher carbon pool index recorded under was recorded under BCS cropping followed by TPRMB, TPRWG, DSRBG, and SBS cropping system.

**Table 4.24 Carbon pool index of different cropping systems**

Treatment	Carbon pool index	
	Soil depth (cm)	
	0-15	15-30
<b>TPRWG</b>	1.17	1.21
<b>DSRBG</b>	1.11	1.12
<b>TPRMB</b>	1.22	1.17
<b>BCS</b>	1.26	1.26
<b>SBS</b>	1.00	1.02
<b>SEm±</b>	0.07	0.10
<b>CD (p=0.05)</b>	0.22	0.28

#### 4.3.4 Economic value of the produce

The data presented in Table 4.25 indicate that the highest economic value of the produce was recorded under the BCS cropping system followed by SBS, TPRMB, TPRWG, TPRMB, and DSRBG.

**Table 4.25 Economic value of the produce different cropping system  
thousands rupees /ha**

<b>Treatment</b>	<b>Kharif</b>	<b>Rabi</b>	<b>Summer</b>	<b>Total</b>
<b>TPRWG</b>	37.9	55.1	23.0	116.0
<b>DSRBG</b>	29.2	42.9	21.2	93.3
<b>TPRMB</b>	45.2	45.3	28.8	119.3
<b>BCS</b>	76.1	265.7	164.0	505.8
<b>SBS</b>	67.6	81.9	60.8	210.3

\*Economic value is calculated based on MSP and their marketed value

## DISCUSSION

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A land's suitability for production depends on its physical, chemical, and biological properties, which determine a soil's quality, health, and fertility, which affect its production potential. An investigation was conducted at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University studied the effects of different cropping systems on yield and soil properties. Many of the parameters that were studied varied significantly across the various cropping systems. We have attempted to discuss the cause-and-effect relationship regarding the results of the investigation.

### 5.1 Impact of various cropping systems on yield

#### 5.1.1 Biological Yield

After carefully examining table 4.1 and fig 4.1 revealed that among different cropping systems. The highest total (*summer, Kharif, and rabi*) biological yield 12.16 q/ha was recorded under SBS followed by TPRWG, DSRBG, BCS. Due to the high leftover and root biomass of the cropping system SBS recorded the highest soil organic carbon in the soil.

#### 5.1.2 Biomass accumulation

According to Table 4.4 and Figure 4.4 biomass accumulation was significantly affected by different cropping systems Among different cropping systems the highest biomass accumulation above and below biomass in soil was statistically higher recorded under 31.84 q/ha under SBS followed by TPRWG, DSRBG, BCS. According to Swamy et al., (2003) the greater biomass buildup is impacted by crop diversification and nutrient-rich soil. the maximum biomass was recorded under the Sudan chari- berseem-Sudan chari cropping system due to its growth habit and genetic make-up of the plant.

### **5.1.3 Carbon stock and CO<sub>2</sub> sequestration**

After the studied the table 4.5 and fig 4.5 critically revealed that the highest soil organic carbon stock was recorded under the carbon under the SBS cropping system followed by TPRWG, DSRBG, BCS. As the SBS cropping system recorded the highest biological yield and biomass accumulation the directly affect the soil carbon stock and recorded the highest soil carbon stock. The lowest soil organic carbon stock was recorded under SBS cropping system. SBS cropping system recorded the highest CO<sub>2</sub> sequestration (above and below) among the cropping system whereas the lowest CO<sub>2</sub> sequestration was recorded under BCS Carbon sequestration was directly related to the biological yield. As the biological yield of the cropping system increase that CO<sub>2</sub> sequestration because biomass is the main function of CO<sub>2</sub> fixation. These findings are also supported by the R.F. (2001). CO<sub>2</sub> sequestration was significantly correlated by the biological yield of the crop. A similar finding was also obtained by Brar et al., (2013)

## **5.2 Impact of different cropping on soil physio-chemical properties of the soil**

### **5.2.1 Organic carbon**

The organic carbon content in different cropping systems ranged from 0.46 to 0.58 % at 0-15cm soil depth as reflected in table 4.7 and fig 4.7. The highest organic carbon was associated with BCS cropping system at both depth 0-15 cm and 15-30 cm. It is important to note that as the depth of soil increases organic carbon decreases in all cropping systems due to lower organic matter content. Inclusion of legumes in the cropping system, fallen leaves, and root biomass, get decomposed easily lead to an increase in organic matter content in soil (Singh et al.,2011).

### **5.2.2 Bulk density**

As shown in table 4.8 and fig 4.8, bulk density varied from 1.53 to 1.58 at depth of 0-15 cm and 1.57 to 1.63 at depth of 15-30 cm in different cropping systems. The highest bulk was recorded under the SBS cropping system at both depths at 0-15cm and 15-30 cm. It is important to note that as the depth of soil increase bulk

density increase in all cropping system due to lower organic matter content. Some scientist findings also reported that with the decrease in organic matter the bulk density increase due to porosity and organic matter in soil have a positive relationship, as organic matter decreases porosity decrease compaction of soil increases that decreases the volume of soil and increases the bulk density. A similar finding was also obtained by Mandal et al., (2003)

### **5.2.3 Soil carbon stock**

The soil carbon stock in different cropping systems ranged from 10.90 to 13.31 Mg/ ha at 0-15cm soil depth and 10.51 to 12.56 Mg/ha as reflected in table 4.9 and fig 4.9. The maximum soil carbon stock was recorded under the BCS cropping at both depths due to soil in this cropping system's rich organic matter content led to higher soil carbon stock. Soil carbon stock due to root biomass and fallen leaves on the soil quickly they got decomposed and help in the soil carbon stock. The variability in carbon stock depended upon the organic carbon content and bulk density of the soil.

### **5.2.4 Soil pH**

According to table 4.10 and fig 4.10 pH of the soil at both depths of 0-15cm and 15-30 cm ranged from 7.58 to 7.95 and 7.63 to 8.00 pH for different cropping systems. The minimum soil pH was recorded under the BCS cropping system at both depth 0-15 cm and 15-30 cm. As the fulvic acid content increases soil pH reduces at 3 DAS. As the depth of soil increases the soil carbon content decreases and the Ph of soil further increases. A similar finding was also reported by Trehan et al. (2001). reported that as the soil organic content decreases the Ph of soil further increases.

### **5.2.5 Soil EC**

Table 4.11 and figure 4.11 illustrate that under the different cropping systems as the depth of soil increases 0-15 to 15-30cm the EC of soil varies significantly. The highest EC at both the depth (0-15 and 15-30 cm) was recorded under the BCS cropping system followed by SBS, TPRMB, TPRWG, RGD. The highest value of EC

was recorded under BCS because of the higher content of soil organic carbon. Whereas the lower value of EC is due to low soil organic carbon in the soil at both the depth 0-15 and 15-30 cm. As the depth of soil increases, organic carbon decreases that affects the soil salt content in soil due to organic matter chelate with ions as well as percolation of water decrease the soluble salt content and lower the EC value of soil. Mohamad et al. (2015) reported a variation in electrical conductivity influenced by the cropping system.

#### **5.2.6 Available N (kg/ha)**

As the data recorded at the depth of 0-15 and 15-30 cm in table 4.12 and fig 4.12 revealed that at both the depth (0-15 and 15-30 cm) highest content of N in soil was recorded under BCS were 295.04 and 286.09 kg/ha, respectively among the different cropping system. The lowest amount of available N at both the depth was recorded under SBS were 232.15 and 223.20 kg/ha, respectively. The significant differences in soil available nitrogen in different cropping systems seen in this study might be attributable to variables such as the addition of organic carbon and the application of variable dosages of inorganic fertilizers. The highest available nitrogen was recorded under the BCS cropping system due to the decomposition of plant biomass. Changes and accumulations in available nitrogen status at the surface layer in cropping systems might be attributed to nitrogen addition via leaf litters and inorganic nitrogen supply during management practices. A similar finding was also reported by Moharana et al., 2012

#### **5.2.7 Available P<sub>2</sub>O<sub>5</sub> (kg/ha)**

Among different cropping systems available P in soil was significantly highest recorded under the BCS at both the depth of soil 0-15 and 15-30 cm. The lowest value of available P<sub>2</sub>O<sub>5</sub> was significantly recorded under the TPRWG at both the depth of soil. As per the data in table 4.13 and fig 4.13 indicated that as the depth of soil increase available P decrease under all different cropping system. also reported that highest content of soil available P will increase as the soil organic carbon increase.

### 5.2.8 Available K<sub>2</sub>O (kg/ha)

As per the data in table 4.14 and fig 4.14, The highest content of soil available K was highest was significantly varies under different cropping systems. Significantly, the highest under the BCS at both the depth were 257.69 and 253.46 kg/ha, respectively, whereas the lowest available K<sub>2</sub>O at both the depth (0-15 and 15-30 cm) was recorded under DSRBG (220.70 and 216.47 kg/ha). Similar findings were also reported by Singh et al. (2004). Variations in application dosage may impact the variability in available potassium in cropping systems.

### 5.3 Energy budgeting

After studied the table and figure critically revealed that the energy budgeting depends upon input and output that was given to individual crop and whole cropping systems. Energy input value was calculated based on what type of inputs were used in the particular cropping system. All inputs have specified values that led to energy budgeting. Energy budgeting was calculated based on dry matter production of cropping system and individual crop. During the energy budgeting various parameter were used *viz* net energy, energy use efficiency, specific energy production, energy productivity, energy profitability, human energy profitability.

#### 5.3.1 Energy Input

After examined table 4.15, revealed that energy input was significantly influenced by different cropping systems. The highest inputs were used in TPRWG (16.43 MJ ha<sup>-1</sup> × 10<sup>3</sup>) cropping system because of the rice crop in the cropping system and followed by TPRMB (13.85 16.43 MJ ha<sup>-1</sup> × 10<sup>3</sup>) cropping system. while the lowest energy inputs were used in the SBS cropping system.

#### 5.3.2 Energy output

After the studied data in table 4.15 revealed that energy outputs were significantly influenced by the different cropping systems. the highest energy outputs were recorded under the SBS (427 MJ ha<sup>-1</sup> × 10<sup>3</sup>) cropping system due to the maximum biomass production in the cropping system that was due to the inclusion of

fodder crop in this cropping system. Fodder crops generally produced more biomass because of their nature and the genetic make-up of the plant.

### **5.3.3 Net energy**

After studied the data in table 4.16 carefully revealed that the highest total energy production (*Kharif, rabi, and summer*) was recorded under the SBS cropping system ( $389 \text{ MJ ha}^{-1} \times 10^3$ ) followed by TPRWG, DSRBG, BCS. This may be due to higher biomass accumulation under the same trend under this cropping system. The lowest net energy production was recorded under the BCS ( $-3.53 \text{ MJ ha}^{-1} \times 10^3$ ) cropping system. As the data on energy use efficiency revealed that higher energy use efficiency was recorded under SBS ( $11.48 \text{ MJ ha}^{-1}$ ) cropping system due to higher biomass ( $\text{CO}_2$  fixed in form of plant biomass) accumulation at the low level of energy used in ATP formation. The lowest energy use efficiency was recorded under the BCS ( $0.91 \text{ MJ ha}^{-1}$ ). Similar, results also obtained by Sharma et al. (2008) and Saha et al. (2011).

### **5.3.4 Energy productivity**

Among the different cropping systems, the highest energy productivity (*Kharif, rabi, and summer*) (Table) was significantly highly recorded with SBS ( $2.99 \text{ kg/MJ}$ ) cropping system followed by TPRWG, DSRBG, BCS. However, the lowest energy productivity was recorded under TPRMB cropping system ( $0.30 \text{ kg/MJ}$ ). Similarly, the highest energy productivity is the function of biomass production, which is positively correlated with energy use efficiency. Similar findings also reported by Singh et al., (2017)

### **5.3.5 Specific energy**

Specific energy is the ratio of energy output to the production of grain yield. After studying the data in table 4.19 affirm that the highest specific energy was recorded under the TPRMB ( $10.27 \text{ MJ/ kg}$ ) cropping system followed by BCS, TPRWG, DSRBG, and SBS. Similar findings also reported by Kachroo et al. (2011).

### **5.3.6 Energy profitability**

The data recorded in table 4.20 on energy profitability under different cropping systems revealed that the highest energy profitability was recorded under SBS (30.73 MJ ha<sup>-1</sup>) cropping system followed by RBD, TPRMB, and TPRWG. However, the negative energy profitability was recorded under the SBS cropping system.

### **5.3.7 Human energy profitability**

As per the human energy profitability data presented in table 4.21 reported that total highest energy profitability was recorded under SBS (263.32 MJ ha<sup>-1</sup>) cropping system followed by TPRWG, DSRBG, TPRMB, and BCS.

## **5.4 Carbon budgeting**

According to table 4.22 carbon emission was calculated based on CO<sub>2</sub> emitted by different inputs that were used during the cropping system from seedbed preparation to the harvesting viz; seed, fertilizers, machinery, herbicides, and water used for irrigation and electricity used for irrigation. The highest emission of CO<sub>2</sub> emission was recorded under the TPRWG cropping system due to various reasons viz diesel consumption was more during the field preparation, and more fertilizers, labor used in DSRBG cropping system. the highest carbon emission was recorded under the DSRBG (5595 CO<sub>2</sub>-eq Kg ha<sup>-1</sup>) cropping system. the lowest carbon emission was recorded under BSB (4182 CO<sub>2</sub>-eq Kg ha<sup>-1</sup>) cropping system. The highest carbon footprint was recorded under the DSRBG (868 kg CO<sub>2</sub>-eq Mg<sup>-1</sup>) cropping system while the lowest carbon footprint was recorded under the SBS (103 kg CO<sub>2</sub>-eq Mg<sup>-1</sup>) cropping system.

The highest N<sub>2</sub>O emission was recorded under the TPRWG (2630 Kg CO<sub>2</sub>-eq ha<sup>-1</sup>) cropping system due to losses of N<sub>2</sub>O was more under the cropping system. volatilization and losses more occurred under this cropping system. While Carbon sequestration in soil was recorded higher in the DSRBG (2304 CO<sub>2</sub>-eq Kg ha<sup>-1</sup>) cropping system.

## **SUMMARY AND CONCLUSION**

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Soil is a complex system that sustains certain physical-chemical biological processes vital to terrestrial biology as well as biodiversity. The essence of life is soil, which feeds and supports all forms of life on earth. Soil is the foundation for all living things. Life relies on soils for the nourishment and support of all forms of life. Furthermore, soil plays a significant role in regulating climate through the sequestration of atmospheric CO<sub>2</sub>. However, intensive agriculture has damaging effects on soils and the atmosphere. In addition to sequestering atmospheric CO<sub>2</sub>, soil also contributes to climate regulation. Intensive soil cultivation has induced soil erosion and degradation, thus contributing to the development of soils with low organic carbon contents. Effective management causes measurable changes in soil mechanical, physical, chemical, and biological properties and improves aggregation, carbon sequestration, and crop productivity. However, intensive cropping systems have negative effects on the soil environment and the atmosphere. Accordingly, the current study endeavors to study the long-term yield and soil properties of cropping systems at Agricultural Research Farm, IAS, and BHU as well as the actual cropping systems themselves. The different cropping systems (Rice-wheat-green gram; Rice-barley-green gram; Rice-Mustard-Green gram; Bottle gourd-cabbage-sponge gourd; Sudan chari -berseem-Sudan chari) were undertaken to study the soil physio-chemical properties, carbon parameters, and energy indices. The investigation was carried out in a Randomized Block Design (RBD) with 5 treatments (cropping systems) and 4 replications to study the effect of cropping system on physio-chemical properties of soil and other carbon and energy parameters.

In the course of the investigation, the following points came to light.

- Different cropping systems significantly influence the soil organic carbon the soil. The maximum soil organic carbon was observed under the TPRMB and the minimum soil organic carbon was observed under the SBS.

- The experimental data showed that the soil carbon stock (Mg/ha) in the different cropping systems had significantly influenced. The maximum soil carbon stock (Mg/ha) was noticed under BCS and the minimum under SBS.
- The bulk density of both soil depths significantly influenced the value. The maximum bulk density was observed under the SBS, and the minimum was observed under the TPRMB.
- Different cropping systems had significantly influenced the EC of 0-15 cm, 15-30 cm soil depth, and mean value. The maximum EC was observed under the BCS, and the minimum was observed under the DSRBG.
- The data revealed that different cropping systems significantly influence the soil pH. The maximum soil pH was noticed under TPRWG, and minimum pH was observed in BCS at 0-15 cm, 15-30 cm soil depth.
- The available nitrogen at both depths in the different cropping systems had significantly influenced. The highest available nitrogen was observed under the BCS, and the lowest available nitrogen was noticed under SBS.
- The experimental data showed that different cropping systems had significantly influenced the P availability at both soil depths. The N availability was maximum under the BCS and minimum under the DSRBG.
- The evaluated data showed that different cropping systems had significantly influenced the available K at 0-15 cm, 15-30 cm soil depths. The maximum amount of available K was noticed under BCS, and the minimum amount of available K was observed under DSRBG.
- The biological yield of different cropping systems had significantly influenced at 0-15 cm, 15-30 cm soil depth. The highest amount of biological yield was noticed under the SBS. The lowest amount of biological yield was detected under the BCS.
- The result showed that different cropping systems had significantly influenced the biomass accumulation at above ground and below ground. The maximum

amount of biomass accumulation was noticed under SBS, and the minimum amount of biomass accumulation was observed under BCS.

- The analyzed data showed that the different cropping systems were significantly improved the carbon stock of the crops. The maximum carbon stock was seen under the SBS. The minimum carbon stock was seen under the BCS.
- The result showed that different cropping systems had significantly influenced the CO<sub>2</sub> sequestration. The maximum amount of CO<sub>2</sub> sequestration was noticed under SBS, and the minimum amount of CO<sub>2</sub> sequestration was observed under BCS of above ground and below ground agricultural products.
- The experiment's data revealed that different cropping systems had a significant effect on NE production. The highest NE production was noticed under SBS, and the lowest NE production was detected under BCS.
- The presented result revealed that different cropping systems had a significant influence on EUE. The highest EUE was noticed under SBS, and the lowest EUE was detected under BCS.
- The experimental data indicated the significant effect of different cropping systems on EP. The maximum amount of EP was observed under SBS. The minimum amount of EP was recorded under TPRMB.
- The Kharif, rabi, and summer agricultural growing crop of 2020 were significantly influenced by different cropping systems. The highest amount of SE production was noticed under TPRMB. The lowest amount of SE production was recorded under SBS.
- The different cropping systems significantly influence energy profitability. The maximum amount of Energy profitability was recorded under SBS. The minimum total amount of Energy profitability was recorded under BCS.
- The evaluated data showed that Human Energy Profitability was significantly influenced under different cropping systems. The maximum human energy

profitability was recorded in SBS. Moreover, minimum human energy profitability was recorded in BCS.

## **CONCLUSION**

According to the study, cropping systems are significantly different in terms of their soil physio-chemical properties. In this study, the adoption of less intensive cropping systems and well-rotated crops and transition from conventional to conservation farming practices had a real effect on soil and its physical and chemical characteristics. In addition, management practices affected cropping system yields. The inclusion of legumes crops in the cropping system are good for soil health and added more biomass into the soil in the form of organic form. that lead to increasing soil organic carbon (SOC) in soil ultimately increases soil carbon stock. Soil carbon sequestration in the soil varies with the cropping system. Cropping systems have the potentials to fix atmospheric carbon into soil that will affect soil health and the ecosystem. Energy indices were also measured in the research. The energy balance in any crop production system is influenced by management strategies (pesticides, fertilizers, crops, rotation, and tillage). Various management strategies resulted in different energy inputs. The amount of energy used in a crop is determined by the crop's type and purpose. Rice uses the most energy inputs because cereal crops require more fertilizer, hence they are liable for more inputs. This would imply that crop production requires less energy when rotation and conservation cultivation are used. Low-input cropping systems are not only less energy-intensive, but also have a lower carbon footprint.

## BIBLIOGRAPHY

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- Abera, T., Tufa, T., Midega, T., Kumbi, H., & Tola, B. (2018). Effect of integrated inorganic and organic fertilizers on yield and yield components of Barley in Liben Jawi District. *International Journal of Agronomy*, 2018.
- Adjei-Nsiah, S. (2012). Role of pigeon pea cultivation on soil fertility and farming system sustainability in Ghana. *International Journal of Agronomy*, 2012.
- Ae, N., Arihara, J., Okada, K., Yoshihara, T., Otani, T., & Johansen, C. (2011). The role of piscidic acid secreted by pigeon pea roots grown in an Alfisol with low-P fertility. In *Genetic aspects of plant mineral nutrition* (pp. 279-288). Springer, Dordrecht.
- Arshad, M. A., & Martin, S. (2002). Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, Ecosystems & Environment*, 88(2), 153-160.
- Ashworth, A. J., Owens, P. R., & Allen, F. L. (2020). Long-term cropping systems management influences soil strength and nutrient cycling. *Geoderma*, 361, 114062.
- Assefa, F., Elias, E., Soromessa, T., & Ayele, G. T. (2020). Effect of changes in land-use management practices on soil physicochemical properties in Kabe Watershed, Ethiopia. *Air, Soil and Water Research*, 13, 1178622120939587.
- Aulakh, C. S., Gill, M. S., Mahey, R. K., Walia, S. S., & Singh, G. (2012). Effect of nutrient sources on productivity of fodder cropping systems in Punjab. *Indian Journal of Agronomy*, 57(2), 200-205.
- Bainard, L. D., Chagnon, P. L., Cade-Menun, B. J., Lamb, E. G., LaForge, K., Schellenberg, M., & Hamel, C. (2017). Plant communities and soil properties mediate agricultural land use impacts on arbuscular mycorrhizal fungi in the Mixed Prairie ecoregion of the North American Great Plains. *Agriculture, Ecosystems & Environment*, 249, 187-195.
- Bandyopadhyay, P. K., Saha, S., & Mallick, S. (2011). Comparison of soil physical properties between a permanent fallow and a long-term rice–wheat cropping with inorganic and organic inputs in the humid subtropics of eastern India. *Communications in soil science and plant analysis*, 42(4), 435-449.
- Bandyopadhyay, P. K., Saha, S., Mani, P. K., & Mandal, B. (2011). Effect of organic inputs on aggregate associated organic carbon concentration under long-term rice–wheat cropping system. *Geoderma*, 154(3-4), 379-386.
- Banerjee, A., Datta, J. K., Mondal, N. K., & Chanda, T. (2011). Influence of integrated nutrient management on soil properties of old alluvial soil under

mustard cropping system. *Communications in soil science and plant analysis*, 42(20), 2473-2492.

- Banjara, T. R., Bohra, J. S., Kumar, S., Ram, A., & Pal, V. (2021). Diversification of rice–wheat cropping system improves growth, productivity and energetics of rice in the Indo-Gangetic Plains of India. *Agricultural Research*, 1-10.
- Barbieri, P., Pellerin, S., Seufert, V., & Nesme, T. (2019). Changes in crop rotations would impact food production in an organically farmed world. *Nature Sustainability*, 2(5), 378-385.
- Bardgett, R. D., & Van Der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. *Nature*, 515(7528), 505-511.
- Bastos, A., Hartung, K., Nützel, T. B., Nabel, J. E., Houghton, R. A., & Pongratz, J. (2021). Comparison of uncertainties in land-use change fluxes from bookkeeping model parameterisation. *Earth System Dynamics*, 12(2), 745-762.
- Batjes, N. H. (1996). Total carbon and nitrogen in the soils of the world. *European journal of soil science*, 47(2), 151-163.
- Bhattacharyya, R., Das, T. K., Sudhishri, S., Dudwal, B., Sharma, A. R., Bhatia, A., & Singh, G. (2015). Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice–wheat cropping system in the western Indo-Gangetic Plains. *European Journal of Agronomy*, 70, 11-21.
- Bhattacharyya, T., Pal, D. K., Chandran, P., Ray, S. K., Mandal, C., & Telpande, B. (2008). Soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. *Current science*, 482-494.
- Bronson, K. F., Neue, H. U., Abao Jr, E. B., & Singh, U. (1997). Automated chamber measurements of methane and nitrous oxide flux in a flooded rice soil: II. Fallow period emissions. *Soil Science Society of America Journal*, 61(3), 988-993.
- Campbell, C. A., Biederbeck, V. O., Zentner, R. P., & Lafond, G. P. (1991). Effect of crop rotations and cultural practices on soil organic matter, microbial biomass and respiration in a thin Black Chernozem. *Canadian Journal of Soil Science*, 71(3), 363-376.
- Celik, I. (2005). Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. *Soil and Tillage research*, 83(2), 270-277.
- Change, I. C. (2007). The physical science basis.
- Chauhan, B. S., Mahajan, G., Sardana, V., Timsina, J., & Jat, M. L. (2012). Productivity and sustainability of the rice–wheat cropping system in the Indo-

- Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. *Advances in Agronomy*, 117, 315-369.
- Chhabra, A., Palria, S., & Dadhwal, V. K. (2003). Soil organic carbon pool in Indian forests. *Forest Ecology and Management*, 173(1-3), 187-199.
- Das, T. K., Nath, C. P., Das, S., Biswas, S., Bhattacharyya, R., Sudhishri, S., ... & Chaudhari, S. K. (2020). Conservation Agriculture in rice-mustard cropping system for five years: Impacts on crop productivity, profitability, water-use efficiency, and soil properties. *Field Crops Research*, 250, 107781.
- Dawe, D., Dobermann, A., Moya, P., Abdulrachman, S., Singh, B., Lal, P. L. S. Y., ... & Zhen, Q. X. (2000). How widespread are yield declines in long-term rice experiments in Asia?. *Field Crops Research*, 66(2), 175-193.
- Díaz-Hernández, J. L., Fernández, E. B., & González, J. L. (2003). Organic and inorganic carbon in soils of semiarid regions: a case study from the Guadix–Baza basin (Southeast Spain). *Geoderma*, 114(1-2), 65-80.
- Faulkner, S. (2004). Soils and sediment. *Wetlands*, 30.
- Gong, W., Yan, X. Y., Wang, J. Y., Hu, T. X., & Gong, Y. B. (2009). Long-term manuring and fertilization effects on soil organic carbon pools under a wheat–maize cropping system in North China Plain. *Plant and Soil*, 314(1), 67-76.
- Gurr, G. M., Lu, Z., Zheng, X., Xu, H., Zhu, P., Chen, G., ... & Heong, K. L. (2016). Multi-country evidence that crop diversification promotes ecological intensification of agriculture. *Nature Plants*, 2(3), 1-4.
- Hartwig, N. L., & Ammon, H. U. (2002). Cover crops and living mulches. *Weed science*, 50(6), 688-699.
- Hobbs, P. R., Sayre, K., & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1491), 543-555.
- Houghton, R. A., & Goodale, C. L. (2004). Effects of land-use change on the carbon balance of terrestrial ecosystems. *Ecosystems and land use change*, 153, 85-98.
- Howden, S. M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the national academy of sciences*, 104(50), 19691-19696.
- Jaiarree, S., Chidthaisong, A., Tangtham, N., Polprasert, C., Sarobol, E., & Tyler, S. C. (2011). Soil organic carbon loss and turnover resulting from forest conversion to maize fields in Eastern Thailand. *Pedosphere*, 21(5), 581-590.

- Johnson, J. F., Allmaras, R. R., & Reicosky, D. C. (2006). Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database.
- Kang, S. W., Kim, S. H., Park, J. H., Seo, D. C., Ok, Y. S., & Cho, J. S. (2018). Effect of biochar derived from barley straw on soil physicochemical properties, crop growth, and nitrous oxide emission in an upland field in South Korea. *Environmental Science and Pollution Research*, 25(26), 25813-25821.
- Katayama, K., Ito, O., Adu-Gyamfi, J. J., Rao, T. P., Dacanay, E. V., & Yoneyama, T. (1999). Effects of NPK fertilizer combinations on yield and nitrogen balance in sorghum or pigeon pea on a vertisol in the semi-arid tropics. *Soil Science and Plant Nutrition*, 45(1), 143-150.
- Kukal, S. S., & Benbi, D. K. (2009). Soil organic carbon sequestration in relation to organic and inorganic fertilization in rice–wheat and maize–wheat systems. *Soil and Tillage Research*, 102(1), 87-92.
- Kumar, S., Meena, R. S., Singh, R. K., Munir, T. M., Datta, R., Danish, S., ... & Kumar, S. (2021). Soil microbial and nutrient dynamics under different sowings environment of Indian mustard (*Brassica juncea* L.) in rice based cropping system. *Scientific Reports*, 11(1), 1-11.
- Kumar, V., Jat, H. S., Sharma, P. C., Gathala, M. K., Malik, R. K., Kamboj, B. R., ... & McDonald, A. (2018). Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. *Agriculture, ecosystems & environment*, 252, 132-147.
- Ladha, J. K., Dawe, D., Pathak, H., Padre, A. T., Yadav, R. L., Singh, B., ... & Hobbs, P. R. (2003). How extensive are yield declines in long-term rice–wheat experiments in Asia?. *Field Crops Research*, 81(2-3), 159-180.
- Ladha, J. K., Fischer, K. S., Hossain, M., Hobbs, P. R., & Hardy, B. (2000). *Improving the Productivity and Sustainability of Rice-Wheat Systems of the Indo-Gangetic Plains: A Synthesis of NARS-IRRI Partnership Research* (No. 2169-2019-1609).
- Ladha, J. K., Pathak, H., Tirol-Padre, A., Dawe, D., & Gupta, R. K. (2003). Productivity trends in intensive rice–wheat cropping systems in Asia. *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts*, 65, 45-76.
- Ladha, J. K., Rao, A. N., Raman, A. K., Padre, A. T., Dobermann, A., Gathala, M., ... & Noor, S. (2016). Agronomic improvements can make future cereal systems in South Asia far more productive and result in a lower environmental footprint. *Global change biology*, 22(3), 1054-1074.

- Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *science*, 304(5677), 1623-1627.
- Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123(1-2), 1-22.
- Lal, R. (2007). Constraints to adopting no-till farming in developing countries.
- Lal, R. (2011). Sequestering carbon in soils of agro-ecosystems. *Food policy*, 36, S33-S39.
- Lal, R. (2018). Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. *Global Change Biology*, 24(8), 3285-3301.
- Liu, J., Zhang, Z., Xu, X., Kuang, W., Zhou, W., Zhang, S., ... & Jiang, N. (2011). Spatial patterns and driving forces of land use change in China during the early 21st century. *Journal of Geographical Sciences*, 20(4), 483-494.
- Majumdar, A., Kaye, J., Gries, C., Hope, D., & Grimm, N. (2008). Hierarchical spatial modeling and prediction of multiple soil nutrients and carbon concentrations. *Communications in Statistics—Simulation and Computation*®, 37(2), 434-453.
- Mandal, U. K., Singh, G., Victor, U. S., & Sharma, K. L. (2003). Green manuring: its effect on soil properties and crop growth under rice–wheat cropping system. *European Journal of Agronomy*, 19(2), 225-237.
- Maron, J. L., Marler, M., Klironomos, J. N., & Cleveland, C. C. (2011). Soil fungal pathogens and the relationship between plant diversity and productivity. *Ecology Letters*, 14(1), 36-41.
- Mi, W., Wu, L., Brookes, P. C., Liu, Y., Zhang, X., & Yang, X. (2016). Changes in soil organic carbon fractions under integrated management systems in a low-productivity paddy soil given different organic amendments and chemical fertilizers. *Soil and Tillage Research*, 163, 64-70.
- Milcu, A., Allan, E., Roscher, C., Jenkins, T., Meyer, S. T., Flynn, D., ... & Eisenhauer, N. (2013). Functionally and phylogenetically diverse plant communities key to soil biota. *Ecology*, 94(8), 1878-1885.
- Minasny, B., Malone, B. P., McBratney, A. B., Angers, D. A., Arrouays, D., Chambers, A., ... & Winowiecki, L. (2017). Soil carbon 4 per mille. *Geoderma*, 292, 59-86.
- Nandan, R., Singh, V., Singh, S. S., Kumar, V., Hazra, K. K., Nath, C. P., ... & McDonald, A. (2019). Impact of conservation tillage in rice–based cropping systems on soil aggregation, carbon pools and nutrients. *Geoderma*, 340, 104-114.

- Nayak, A., Maity, S. K., & Khanda, C. (2020). Improving N, P, K content, other properties of soil and system productivity through integrated nutrient management practices in SRI hybrid rice-mustard cropping sequence in Eastern India. *ORYZA-An International Journal on Rice*, 57(4), 296-301.
- Pandey, O. P., Shahi, S. K., Singh, S. P., Singh, M. K., Singh, R. K., Maurya, S. K., & Dubey, A. N. Effect of integrated nutrient management of fertility status of soil under green gram (*Vigna radiata* L.).
- Pathak, H., Saharawat, Y. S., Gathala, M., & Ladha, J. K. (2011). Impact of resource-conserving technologies on productivity and greenhouse gas emissions in the rice-wheat system. *Greenhouse Gases: Science and Technology*, 1(3), 261-277.
- Paul, N., Giri, U., Datta, A., Dhar, D., & Saha, D. (2017). Comparative Study of Organic Matter Vis-a-Vis Humic Acid on Change in Nutrients Availability in Rice-Mustard Cropping Sequence. *International Journal of Agriculture, Environment and Biotechnology*, 10(3), 303.
- Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., & Smith, P. (2016). Climate-smart soils. *Nature*, 532(7597), 49-57.
- Pielke, R. A. (2005). Land use and climate change. *Science*, 310(5754), 1625-1626.
- Pikul, J. L., Johnson, J. M., Schumacher, T. E., Vigil, M., & Riedell, W. E. (2008). Change in surface soil carbon under rotated corn in eastern South Dakota. *Soil Science Society of America Journal*, 72(6), 1738-1744.
- Porpavai, S., Devasenapathy, P., Siddeswaran, K., & Jayaraj, T. (2011). Impact of various rice based cropping systems on soil fertility. *Journal of cereals and oilseeds*, 2(3), 43-46.
- Porpavai, S., Devasenapathy, P., Siddeswaran, K., & Jayaraj, T. (2011). Impact of various rice based cropping systems on soil fertility. *Journal of cereals and oilseeds*, 2(3), 43-46.
- Power, A. G. (2011). Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical transactions of the royal society B: biological sciences*, 365(1554), 2959-2971.
- Prakash, A., Rao, J., & Nandagopal, V. (2008). Future of botanical pesticides in rice, wheat, pulses and vegetables pest management. *Journal of Biopesticides*, 1(2), 154-169.
- Prakash, H. C., Shekara, B. G., Jagadeesh, B. R., Kalayanamurthy, K. N., & Shivalingaiah, M. L. (2008). Paddy pulse cropping system for sustaining soil health and rice yield in Cauvery command area. *Research on Crops*, 9(1), 7-9.

- Prasad, G., Nandi, A., & Swain, P. K. (2016). Soil amendment and integrated nutrient management on growth, yield, soil health, and economics of bottle gourd. *International Journal of Vegetable Science*, 22(1), 3-13.
- Purakayastha, T. J., Chhonkar, P. K., Bhadraray, S., Patra, A. K., Verma, V., & Khan, M. A. (2007). Long-term effects of different land use and soil management on various organic carbon fractions in an Inceptisol of subtropical India. *Soil Research*, 45(1), 33-40.
- Purakayastha, T. J., Chhonkar, P. K., Bhadraray, S., Patra, A. K., Verma, V., & Khan, M. A. (2007). Long-term effects of different land use and soil management on various organic carbon fractions in an Inceptisol of subtropical India. *Soil Research*, 45(1), 33-40.
- Ramankutty, N. (2008). Farming the planet. Part 1: The geographic distribution of global agricultural lands in the year 2000. *Global Biogeochemical Cycles*, 22, 1-19.
- Rasmussen, P. E., Allmaras, R. R., Rohde, C. R., & Roager Jr, N. C. (1980). Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. *Soil Science Society of America Journal*, 44(3), 596-600.
- Regmi, A. P., Ladha, J. K., Pathak, H., Pasuquin, E., Bueno, C., Dawe, D., ... & Pandey, S. P. (2002). Yield and soil fertility trends in a 20-year rice–rice–wheat experiment in Nepal. *Soil Science Society of America Journal*, 66(3), 857-867.
- Saha, S., Chakraborty, D., Sharma, A. R., Tomoar, R. K., Bhadraray, S., Sen, U., ... & Kalra, N. (2011). Effect of tillage and residue management on soil physical properties and crop productivity in maize (*Zea mays*)–Indian mustard (*Brassica juncea*) system. *Indian Journal of Agricultural Sciences*, 80(8), 679-685.
- Sarwar, G., Schmeisky, H., Hussain, N., Muhammad, S., Ibrahim, M., & Safdar, E. (2008). Improvement of soil physical and chemical properties with compost application in rice-wheat cropping system. *Pakistan Journal of Botany*, 40(1), 275-282.
- Serme, I., Ouattara, K., Logah, V., Taonda, J. B., Pale, S., Quansah, C., & Abaidoo, C. R. (2015). Impact of tillage and fertility management options on selected soil physical properties and sorghum yield. *International Journal of Biological and Chemical Sciences*, 9(3), 1154-1170.
- Sharma, S. N., Prasad, R., Dwivedi, M. K., Kumar, S., Davari, M. R., & Ram, M. (2009). Effect of cropping system on production and chemical and biological properties of soil. *Archives of Agronomy and Soil Science*, 55(4), 429-438.
- Singh, M., Singh, M. P., Singh, Y., & Gupta, G. R. (1988). Long range effect of continuous rice wheat cropping under varying levels of N, P and K on yield

and fertility status of soil with particular reference to iron. *Journal of plant nutrition*, 11(6-11), 1471-1478.

Singh, R. K., Bohra, J. S., Srivastava, V. K., & Singh, R. P. (2008). Effect of diversification of rice-wheat system on weed dynamics in rice. *Indian Journal of Weed Science*, 40(3and4), 128-131.

SINGH, Y., DEY, P., YADAV, R., & SINGH, R. Nutrient Management for Rice-Barley Cropping System Using Soil Test Target Yield Equation in Village Persiya, Block-Naugarh, District Chaundauli (UP).

Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. *Plant and soil*, 241(2), 155-176.

Srivastava, K., Jat, H. S., Meena, M. D., Choudhary, M., Mishra, A. K., & Chaudhari, S. K. (2016). Long term impact of different cropping systems on soil quality under silty loam soils of Indo-Gangetic plains of India. *Journal of Applied and Natural Science*, 8(2), 584-587.

Timsina, J., & Connor, D. J. (2001). Productivity and management of rice-wheat cropping systems: issues and challenges. *Field crops research*, 69(2), 93-132.

Timsina, J., Buresh, R. J., Dobermann, A., Dixon, J., & Tabali, J. (2011). Strategic assessment of rice-maize systems in Asia. *IRRICIMMYT Alliance Project "Intensified Production Systems in Asia (IPSA)", IRRI-CIMMYT Joint Report, IRRI, Los Banos, Philippines.*

Timsina, J., Jat, M. L., & Majumdar, K. (2011). Rice-maize systems of South Asia: current status, future prospects and research priorities for nutrient management. *Plant and Soil*, 335(1), 65-82.

Varvel, G. E. (2006). Soil organic carbon changes in diversified rotations of the western Corn Belt.

Velmurugan, A., Suresh, K., Dadhwal, V. K., & Gupta, M. K. (2014). Soil organic carbon status of Indian forests. *Indian Forester*, 140(5), 468-477.

Verma, R. K., Shivay, Y. S., Prasanna, R., Choudhary, M., & Ghasal, P. C. (2020). Nutrient management options modulating soil physico-chemical and biological properties under direct-seeded rice-based cropping systems. *Archives of Agronomy and Soil Science*, 1-16.

Verma, R., Maurya, B. R., Meena, V. S., Dotaniya, M. L., Deewan, P., & Jajoria, M. (2017). Enhancing production potential of cabbage and improves soil fertility status of Indo-Gangetic Plain through application of bio-organics and mineral fertilizer. *Int J Curr Microbiol App Sci*, 6(3), 301-309.

- Wilhelm, W. W., Johnson, J. M., Karlen, D. L., & Lightle, D. T. (2007). Corn stover to sustain soil organic carbon further constrains biomass supply.
- Xiubin, H., Keli, T., Junliang, T., & Matthews, J. A. (2002). Paleopedological investigation of three agricultural loess soils on the Loess Plateau of China. *Soil Science*, *167*(7), 478-491.
- Yadav, G. S., Das, A., Lal, R., Babu, S., Datta, M., Meena, R. S., ... & Singh, R. (2019). Impact of no-till and mulching on soil carbon sequestration under rice (*Oryza sativa* L.)-rapeseed (*Brassica campestris* L. var. rapeseed) cropping system in hilly agro-ecosystem of the Eastern Himalayas, India. *Agriculture, Ecosystems & Environment*, *275*, 81-92.
- Yang, C. H., Kim, B. S., Park, W. K., Lee, D. B., Yoo, C. H., Kim, J. D., & Jeong, K. Y. (2007). Effect of barley straw application on soil properties, rice yield and plowable stress with plowing methods and irrigation rates in barley-rice double cropping system. *Korean Journal of Soil Science and Fertilizer*, *40*(3), 201-207.
- Yang, R. M., Zhang, G. L., Yang, F., Zhi, J. J., Yang, F., Liu, F., ... & Li, D. C. (2016). Precise estimation of soil organic carbon stocks in the northeast Tibetan Plateau. *Scientific reports*, *6*(1), 1-10.
- Zhangliu, D., Shufu, L., Xiaoping, X., Guangli, Y., & Tusheng, R. (2009). Soil physical quality as influenced by long-term fertilizer management under an intensive cropping system. *International Journal of Agricultural and Biological Engineering*, *2*(1), 19-27.
- Zhou, K., Sui, Y., Liu, X., Zhang, X., Jin, J., Wang, G., & Herbert, S. J. (2015). Crop rotation with nine-year continuous cattle manure addition restores farmland productivity of artificially eroded Mollisols in Northeast China. *Field Crops Research*, *171*, 138-145

