

**BUAT Publication No.: EB/01/2025**

# **CLIMATE-SMART AGRICULTURE**

**INNOVATIONS FOR SUSTAINABLE FOOD SYSTEMS**

**Editors**

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**Banda University of Agriculture & Technology**

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# **CONTENT**

BIODYNAMIC FARMING : A WAY TO MITIGATE CLIMATE CHANGE IN AGRICULTURE .....	1
SOIL HEALTH MANAGEMENT UNDER THE CHANGING CLIMATE SCENARIO .....	20
NUTRIENT MANAGEMENT APPROACHES FOR CLIMATE RESILIENT AGRICULTURE .....	32
CLIMATE SMART WATER CONSERVATION TECHNOLOGIES FOR ENHANCING PRODUCTIVITY OF RICE-WHEAT CROPPING SYSTEM.....	52
INTEGRATED FARMING SYSTEM: AN APPROACH FOR CLIMATE RESILIENT AGRICULTURE .....	70
SMART FARM MECHANIZATION: AN OPTION FOR MITIGATING THE EFFECTS OF CLIMATE CHANGE IN AGRICULTURE .....	88
CEREAL CROPS UNDER THE CLIMATE CHANGE SCENARIO: IMPACT, ADAPTATION AND MITIGATION .....	111
DYNAMICS OF METHANE EMISSION IN AGRICULTURE .....	127
EFFICIENT RESOURCE UTILIZATION FOR CLIMATE-SMART AGRICULTURE .....	146
GEOINFORMATICS: A TECHNOLOGY TO SECURE AGRICULTURAL PRODUCTION IN THE CLIMATE CHANGE SITUATION.....	165

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# **Biodynamic Farming: A Way to Mitigate Climate Change in Agriculture**

Kushagra Chaturvedi, Rinku Kumar, Shibya Gokhale and G.S. Panwar

## **Introduction**

Over the centuries, many changes have been faced by human population for agricultural production. As estimated by The United Nations the global population will expand to 8.3 billion to 10 billion till 2050 and 11 billion by 2100. Meaning, by 2050 two billion more people will be there whom we have to feed. This creates a significant necessity for the production of crop for expanding global population, and that's why we have to double the crop production to comply with the global food requirement (Tilman *et al.*, 2011). This is causing world-wide scarcity of food which in turn is creating a pressure on agriculture for increasing crop production, further creating pressure on land use, water resources, and agricultural practices, leading to the rising dependence over synthetic pesticides, insecticides, fertilizers, reduced soil fertility and over cultivation, throughout the time of confronting climate change, which further worsen the global food security by disrupting agricultural yield.

This demand of food for the expanding population is pressuring us to utilize the advanced technologies for more farm produce which eventually leads to climate change. Modern crop production tactics contributes crucially in climate change mainly by releasing the greenhouse gases such as methane and nitrous oxide, primarily by chemical use and enteric fermentation in livestock, additionally the increased release of carbon dioxide due to deforestation for getting more land for crop production. As the world faces challenges of climate change, it's imperative to prioritize sustainable agriculture practices to ensure food security, mitigate emissions, and build a resilient future. Biodynamic farming is an approach to farming that goes beyond organic practices by integrating spiritual and holistic principles. It was developed by the philosopher Rudolf Steiner in the early 20<sup>th</sup> century. Biodynamic farmers focus on the health of the entire farm ecosystem, emphasizing the importance of soil, plants, animals, and cosmic rhythms (like lunar cycles) to create a balanced and self-sustaining farm.

## **Climate and Climate Change**

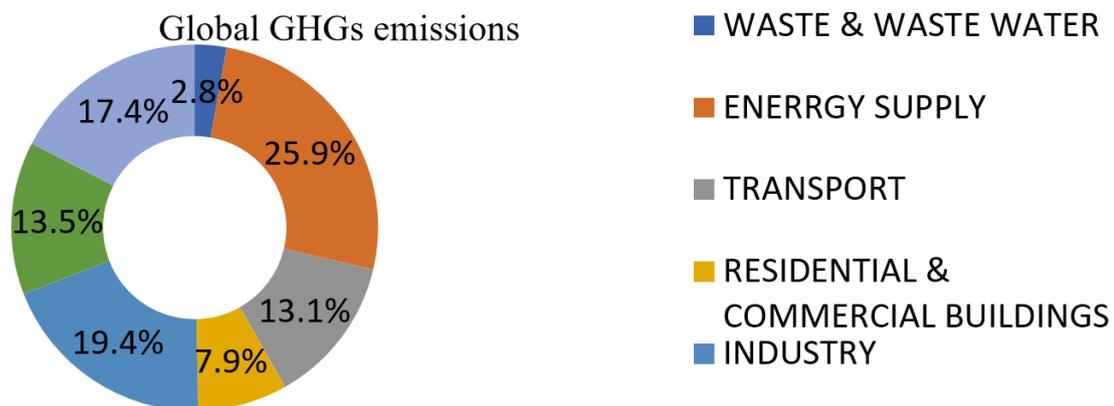
According to **IPCC (Intergovernmental Panel on Climate Change)** climate change is defined as “A change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer. In other word it refers to “Any change in climate over time, whether due to natural variability or as a result of human activity”. Also, according to UNFCCC (United Nations Framework Convention on Climate Change) “a change that is attributed directly or indirectly to human activity altering the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods” is known as climate change.

## Effect of Climate Change on Agriculture

Agricultural production depends on climate and in the tropics or sub-tropics climate change will ultimately decrease the crop yields. Climate change not only decreases the yield of crop but also decreases the nutritional value of the crop. Nutrient uptake of the crop is also affected by the extreme climate condition like heavy precipitation causing flood. Climate change make alternation in rainfall, moisture, temperature, and transformation of organic carbon, which ultimately changes the soil composition. Extreme precipitation leads to flood and this flood washes away nutrients from top soil, also causes soil erosion and destroy crops. Extreme temperatures reduce the yield, primarily when the temperature goes higher than the optimal temperature for crop growth. Disturbance in Monsoon pattern, whether it is early onset, extreme precipitation, or irregular distribution, potentially affect crop production by resulting in failure of crop, decreased yields, and disturbance in cropping cycles, which results in food scarcity, mainly in areas which dependents upon monsoon for irrigation. This drastic change in climate permit the pest to persist for longer period of time specially in winters, also these pest produces a greater number of generation than usual which further rises the threat of invading new regions by migratory pest. Present pest management practices are not efficient, growing the virulence and competitive ability of pests. Climate changes and increasing farming areas results in the loss of biodiversity. Thus, these adverse consequences of climate change on agriculture needs to be managed.

## World's Contribution to Climate Change

According to the present data, agriculture is at fourth rank in contributing to climate change, mainly due to the release of greenhouse gas, including methane and nitrous oxide from cattle and chemical input respectively and additional gas emissions from deforestation for increasing farming areas.



**Fig. 1** Global GHGs emissions by different sectors

*Source: IPCC 2013*

Also as estimated by **USGCRP 2023, Climate Science Special Report**

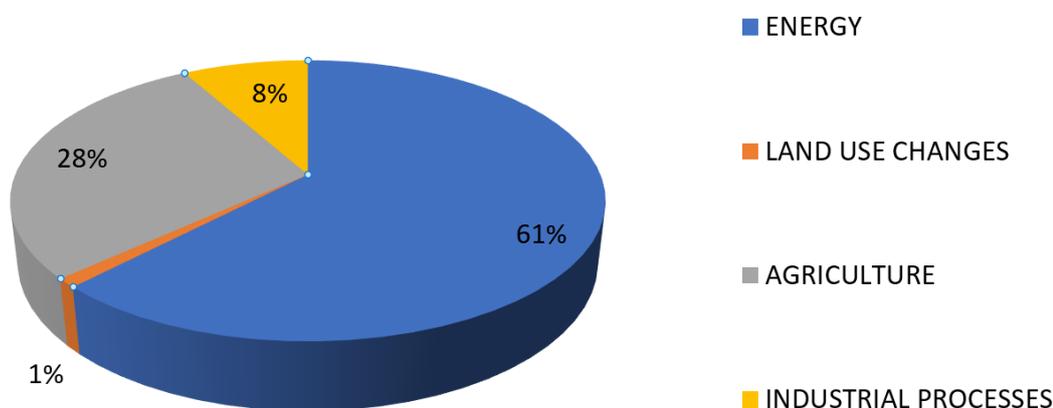
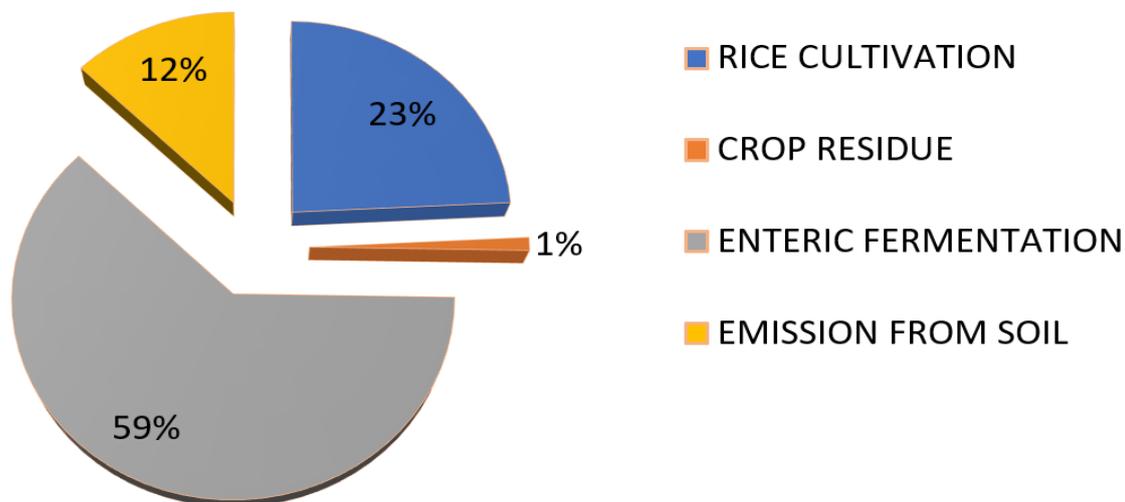
- Total global Average Carbon dioxide level 2023 was 419.3 ppm, which is 50% higher than Industrial Revolution,
- Carbon emission by burning of fossil fuel was 9.5 billion metric tons.
- Carbon emission by deforestation was 1.5 billion metric tons.
- Greenhouse gas emission by crop production was 10.9 billion metric tons.

## Contribution of India to Climate Change

The main farming roots of greenhouse gas emission in India are rice field for methane emissions, manure and fertilizer for nitrous oxide and enteric livestock digestion.

**Fig 2.** Agricultural sector contributing to climate change

**Source:** IPCC 2013



**Fig 3.** Different sector contributing to climate change

**Source:** IPCC 2013

Also as estimated by **Climate change Agriculture policy in India report, USDA 2022**

- In 2022 total greenhouse gas emission was 3.0 billion tons.
- 54.6 % of GHGs emission was from enteric fermentation (livestock).
- 19.6 % of GHGs emissions was from fertilizers.
- 6.7 % of GHGs emissions was from manure management
- 2.2 % of GHGs emissions was from crop residue management.

## Introduction to Biodynamic Farming as Climate Change Mitigation

Global agriculture and food security faces notable challenges by climate change. Increasing global temperatures, altering monsoon distribution, and high prevalence of severe environmental conditions result in failure of crop, yield loss and reduced available water. Biodynamic farming plays a great role in resolving the effects of climate change. This practice of farming can improve soil condition, conserve biodiversity, increase water holding

capacity and supports climate-resilient agriculture as well as come up with the mitigation of climate change. Farmers can lower his dependence on chemical inputs, reduced soil erosion and aid to environment by adopting biodynamic farming practice. Biodynamics comes from the Greek terms "bios," which means life, and "dynamis," which signifies energy. Biodynamics refers to an integration of "biological" and "dynamic" agricultural methods. The "biological" aspect involves recognized organic farming techniques aimed at enhancing soil health, while the "dynamic" aspect focuses on influencing both the biological and metaphysical elements of the farm, such as boosting its vital life force, or aligning agricultural activities with natural cycles, like planting seeds during specific lunar phases. In Lyman language Biodynamic agriculture is a practice which treats the cropland like a “life form” that interact with the surrounding ecosystem, to make better fertile soil, and to bring about the food which provide nourishment, vivify and support humanity development. According to **Diver (1999)**, “A basic ecological principle of biodynamics is to conceive the farm as an organism, a self-contained entity. A farm is said to have its own individuality. Emphasis is placed on the integration of crops and livestock, recycling of nutrients, maintenance of soil, and the health and wellbeing of crops and animals; the farmer too is part of the whole.”

### **History of Biodynamic Farming**

Biodynamic agriculture was established based on a series of eight lectures on farming delivered by **Rudolf Steiner** in 1924. This series of lecture in addition to four additional lessons, were published in the book titled "**Spiritual Foundations for the Renewal of Agriculture**", in the English language as course of Agriculture. The biodynamic agriculture which was established by **Steiner** is intended to be regenerative in nature, i.e., it is intended to ‘heal’ the earth. It could be considered more beneficial than agriculture that is simply sustainable.

#### **The History of Biodynamic is Split into Two Points**

- a. **Origin of a theory-** Steiner developed a research group, the "**Agricultural Experimental Centre of Anthroposophical Farmers and Gardner's of the General Anthroposophical Society**" which in 1933 was changed to "**The Imperial Association for Biodynamic Agriculture**". The practices and philosophies of the biodynamic methods are rooted on the worldview of anthroposophy. The word "**Anthroposophy**" is derived from Greek language meaning "**wisdom of the human being**". According to Steiner Anthroposophy is "a path of knowledge whose objective is to guide the spirituality in man to the spiritual in the universe". It's an advanced path of wisdom and science of spirituality, that enables the mankind to acquire a great and deep understanding of her/ his own true nature, and of the world we live in.
- b. **Geographic Development:** Biodynamic farming is widespread over Asia, Europe, and Africa including sixty countries. Biodynamic farming was firstly practiced by Ernesto Genoni. In 1928, **Anthroposophical Agricultural Foundation** today known as **Biodynamic Agriculture Association** was founded in England.

## Scenario of Biodynamic Farming in India

According to **Demeter International**, there are **9,131.89 hectares** of **certified biodynamic farms** in India. However, the **uncertified area could be around 60,000-70,000 hectares**. Also, according to **Demeter International** there are around **48 certified projects** across the country. Gujarat, Madhya Pradesh, Uttarakhand, Uttar Pradesh, Andhra Pradesh, Kerala, Punjab, Karnataka, Tamil Nadu, Telangana, West Bengal, and Assam are those states where the biodynamic farming is practiced. According to data of **Biodynamic Association of India**, more than **500 small and large farms** practice biodynamic farming in the whole country. But these farms are not certified under Demeter, making it difficult to quantify the area and farm scale where BDA is practiced.

However, according to Sundeep Kamath, the ex-secretary of BDAI, India has nearly **100,000 farmers** practicing some form of biodynamic farming, based on sales of biodynamic preparations and self-reports. Biodynamic farming is mainly adopted in India for growing herbs, spices, tea, and coffee. The organizations certified for biodynamic products include Darjeeling Organic Tea Estates, Selim Bong Tea Estates, Mother India Farms, Ambootia Tea Exports, etc.

**Table 1 : Countries ranked by BD hectares**

Country	BD Hectares	Country	BD Hectares
Germany	84,426	Egypt	2,610
Australia	49,797	Sri Lanka	1,479
France	14,629	Chile	1,474
Italy	10,781	Dominican Republic	1,410
India	9,303	Lithuania	1,389
United States	9,001	Argentina	1,187
Netherland	8,681	Turkey	1,148
Spain	7,743	Paraguay	996
Austria	7,164	New Zealand	928
Hungary	6,371	Sweden	873
Switzerland	5,070	Tunisian	699
Poland	4,261	Guinea Bissau	694
United Kingdom	3,886	Portugal	574
Czech Republic	3,537	Norway	548
Brazil	3,388	Luxembourg	536
Denmark	2,998		

**Source:** Council on Energy, Environment and Water (India)

## Principles of Biodynamic Farming

**Soil Fertility:** Restoring soil is the fundamental value of Biodynamic farming. Biodynamic farming focuses primarily on soil structure and its life form in order to obtain crop in good health. This principle concentrates on whole development of soil which include the nutrient uptake, the trace elements, the life form present in soil such as the worms and other animals. This act as a base of nutrient supply for crop, stabilizes the heat and air element of soil, and cohere CO<sub>2</sub> present in soil.

**Organic Matter and Humus:** The key concept of Biodynamic farming is to regenerate the organic matter of the soil as well as humus, expanding the microbial flora in soil. Humus and its restoration should be the primary aim during transforming the farm in a Biodynamic farm. Skilled application of organic matter is basic requirement to balance the living soil and it is achieved by forming biodynamic compost load and utilizing the preparations of Biodynamic farming.

**Cow Manure:** The most popular Biodynamic preparation is the Biodynamic preparation 500 and its main ingredient is cow manure itself, this cow manure is exceptional as it is obtained after the long and complex digestive activity of the cow, adding good bacteria to the manure which makes it a good nutrient source, like phosphorus, nitrogen, and potassium, necessary for the growth of plant. As this Cow dung is also very rich in organic matter it also enhances the structure of soil and moisture retention ability. Barrel preparation (or Cow Pat Pit) can be sprinkled on farm or garden and can also be put on the compost load as a starter.

**Biodiversity Preservation:** Biodynamic farming protects the endangered species and balances the ecosystem. This method thus uses method that conserve natural resources i.e. sustainable cultivation of crops with aim of conserving or maintaining microbial population in soil, animal and human health.

**Cosmic Forces & Planetary Influences:** In Biodynamic farming cosmic energy and natural resources are used for creating and maintaining life. Celestial and astrological patterns play a major role in the timing of biodynamic practices like creating the BD preparations and time of planting and harvesting according to the biodynamic calendar. Biodynamic practitioners understand the patterns and astrological cycles of the celestial bodies and planets understanding the indirect methods by which the environment and wider cosmos effect the plants and animals.

**Biodynamic Preparations:** These uncomplicated, homeopathic, candid, preparations are applied to increase the impact of the celestial bodies and earth on the crops and the soil, and to increase the microbial digestion of the compost load. **Dr. Steiner** established two types of preparations one which will be sprinkled directly on the top soil or the crop (BD 500 and BD 501), and the other six preparations which will be applied during compost making (BD 502 to BD 507). Compost quality is enhanced by the Biodynamic farming as it stabilizes the nutrients, multiply soil flora and bring much carbon into the living dimension therefore, restoring the equilibrium of the climate.

**Peppering:** In biodynamic agriculture, peppering is practise to make your farm pests free such as weeds, insects pest and animals. The pest's skin, weed's seed and insect pest are burnt at astrologically suitable time to create ash known as "peppers". These peppers are mixed in

water to make **homeopathic medicine**, and sprinkle them on the soil. It is an effectful substitute for chemical sprays. The peppers look like fine black pepper that's why it is named as "peppering". It works by engaging in the rhythms and energies of the farm to communicate that the environment is not conducive to the problem plant.

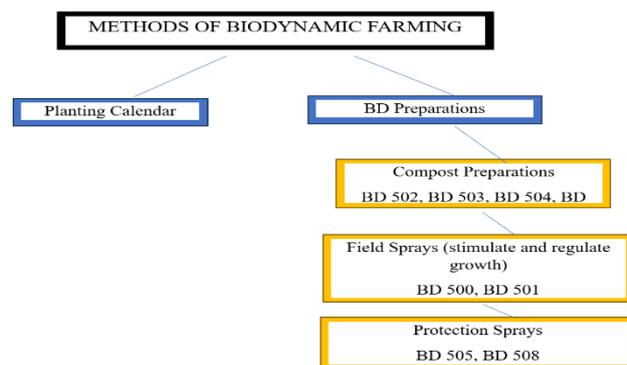
**Liquid Manures and Herbal Teas:** The liquid manure is made up of fermented solution of herbal plants in addition with extract of seaweed or fish meanwhile the Herbal teas are made up of only a single fermented plant. These liquid manures and herbal teas play a vital role by encouraging dynamic and biological processes in the field and suppressing diseases.

**Compost:** The goal of Biodynamics is to return more as compared to what it takes from the nature by using manure and vegetable waste to create compost that helps to build up nutrient-rich and carbon-storing humus in the soil. Biodynamic agriculture improve soil, conserve environment, biodiversity and water, all with producing healthy and nutrient rich produce. The goal of Biodynamic farming is to make, the soil healthy by utilizing compost, manure and crop rotations.

**The Farm Organism:** Biodynamic farming aims to have a good biodiversity of animals and plants and to not take anything from outside the field (like chemical inputs). The main features of biodynamic farms are the source of water, conservation of soil by including more plants, trees and shrubs that also protect from heavy wind and provide habitat for animals. Biodynamic fields work to aggregate flora, fauna and soil with each other by living and conscious relationships, so to stabilize the whole system. Thus, making the farm fertile by their own by crop rotation, manure, interconnecting livestock with other farm elements etc.

## Method of Biodynamic Farming

The two pillars of biodynamic farming are BD preparation and Planting calendar. BD preparation includes the organic compost made out of various materials that can be applied to crop for nutrition, development and growth while the lunar forces and patterns are the basis of Planting calendar.



**Planting Calendar of Biodynamic for Climate Change Mitigation:** RHYTHMS are the main feature of planting calendar. Rhythm is entertained to the movement of moon and the tides cosmic, solar, lunar and earthly rhythms. Biodynamic agriculture is divided into two poles – the earthly one and the cosmic one. The biodynamic farming includes six different moon patterns/rhythms that occurs every 27 to 29 days. These moon rhythms are the Ascending days, Descending days, Perigee, Apogee, Full moon and new moon. This planting calendar helps farmer with the date and time of the various astrological events so farmer may plan farm work and activities to enhance the beneficial influences and negate and mitigate with the changing climate scenario affecting agricultural production quality and produce.

**Ascending Days:** The ascending period is when the Earth exhales just like summer and spring. It can be noticed on the surface of soil during growth. The sap will carry growth

driving forces more efficiently with the ascending Moon that enhances the vitality of plant. Though the germination processes take place below the soil surface, these uphill growth force aids in the germination process.

- **Activities in Ascending Days**

- i. Seed sowing for seedling.
- ii. Foliar spraying of liquid manures.
- iii. Foliar spraying of panchgvya.
- iv. BD 501 be sprayed before 10.00 am.
- v. Fruits and green leafy vegetables should be harvested

**Descending:** In the descending period all the growth driving forces are taken back under the soil surface as in this period the earth inhales. This period is just like winter and autumn. Energizing the plant part near the ground and particularly those below the soil surface, primarily the root system. It's the time of cultivation and spreading of compost before planting.

- **Activities in Descending Days**

- i. Seedlings transplantation.
- ii. Compost making and its application
- iii. Field should be ploughed
- iv. B.D.500 should be applied
- v. Liquid manure should be applied.
- vi. Roots and bulbs should be harvested

**Apogee & Perigee:** **Apogee:** means the farthest point or culmination point of astronomical body such as stars, mars, Jupiter and other planets on their orbit. Simply putting, Apogee refers to the highest point on the orbit of an astronomical body around a bigger astronomical body. **Perigee** means the nearest point on the orbit of an astronomical body around a bigger astronomical body. Simply putting, perigee denotes to the nearest point or point of culmination of an orbit of an astronomical body. Consideration of influences of the apogee & perigee on growth and development of plant, soil and cosmic patterns are crucial in Biodynamic farming.

- **Activities in Apogee & Perigee**

- i. Don't cultivate the soil, even sowing and pruning is not done during Perigee phase.
- ii. Avoidance of sowing and transplanting activities before a certain period for 12 hrs.
- iii. Bulbs such as potatoes should be sown during Apogee.

**Full Moon:** Full moon is regarded as a noteworthy lunar occasion in biodynamic agriculture which exert influence on growth and development of plant, health of soil and other agriculture related stuffs. Full moon enhances the vitality of plant, growth and development of plant, also expands leaf surface area and act as a tonic for activities taking place above the soil surface.

- **Activities in Full Moon**

- i. Seeds should be sown 48 hours before the Full moon.
- ii. BD 501 should be applied.
- iii. Spraying of Panchgvya in the morning.
- iv. Foliar spraying of liquid manures.

**New Moon:** New moon is regarded as a noteworthy lunar occasion in biodynamic agriculture which exert influence on growth and development of plant, health of soil and other agriculture related stuffs. New moon enhances the growth and development of plant, also foster growth of root, and boost activities under soil surface. It also acts as a tonic for activities taking place above the soil surface.

• **Activities in New Moon:**

- i. Seeds should be sown and seedlings should be transplanted
- ii. BD 501 should be sprayed
- iii. Collection of seeds of pea, green gram, black gram, etc. for sowing purpose
- iv. Goods should be preserved

### **Preparation of Biodynamic Farming**

Steiner described nine biodynamic preparations. The purpose of these preparations is the enhancement of quality of soil and boosting plant vitality. The ingredient of these preparations are minerals, plants and manure extracts, mostly in fermented form. These preparations are than diluted and stirred well in a process called Dynamizations after that these preparations are used in little amounts in manures, compost, soil or straight on the plants.

The measures are divided into two groups of particularly fermented substances, known as preparations. Group one includes the spraying preparation which are categorized by number 500 and 501. The other group involve six separate herbal substances which are categorized by number 502-507 and are applied in little proportions to composts and manure, so these together are known as Compost preparations. The ninth preparation BD 508 which consist of boiled Horse tail plant is predominantly used in excessive wet year to protect the crop from diseases caused by fungus. So, Biodynamic preparation is namely **BD 500, BD 501, BD 502, BD 503, BD 504, BD 505, BD 506, BD 507, BD 508.**

**BD 500 Cow Horn Manure:** Horn Manure, generally called as "BD 500" is the most popular applied biodynamic preparation made by transforming highest-quality cow dung which has been stuffed in the cow horns and are buried beneath the soil during winters (Sept/Nov). After half a year in (Feb/March) the cow horns are brought out of the soil, the organic matter is separated and is dynamized. Horn Manure is sprayed on soil in winter and spring.

**a. Preparation Procedure of BD 500 Cow horn manure**

- Two days before the collection of dungs the cow are feed with good quality of cattle Feed such as high-quality green fodder.
- Preparation of burial pit: depth of 18 inches is a must.
- The Pit area must be free from earthworms, excessive roots and waterflooding.
- BD 500 will have the exact same feature of the soil in which it was buried in, therefore high-quality soil should be used.
- Gather cow horns and clean them. Geather the fresh dung.
- Stuff the cow dung in cow horns during October/November

- Put horns in the burial pit, 100 centimetres away from the base facing downwards, neighbouring by half compost and half soil.
- Place soil on its top and leave for 5 to 6 months. If the soil quality is poor adding compost up to 50% will work.
- Maintain a pest (earthworm and weed) free soil and make sure the soil is sufficiently moistened with temperature around 20 °C.
- Check for cow dung fermentation after 4 months. Unbury a single horn. If cow dung has transformed in a plane earthly scent dark colored humus (BD 500) it is ready. Collect BD 500 and store it. If it is not fully developed, wait a little longer.

#### **b. Application Process**

- It should be applied when the dew falls (when the Earth inhales) i.e. or during dusk time in descending Moon phase.
- Mix 25 grams of BD 500 per acre with 15 liters warm water or rain water of approximately 15-20 °C temperature.
- It should be Stirred well for an hour anticlockwise and clockwise (alternatively) such that it forms a vortex.
- It should be Sprayed in the Descending Moon just before the sun is about to set (late in afternoon).
- Spraying four times in a year before and after the rainy February-May-November-December.

**c. Storage of Horn Manure (BD 500)-** Keep the horn manure buried in a box which will be surrounded by coco peat. Keep it moist and closed in a dark space with 25°C temperatures. In this way the Horn manure (BD 500) can be stored for 1 year.

**BD 501 Cow Horn Silica:** Cow horn silica is generally known as (BD 501) and is applied with BD 500. This is not applied on soil rather applied on the shoot part of the plant in their growth phase. It is nothing but quartz which is finely crushed into fine talcum like powder and then stuffed in the cow horn at the rate of 200-300 grams. These are then buried in the soil just like the Horn manure, the only difference will be the timing. BD 501 will be buried in the month of April/May and will be unburied in September.

#### **a. Procedure of BD 501 Preparation**

- The pulverized quartz is then filled in the cow horn preparation. A high-grade quartz crystal is involved in the preparation of Cow horn silica as the composition is on pin point that absorbs and emits light.
- This silica paste will be filled in the cow horns and will be left lasting one night. The excess water will be drained off next morning.
- On a flower day this preparation is then buried during the Descending moon in the spring then it will be unburied in autumn.
- Fill the cow horn with the preparation and burry in the soil I a pit, at a distance of 1 inch from each other with the base facing downward, surrounded with half compost and half soil from March or April (spring equinox) till September (autumn equinox).

**b. Application Process:**

- At first 1 to 2 application of BD 500 should spray before applying BD 501.
- It shouldn't be sprayed during rain.
- Use 4 g per hectare in 30 - 35 litres of high-quality water. For areas smaller than 1,000 sq. metres, use 1 g in 5 - 10 litres of water, and spray the total volume.

**c. Storage**

Horn Silica should be stored in a glass container only, and not hermetically sealed. Place the 501 where it will receive morning sunlight only. An East-facing, outdoor window ledge is ideal.

**BD 502 Yarrow (*Achillea millefolium*):** This is a fermented liquid manure preparation made from Yarrow (*Achillea millefolium*) combined with the bladder of a stag. This attracts trace elements from the cosmos and provides selenium and micro-nutrients to plants. Also, it converts urea into protein, and develops nitrogen fixing bacteria.

**a. Procedure of BD 502 Yarrow Preparation**

- Start the preparation by moistening the flowers with plant extract and the bladder with water.
- Blow up the bladder with air when the bladder is fresh.
- Then cut the bladder, insert a funnel and introduce the flowers till the bladder is packed.
- Moisten the flowers with plant extract, stitch up the slit with cotton thread.
- Hang the bladder up in March in a sunny place for at least 3 months.
- Moisten the bladder with water before burying the bladder at the end of September to October.
- Surround the pot with fertile soil or compost. Mark the pit with dates and detailed labels.
- It can be taken out of earth after 4-5 months in March/April.

**b. Storage:** Store in a closed basket to keep away from rodents/pests.

**BD 503 Chamomile:** This is composed of the flowers of the Chamomile plant (*Matricuria chamomilla*) combined with cow intestine. It helps retain nitrogen, calcium and sulphur and stimulates plant growth by increasing soil life.

**a. Method of BD 503 Preparation:**

- The small intestine (Jejunum) of a cow or bull can be used.
- The fresh intestine must be emptied, to squeeze out the undigested matter. Do not wash the intestines.
- Cut into 15 cm bits. Tie cut bits at one end with a cotton string.
- Fix funnel to open end and fill with dry flowers and bury these flowers filled intestine in October and let it remain in the soil till Feb/March.

- Stack the filled sausages into a bundle, which could be placed in a mud pot surrounded with fertile soil.

**b. Storage:** Store in a glass jar or paper bag in a well-ventilated cupboard.

**BD 504 Stinging Nettle:** BD 504 is made up of dried Stinging Nettle (*Urtica parviflora*) compacted in a clay pot during autumn which becomes dark colloidal humus after 1 year. It balances iron, magnesium and sulphur and make the soil looser.

**a. Method of BD 504 Preparation:**

- The stalk and leaves should be harvested in May/September before the plant flowers. The whole plant should be completely dry.
- The preparation is made in the autumn.
- The dried nettles should be compacted into 10-15cm diameter unglazed clay pots that are placed head-to-head into fertile soil.
- The preparation needs to be left for a year so ensure the site is well marked.
- Over the next 12 months, the nettles will transform leaving dark colloidal humus.
- It should be sieved to break up any stalks that have not fully transformed and stored in a cool dry place until you are ready to use it.

**BD 505 Oak Bark:** In biodynamic farming, BD 505 Oak Bark is a preparation used primarily to help combat harmful plant diseases by providing "healing forces", often applied when there's excessive rain or during a full moon to regulate plant growth and protect against fungal diseases. It is prepared with the oak bark being placed inside a cow skull and steeped in water over winter to create the preparation.

**a. Method of BD 505 Oak Bark Preparation:**

- Crush the oak bark and place the crushed oak bark in the brain cavity of the skull.
- The link between the skull and bark is their calcium properties.
- Place the skull in a watery environment with weeds and plant muck which would have been damaged by the local diseases that effect the crop. This helps build up the resistance of the plants and follows the principles of Homeopathy.
- It should be noted that a foul smell is emitted on lifting the preparation and removing it from the skull.
- This gradually reduces with drying after removal in a dark dry place.
- Fungus may form so turn over frequently to correct the same.
- This preparation is lifted in March

**b. Application:** Typically applied as a spray to the soil around plants, particularly during periods of heavy rain or full moon phases.

**c. Store:** The skull should be discarded and its contents can be placed in a glass jar.

**BD 506 Dandelion:** BD506 is a compost, prepare from the flowers of dandelions (*Taraxacum officinale*) wrapped up in bovine mesentery. BD 506 is used to stimulate the soil's potassium/silica bacteria and fungi, which helps the soil work more effectively and stimulate the soil's magnesium, boron, and selenium activity.

**a. Method of BD 506 Preparation**

- The dry flowers should be placed in a cow's mesentery. The mesentery is used because it has a very sensitive influence on life forces. The mesentery filled with flowers is then folded like a parcel and sewn tightly together.
  - The "Parcel" is then buried in autumn (September) on a descending moon between two unglazed terracotta pots to ensure it is not disturbed by animals and can be easily located months later.
  - In spring (March) the preparation should be ready to lift out of the ground at around the same time BD500 is lifted (It follows a similar cycle).
  - Cut open the mesentery, remove the transformed flowers and scrape the rest of the mesentery.
- b. Application:** To apply BD 506, dilute the tincture and spray it onto the soil or plants during the early growing stages by mixing 50 grams of the tincture with 10 litres of water.
- c. Store:** Store in a glass jar, with the lid off and stir for the first couple of weeks.

**BD 507 Valerian:** BD 507 Valerian is a biodynamic compost preparation made from the valerian plant that can be used to protect plants from frost and improve compost. The juice of valerian flowers is used for this preparation. BD 507 has a great relationship with light. It stimulates compost so that Phosphorus component is properly used by the soil.

**a. Method of Preparation**

- Using the tincture of Valerian flowers make a 5% solution and then use 10mm per 13.5 litres of rainwater. This liquid is then dynamized for 10 minutes.
  - The flowers are then crushed and mixed with distilled water (with a ratio of 20:80 i.e. 20% solution) and placed in a glass jar on a window sill in light where they remain for a week imparting energy and focus to the water.
  - The preparation is then filtered, the flowers are discarded and the liquid is returned to airtight glass jar, filled to the top and overflowing to exclude any oxygen, and is then placed in a dark cupboard until needed.
- b. Application:** Use 10 ml of 507 in 2-5 liters of water. Most preparations are placed directly into the compost but BD507 is applied in two ways; half is poured into 2 holes made in the compost, and the remainder is sprinkled over the surface.
- c. Store:** The liquid is run into sterilised 20-50ml bottles, ideally within an insulated storage box lined with material like coir pith to maintain consistent temperature and moisture levels. To store BD 507 Valerian (a biodynamic compost preparation), keep it in a cool, dark, and moist; ensure good air circulation and regularly check the preparation to maintain its moisture content.

**BD 508 Horsetail or Casuarina:** BD 508 is a biodynamic preparation also known as Horsetail (*Equisetum Arvense*) preparation. It is a ferment or 'tea' style preparation prepared by diluting *Equisetum arvense* in 10 litres of water that can be applied direct to the soil, plant

or atmosphere. Its purpose is to regulate the watery element brought on by too strong or too weak moon forces.

**a. Preparation Process of BD 508 Horsetail or Casuarina:** There are two methods for making the preparation:

- **Tea method:** Add the 200-300g dried material of horsetail in 10 litres of rainwater or stream water and boil covered in a saucepan or pot. Simmer for 20 minutes to an hour then leave for 24 hours to extract the silica.
- **Fermentation Method:** Bring dried material of horsetail to the boiler and simmer for up to 1 hour, then transfer into a barrel or earthen vessel for around 2 weeks out of sunlight. The preparation should develop a slight sulphur smell once fermented.

**b. Application Process:** The best time to spray is from sunrise to mid-morning because of the preparation's link to light as with BD 501. BD 508 preparation is used on specific days within the Lunar Calendar, 2 to 3 days before a full moon and following bad weather when the water forces are at their strongest, which is when there is the highest risk of fungal disease. Unlike many biodynamic preparations BD508 is applied by diluting in 1:10 ratio and in rate of 100 to 300L/ha depending on the density of the crop.

**c. Store:** Store this in a glass container in a cool, dark place.

### Benefits of Biodynamic Farming

**a. Soil Carbon Sequestration:** Practices such as cover cropping, composting, and reduced tillage increase organic matter in soil which store carbon dioxide thus enhances soil carbon sequestration. Biodynamic farming showed 30% higher soil carbon levels compared with other farming practices (Rodale Institute's Farming Systems Trial, USA).

Location	Study	Soil depth	Organic Farming (Kg C/ha/yr)	Biodynamic Farming (Kg C/ha/yr)
Sweden	33 yr trial	60 cm	300	800
Switzerland	28 yr FIBL trial	20 cm	23	42

*Source: Turinek et al., (2009)*

**b. Increased Crop Yields and Quality:** Biodynamic Farming generally produces higher yield even as compared to organic farming and continuously high in the subsequent years which is the opposite case in farming practices using chemical inputs. Fruits and vegetable which are grown biodynamically are stronger flavored and have high nutrient content.

Treatments	Pods/ plant	Yield q/ha	B:C ratio
BD	54.03	9.5	2.24

Neem Oil	52.54	8.7	1.82
Mustard oil	51.66	8.3	1.93
<i>Ampelomyces quisqualis</i>	49.86	8.3	1.93
<i>Azadirachtin</i>	44.81	7.9	1.68
Source: Trivedi <i>et al.</i> , (2013)			

<b>Table 4. Quality factor of Rice under Synthetic &amp; Biodynamic Farming</b>			
Parameters	Control	Synthetic	Biodynamic
Whiteness of rice grain	8.23	8.27	8.61
Gloss of rice grain	1.00	1.18	1.09
Acceptability of raw grain	10.98	10.46	10.49
Cohesiveness of freshly cooked rice	5.32	4.89	5.26
Tenderness of freshly cooked grain	5.97	5.14	5.21
<b>Source:</b> Valdez <i>et al.</i> , (2008)			

- c. **Enhanced Soil Health:** As Biodynamic farming involves the use of natural ingredients such as cow dung, herbs and quartz thus improves overall soil fertility as well as productivity. This farming system plays an important role in the improvement of chemical, physical and biological properties of soil, by improving soil texture, porosity, and organic matter content. It also improves microbial growth in soil hence results in the humus formation and stabilization of soil.
- d. **Biodiversity Conservation:** Biodynamic farming protects vulnerable species and conserve biodiversity thus play a great role in maintaining ecological balance. Biodynamic farming conserves natural resources by applying sustainable practices for cultivation of crop with goal of conserving and maintaining soil flora and fauna.
- e. **Water Conservation:** Biodynamic farming play vital role in water conservation by adopting practices such as composting, mulching and improvement of soil structure. Increase of organic matter in soil by biodynamic farming helps in more water retention in soil and thus decreases runoff loss and lead to overall conservation of water.
- f. **Reduced Synthetic Inputs:** Biodynamic farming reduces synthetic inputs by using organic and biological inputs. Biodynamic farming reduced synthetic fertilizer use by 20% compared to conventional production system (**Indian Institute of Soil Science, India**).
- g. **Increased Crop Resilience:** Biodynamic farming uses Diversified cropping systems (Trap crop cropping, Inter Cropping, Cover Cropping, & Crop Rotation) in association with Natural Preparations (BD Mixtures) which help the crops to adapt to changing weather patterns.

- h. Improved Nutrient Cycling:** This farming practice decreases waste by efficiently using nutrients, minimizes emission of methane and nitrous oxide. Biodynamic farms recycle nutrients and use different biologically-based processes to supply nutrient.
- i. Reduced Greenhouse Gas Emissions:** Biodynamic agriculture makes the ecosystems to adapt to the impacts of climate change and potentially reduces greenhouse gas emissions by agriculture. The fumigant pesticides, usually applied on crops release nitrous oxide (N<sub>2</sub>O), which is the major greenhouse gas and is not a part of Biodynamic farming thus reduces GHGs emission. Biodynamic farming demonstrated 40% lower Greenhouse gas emissions, (Research Institute of Organic Agriculture, Switzerland).

### Case Study of Biodynamic Farming

The economic performance of biodynamic vs conventional soybean was studied using data from a consecutive 7-yr case study in a farm with 48.4 ha of biodynamic soybeans in Paraná State, Brazil and the conclusion drawn are as follows:

- Effective operational costs were 4.4% higher in biodynamic than in conventional farming.
- Prices were 57% higher in biodynamic than in conventional, making biodynamic farming more profitable than conventional farming
- Gross revenue, Gross margin, Net margin., Net income and capital income were 50.7, 99.9, 122.9, 150.4 and 166.9%, respectively, higher in biodynamic than in conventional.
- The price equilibrium point (PEP) was 3.4% higher for biodynamic farming; the levelling point was 36.9% higher for conventional farming.

These above conclusions drawn from a case study in Brazil on soyabean depicts how biodynamic is better in comparison to conventional agricultural practices in accordance with production on terms of ecological sustainability and through mitigating climatic change scenario.

### Constraints in Adoption of Biodynamic Farming

- a. Lack of Technical Knowledge:** Biodynamic farming comes with dispute for farmers with a little technical knowledge as it relies on complicated, sometimes spiritual practices grounded on cosmic sequences and esoteric faiths, which are hard to understand without a deep grasping of the basic principles and certain preparation methods associated with this farming method.
- b. Lack of Marketing and Distribution Network:** Biodynamic farming practicing farmers are usually challenged by a poor marketing system, lack of well-established transporting channels and storage facilities.
- c. Low Level of Awareness:** Farmers and consumers have no or just a little understanding of the methods and principles of Biodynamic Farming, usually not knowing the distinct characteristics such as certain biodynamic preparations, the lunatic cropping calendar, and the farm management grounded on natural patterns, which leads to an absence of extensive adoption of Biodynamic Farming. Even it is not a distinguish part of courses taught in agriculture schools and training institutes.

- d. **Lack of Government Assistance:** Biodynamic farmers do struggle to go for any subsidy, grant and loan for adopting to Biodynamic Farming as there is no such support system from government which can provide any policy and regulation for Biodynamic Farming.
- e. **Biodynamic Products Demand Higher Prices:** As there are more labours required in Biodynamic farming which makes its produce costly. Also the certification process, transportation, marketing channels and high requirement of experts leads to a high cost of production thus increasing the price of the produce.
- f. **Need of Certification:** Certification process in biodynamic farming is complicated and time-consuming creating problems for farmers. Also, the other documental processes are complex too. Not only this but the certification process is also very costly posing burdens on the farmers pocket leading to discouragement.
- g. **Requires More Labour:** Biodynamic farming involves more labours and experts as compared to other farming practices as it involves different types of unique tasks which are not even a part of the other farming practices such as collection of certain flowers at certain period of time, making of biodynamic preparation making, collecting cow horns, burring and unburning, etc.
- h. **Non-Adaptability of Farmers:** Farmers usually have mindset that prevent them from adopting to any new farming practices such as Biodynamic Farming. This may be because they have gained experience in traditional farming or because of lack of knowledge. One of the major problems for adopting biodynamic farming is the involvement of dead animals and their internal body part which make it hard for the farmers to adopt to Biodynamic farming as not every farmer can accept this.

## Conclusion

As we are brawling with the challenge of climate change, biodynamic farming is providing a ray of light for a more restoring, sturdy, and sustainable food producing system. As Biodynamic Farming provides a robust solution for mitigating climate change, exploiting the inherent resilience of living ecosystems to sequester carbon, enhance biodiversity, and promote ecological balance. Biodynamic farming is an environment friendly approach of farming having the capability even to convert the marginal and small farms to self-sustaining farms and to alleviate climate change impacts on farms so, there's a serious call for glorifying and popularizing the biodynamic farming along with the traditional agriculture practices, that might be possible sustainable solution for sustainable farming. Let's together, hitch up the transformative capability of biodynamic farming to make a more restoring and climate-resilient food producing system for each and everyone.

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# Soil Health Management under the Changing Climate Scenario

Arpit Yadav, Rahul Verma, Brijesh Sonkar and Aniket H. Kalhapure

## Introduction

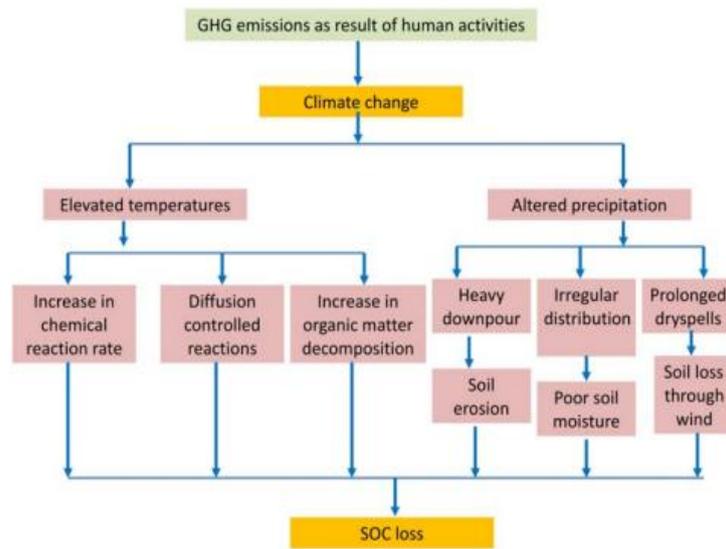
**Climate:** It is the average weather in a given area over a longer period of time. A description of a climate includes information on e.g. the average temperature in different seasons, rainfall, and sunshine.

**Climate change:** Climate change is any systematic change in the long-term statistics of climate variables such as temperature, precipitation, pressure, or wind sustained over several decades or longer. Climate change can be due to natural external forcing (changes in solar emission or changes in the earth's orbit, natural internal processes of the climate system) or it can be human induced.

- The late 20th century has been an eyewitness of the rise in global surface temperature by 0.8 °C and in India 0.4-0.6 °C in last 100 years.
- Climate change may adversely impact soil health by reducing the amount of organic matter in the soil, harming the structure of the soil and increasing its vulnerability to erosion and other degradation processes.
- Water can affect soil health; extreme downpours can lead to run off and erosion. This strips the soil of key nutrients needed to sustain agriculture. In coastal areas, sea level rise may also lead to an increase in ground water salinization as the salty sea floods further inland. Consequently, this will compromise the availability of fresh water used for primary production in agriculture.

Soil health is the continued capacity of a soil to function as a vital system, within ecosystem and land use boundaries, to sustain biological productivity, maintain the quality of air and water, environment, and promote plant, animal and human health. Indian agricultural soils are low in organic carbon content and for achieving higher agricultural production; we have to depend on the fertilizers. All India Co-ordinated Long Term Fertilizer Trial (around 25 years) results indicated that regions having higher organic carbon content (>0.60%) in the beginning showed a declining trend in the organic carbon. Whereas, regions with lower organic carbon content remained more or less static or slightly increase in the organic carbon content was noticed. At low levels of water availability, it is difficulty to decide optimal levels of N fertilizers for maximizing yield returns. Changes in rainfall due to global climate change may affect the surface moisture availability, which becomes important for germination and crop stand establishment in the rainfed areas. Microbes have emerged as major contributor as well as consumer of greenhouse gases as they are the main intermediates of carbon turnover in the soil. Microbes are also considered as sole agents for soil humus formation, cycling of nutrients, soil tilth and structure and perform myriad of other functions. For real measurement of the impact of soil processes, one needs to consider proportion of total organic C or N within the microbial biomass i.e. microbial quotient. The interaction of nitrogen, irrigation and seasonal climatic variability particularly at low input of irrigation has

several implications. Under adequate moisture supply situation like Punjab and Haryana states the yield benefits are obtained at higher nitrogen application. Whereas, in the regions of limited to moderate water supply situations, the increasing trends in yields are not up to relatively lower values of nitrogen. At low levels of water availability, it is difficult to decide optimal levels of N fertilizer for maximizing yield



returns in view of uncertainty N responses which is strongly related to a good post monsoon rainfall receiving during crop growing period (Kalra and Aggarwal, 1994) Farmers often achieve far less than 50% of the climatic and genetic yield potential for a given sowing date, cultivar choice and site. The potential yield or maximum yield is limited by climate and crop cultivar only, all other factors being optimal. Therefore, climate plays a major role while attaining potential yield or maximum yield (Karmakar *et al.*, 2016). Climate change has an impact on the soil, a vital element in agricultural ecosystem. Higher air temperatures cause higher soil temperatures, which generally increases solutions chemical reaction rate and diffusion controlled reactions (Buol *et al.*, 1990) Solubility of solid and gaseous components may either increase or decrease, but the consequences of there may take many years. Furthermore, higher temperature will accelerate the decomposition of organic matter, resulting in release of CO<sub>2</sub> to atmosphere and decrease in carbon to nitrogen ratio's (C: N) although these two effects should be offset somewhat by the greater root biomass and crop residues resulting from plant response to higher CO<sub>2</sub>. Soil temperature influences the rate at which organic matter decomposes. It resulted into release, uptake of nutrients and plant metabolic processes. Chemical reactions that affect soil minerals and organic matter are strongly influenced by higher soil and water temperature. Soil productivity and nutrient cycling are therefore influenced by the amount and activity of soil micro-organisms. Soil micro-organisms fulfil two major functions i.e. they act as agents of nutrient element transformation and transportation, as well as store carbon and mineral nutrients (mainly N, P and S) in their own living biomass acting as a liable reservoir for plant available nutrients with fast turnover. The changes in C:N ratios of plant residues returned to the soil have impact on soil microbial processes and affect the production of trace gases. Climate change could increase rate of soil erosion, further hampering food production. Increases in rainfall will accelerate the rates of soil loss, reducing the farm productivity even more. A further negative consequence of accelerated soil erosion will be increased sedimentation in streams and reservoirs. Another way, in which erosion could accelerate, is through a decrease in rainfall, which could lead to dry spell and increased risk of wind erosion (Parry *et al.*, 1999).

## Causes of Climate Change

### Natural

- a. **Volcanoes:** Volcanoes affect the climate through the gases and particles (tephra/ash) thrown into the atmosphere during eruptions. The effect of volcanic gases and dust may warm or cool the Earth's surface, depending on how sunlight interacts with the volcanic material (Fig.1).



Fig.1 Volcanoes

- b. **Temperature:** As greenhouse gas emission blanket the earth, they trap the sun heat this leads to global warming and climate change. The world is now warming faster than at any point in recorded history. Warmer temperatures over time are changing weather patterns and disrupting the usual balance of nature (Fig.2).



Fig.2 Temperature

- c. **Precipitation:** Climate change can affect the intensity and frequency of precipitation. Warmer oceans increase the amount of water that evaporates into the air. When more moisture-laden air moves over land or converges into a storm system, it can produce more intense precipitation—for example, heavier rain and snow storms (Fig.3).

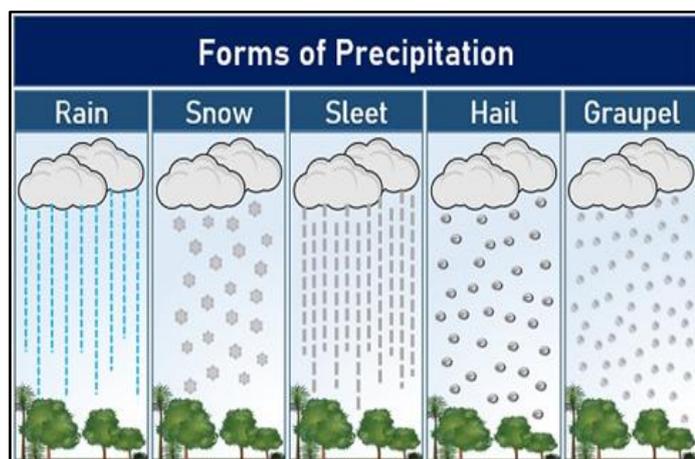


Fig.3 Precipitation

- d. **Green House:** The greenhouse effect helps trap heat from the sun, which keeps the temperature on earth comfortable. But people's activities are increasing the amount of heat-trapping greenhouse gases in the atmosphere, causing the earth to warm up (fig4).

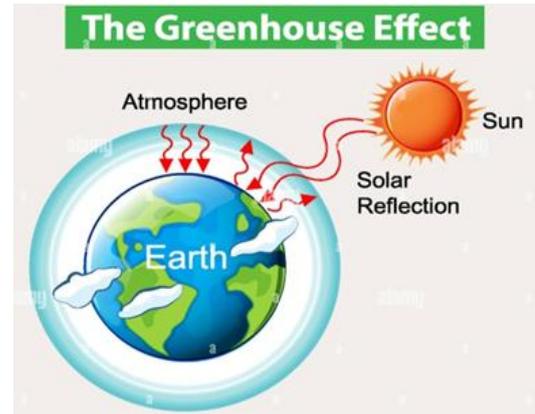


Fig.4 Green house

### Anthropogenic

- a. **Fossil Fuels for Burning:** When fossil fuels are burned, they release large amounts of carbon dioxide, a greenhouse gas, into the air. Greenhouse gases trap heat in our atmosphere, causing global warming (Fig.5).



Fig. 5 Fossil Fuel Burning

- b. **Deforestation:** Trees absorb and store carbon dioxide. If forests are cleared, or even disturbed, they release carbon dioxide and other greenhouse gases. Forest loss and damage is the cause of around 10% of global warming. There's simply no way we can fight the climate crisis if we don't stop deforestation (Fig.6).



Fig.6 Deforestation

- c. **Population Pressure:** People need food to survive, and as the world's population grows, so too does the demand for food. To meet this demand, agricultural development has caused deforestation on a large scale. The shrinking forests are unable to counteract the effects of the increasing carbon emissions, causing temperatures to rise (Fig.7).



Fig.7 Population pressure

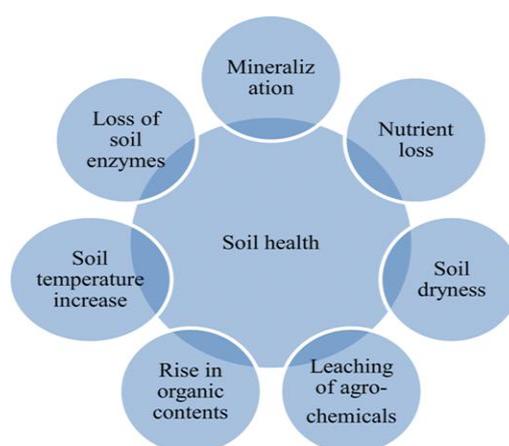
d. **Industrialization:** The changes in atmospheric greenhouse gases are a result of continually growing industrialization and economic growth across the Global North. Changes in agricultural practices, urbanization and a new reliance on fossil fuels both drove the industrial revolution, and were a result of it. (Fig.8).



**Fig.8** Industrialization

### Impact of Climate Change on Soil Health

The potential impact on soil health resulting due to the climate change is through organic matter supply, temperature regimes, hydrology and salinity. Following are the major consequences of global climate change on soil health. Soil health refers to the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Fig.9).

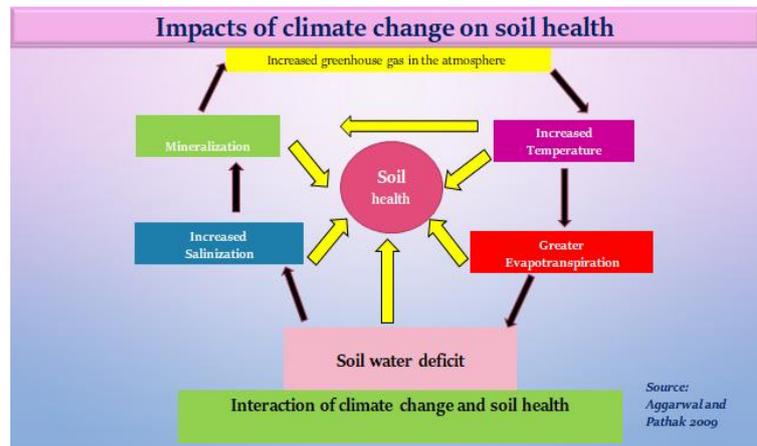


**Fig.9** Soil health

**Soil Physical Parameters:** The major physical processes in soils are related to gains, losses, transfers and movement of water, air, organic matter, soluble salts, carbonates, silicate clay minerals, sesquioxide's and silica. These gains are normally consists of addition of organic matter and of oxygen and water through oxidation and hydration, but in some sites slow continuous addition of new mineral materials take place at the surface of soluble materials are deposited from groundwater. Losses are chiefly of materials dissolved or suspended in water percolating through the profile or running off the surface along with water and through the porous soil. The physical properties and processes of soil affect soil health by altering water movement through soil, root penetration in soil and water congestion. Important soil physical properties that affect soil health due to impact of climate change are as follow.

Soil property Physical Soil texture, aggregate distribution, aggregate stability, maximum rooting depth, bulk density, penetration resistance, porosity, hydraulic conductivity, infiltration, water holding capacity, mineralogy Chemical Organic C, labile C, organic C fractions of different oxidizability, total N, mineral N, pH, electrical conductivity, available nutrient status, cation exchange capacity, potentially toxic elements, organic chemical contaminants Biological Microbial biomass C and N, potentially mineralizable N, soil respiration, metabolic quotient, respiratory quotient, enzyme activities, phospholipid fatty acid, DNA.

a. **Soil texture:** Soil texture is the relative proportion of sand, silt and clay in a soil. It has direct impact of climate change. The four potential climate scenarios (Arid, Semi-arid, Sub-humid and Humid) have great impact on important soil processes as the texture differentiation in the soil profile (Brinkman and Brammer, 1990; Scharpenseel *et al.*, 1990).



- b. **Soil structure and Aggregate Stability:** The arrangement and organization of primary and secondary particles in a soil mass is known as soil structure. It controls amount of water and air present in soil. Aggregate stability, the resistance of soil aggregates to external energy such as high intensity rainfall and cultivation is determined by soil structure as well as a range of chemical, biological properties and management practices (Dalal and Moloney, 2000; Moebius *et al.*, 2007).
- c. **Porosity:** Porosity a measure of the void spaces in a material as fraction (volume of voids to that of total volume) and pore size distribution provide the ability of soil to store root zone water and air necessary for plant growth (Reynolds *et al.*, (2002). Pore characteristics are strongly linked to soil physical quality, bulk density, micro porosity and functions of pore volume. While soil porosity and water release characteristics directly influence a range of soil indices including soil aeration capacity, plant available water capacity and relative field capacity. Since root development and soil enzyme activities are closely related soil porosity and pore size distribution. And because of future climate change scenarios (elevated CO<sub>2</sub> and temperature, variable and extreme rainfall events) may alter root development and soil biological activities. Soil porosity and pore size distribution consequently soil functions are likely to be affected in unexpected directions.
- d. **Infiltration and Plant Available Water:** The water availability for plant growth and important soil processes are governed by a range of soil properties including porosity, field capacity, lower limit of plant available water (thus excluding osmotic potential), micro pore flow and ~ 2401 ~ International Journal of Chemical Studies texture (Jarvis, 2007; Reynolds *et al.*, 2002) Plant available water capacity has been used as part of integrative soil health tests to assess management impacts. Further, more the soil available water and distribution may respond rapidly to climate change, especially to variable and high intensity rainfall or drought events and thus management strategies, could be planting of cover crops, conservation tillage and incorporation of organic matter, that maintain or even enhance water infiltration and available water in soil may help in mitigating the impact of severe rainfall and drought events or severe erosion events (Lal, 1995; Salvador Sandris *et al.*, (2008).
- e. **Bulk Density:** Bulk density is routinely assessed to characterize the state of soil compactness in response to land use and management (Hakansson and Lipiec, 2000).

Bulk density in general negatively correlated with soil organic matter (SOM) or soil organic carbon (SOC) content (Weil and Magdoff, 2004). The loss of organic carbon from increased decomposition due to elevated temperature (Davidson and Janssens, 2006).

- f. **Rooting Depth:** Changes in rooting depth is likely to affect plant available water capacity, subsoil salinity, SOC content or other properties to indicate major constraints in the soil profile (Birkas *et al.*, 2009; Dalal and Moloney, 2000).
- g. **Soil Surface:** cover Soil surface cover provides a range of important ecological functions including protection of soil surface water and nutrient retention, C fixation and in some instances N fixation and support native seed germination (Box and Bruce, 1996).
- h. **Soil Temperature:** The soil temperature regime is governed by gains and losses of sun radiation at the surface, the process of evaporation, heat conduction through the soil profile and convective transfer via the movement of gas and water (Karmakar *et al.*, 2016).

**Soil Chemical Parameters:** Soil pH Soil pH is a function of parent material, time of weathering, vegetation and climate. It is considering as important indicators of soil health. Soil pH has thus been included in integrative soil health tests to assess impacts of land use change and agricultural practices. Most soils would not be subjected to rapid pH changes resulting from drivers of climate change such as elevated temperatures, CO<sub>2</sub> fertilization, variable precipitation and atmospheric N deposition. However, these drivers of climate change will affect organic matter status, C and nutrient cycling, plant available water and hence plant productivity, which in turn will affect soil pH (Reth *et al.*, 2005).

- a. **Electrical Conductivity:** Soil electrical conductivity (EC) is a measure of salt concentration. It can inform trends in salinity, crop performance, nutrient cycling and biological activity. Along with pH it can act as a surrogate measure of soil structural decline especially in sodic soils (Arnold *et al.*, 2005). Electrical conductivity has been used as a chemical indicator to inform soil biological quality in response to crop management practices (Gil *et al.*, 2009).
- b. **Sorption and Cation Exchange Capacity:** Sorption and Cation exchange capacity (CEC) are considered important properties particularly the retention of major nutrient cations Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup> and immobilization of potentially toxic cations Al<sup>3+</sup> and Mn<sup>3+</sup>. These properties can thus be useful indicators of soil health informing of a soil's capacity to absorb nutrients as well as pesticides and chemicals, Since CEC of coarse textured soils and low-activity clay soils is attributed to that of SOM, the increasing decomposition and loss of SOM due to elevated temperatures (Davidson and Janssens, 2006).
- c. **Plant Available Nutrients:** Measurement of extractable nutrients may provide indication of a soil's capacity to support plant growth; conversely, it may identify critical or threshold values for environmental hazard assessment (Dalal and Moloney, 2000) Nutrient cycling especially N is intimately linked with soil organic carbon cycling (Weil and Magdoff, 2004).

**Soil Biological Parameters:** The soil biota is adaptive to changes in environmental circumstances. Under conditions of climate change, biological indicators form an integral

component in soil health assessment. Key biological indicators selected for the scope of this study include SOM and its constituents, soil C, respiration and soil microbial biomass.

- a. **Soil Organic Matter:** Soil organic matter comprises an extensive range of living and non-living components; SOM is one of the most complex and heterogeneous components of soils which vary in their properties, functions and turnover rates (Weil and Magdoff, 2004) [It provide and/or support including the contribution to the charge characteristics of soils, a sink for and source of C and N, and to a variable extent regulates phosphorus and sulphur cycling. It possesses ability to form complex with multivalent ions and organic compounds. It provides microbial and faunal habitat and substrates, as well as affecting aggregate stability, water retention and hydraulic properties (Haynes, 2008; Weil and Magdoff, 2004).
- b. **Potentially Mineralizable C And N:** Mineralizable organic matter acts as an interface between autotrophic and heterotrophic organisms during the nutrient cycling process (Gregorich *et al.*, 1994).
- c. **Soil Respiration:** Soil respiration is used as a biological indicator for soil health, since it is positively correlated with SOM content. Soil respiration particularly its temperature response is critical link between climate change and the global C cycle (Wixon and Balsler, 2009).
- d. **Soil Microbial Biomass:** Microbial biomass is the living component of SOM. It is considered as the most labile C pool in soils and sensitive indicator of changes in soil processes with links to soil nutrient and energy dynamics including mediating the transfer between SOC fractions (Saha and Mandal, 2009).
- e. **Soil Enzyme Activities:** may serve to indicate change within the plant-soil system, since these are closely linked to the cycling of nutrients and soil biology are easily measured, integrate information on both the microbial status and the physicochemical soil conditions, and show rapid response to changes in soil management (Garcia-Ruiz *et al.*, 2009).

### Mitigation of adverse effect of climate change on soil health

The conservation tillage and residue management help in the following ways in influencing some of the soil properties and mitigating the adverse effects of climate change on soil health (Sharma, 2011).

**Soil Temperature:** The surface residues significantly affect soil temperature by balancing radiant energy and insulation action. The radiant energy is balanced by reflection, heating of soil and air and evaporation of soil water. The reflection is more from bright residue.

**Soil Structure and Soil Aggregation:** It refers to binding together of soil particles into secondary units. Water stable aggregates help in maintaining good infiltration rate, good structure, protection from wind and water erosion. Aggregates binding substances are mineral substances and organic substances. Mulches and cover crops serve this purpose well, as do no-till practices which allow the accumulation of surface residue.

**Bulk Density and Porosity:** Bulk density and porosity are inversely related. Tillage layer density is lower in ploughed than unploughed low tillage area etc.

**Soil Crusting, Hydraulic Conductivity and Erosion:** Tillage also influences crusting, hydraulic conductivity and water storage capacity. It has been understood that the textural influences and changes in proportion of sand, silt and clay occur due to inversion and mixing caused by different tillage instruments, tillage depth, mode of operation and effect of soil erosion. Soil crusting which severely affects germination and emergence of seedling is caused due to aggregate dispersion and soil particles resorting and rearrangement during rainstorm followed by drying.

**Soil Organic Matter and Soil Fertility:** Conservation agricultural practices help in improving soil organic matter by way of (i) regular addition of organic wastes and residues, use of green manures, legumes in the rotation, reduced tillage, use of fertilizers, and supplemental irrigation( ii) drilling the seed without disturbance to soil and adding fertilizer through drill following chemical weed control and iii) maintaining surface residue, practicing reduced tillage, recycling of residues, inclusion of legumes in crop rotation.

### Soil Organic Carbon: A Key Indicator of Soil Quality

Soil organic matter exerts a major influence on soil physical, chemical and biological properties. The physical properties most commonly affected include soil bulk density, aggregate stability and moisture retention. In general, soil bulk density decreases as the SOM content increases. A significant correlation between SOM content and change in bulk density has been reported (Khaleel, *et al.*, 1981). Addition of organic amendments is known to decrease soil bulk density (Benbi *et al.*, 1998).

### Consequences of Climate Change

**Erosion:** Climate change can also exacerbate soil erosion on land. Changes in precipitation patterns, such as more intense rainfall and prolonged droughts, can strip away topsoil, making it difficult to grow crops and leading to desertification in some areas. 167-million-hectare degraded land of which 90 million ha is degraded through erosion (Fig.10).



### Adaptation and Mitigation Strategies

**Science and technology:** Basic research on soil-plant processes, Soil monitoring networks, Advanced GHGs network, Remote sensing, Spatial databases and model integration.

**Implementation:** National and international GHGs mitigation programmed, GHGs offset and ecosystem service markets, Agricultural product supply chain management Decision-support systems.

**Land use Management Practices:** The land use management practices are effective strategies for promoting sustainable agriculture and improving soil health, productivity, and environmental outcomes. Here are some common land use practices:

- a. **Improved Crop Rotations:** Crop rotation involves changing the type of crops grown in a particular field over several growing seasons. This practice helps break pest and disease cycles, reduces the risk of soil depletion, enhances soil fertility. Improved crop rotations can lead to better soil structure, reduced erosion, improved nitrogen fixation (in legumes), and increased biodiversity in the soil. It also helps to reduce reliance on synthetic fertilizers and pesticides.
- b. **Organic Amendments:** Organic amendments include natural materials such as compost, manure, cover crop residues, and other organic matter added to the soil to improve its fertility and structure, enhance soil organic matter content, promote beneficial microorganisms, improve soil moisture retention, and increase nutrient availability. They also reduce the need for chemical fertilizers and help sequester carbon in the soil.
- c. **Nutrient Management:** Nutrient management involves applying the right type, amount, and timing of nutrients (such as nitrogen, phosphorus, and potassium) to crops to optimize growth while minimizing environmental impacts (e.g., nutrient runoff into water bodies). This practice helps increase crop yields, reduce nutrient waste, lower environmental pollution, and improve the efficiency of fertilizer use, promoting both economic and ecological sustainability.
- d. **Reduced Tillage:** Reduced tillage involves minimizing the disturbance of the soil through tillage operations, which is traditionally done to prepare the soil for planting. This practice helps maintain soil structure, reduces erosion, improves water infiltration, and preserves soil organic matter. It also benefits soil microorganisms and reduces the carbon footprint by decreasing fuel consumption and soil disturbance.
- e. **Cover Crop:** Cover crops are plants grown primarily to cover and protect the soil during off-season periods when no cash crops are being cultivated. Common cover crops include legumes, grasses, and brassicas. Cover crops prevent soil erosion, improve soil structure, enhance nutrient cycling (particularly nitrogen fixation with legumes), suppress weeds, and increase organic matter in the soil. They also improve moisture retention and reduce nutrient leaching.
- f. **Agroforestry:** It involves integrating trees, shrubs, and other perennial plants into agricultural landscapes, either alongside or within crop and livestock systems. Agroforestry can improve biodiversity, provide habitat for wildlife, reduce soil erosion, increase water retention, enhance soil fertility, and diversify farm income through timber, fruit, nuts, and other products. It also helps sequester carbon, contributing to climate change mitigation.
- g. **Biochar Application:** Fine grained and porous substance similar in its appearance to charcoal produced by natural burning. It is proposed as a new form of soil carbon sequestration in which fine ground charcoal is applied to soil. Ibi (labile of bio char industries) argues that applying charcoal to soil would create a permanent carbon sink and makes soil more fertile and water retentive. These practices, when implemented together, form a holistic approach to land use management that prioritizes sustainability, environmental health, and agricultural productivity. They can improve

soil health, reduce dependence on chemical inputs, and create more resilient farming systems.

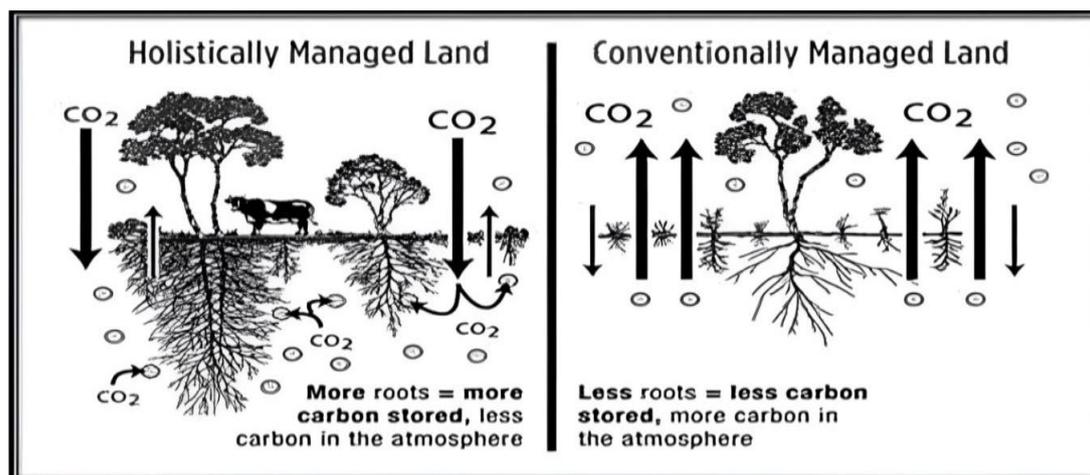


Fig. 11 Land management

### Mitigation of CH<sub>4</sub> Emission

Alternate wetting and drying soil (AWD), Growing DSR, SRI Improving organic matter management (low C:N ratio), Develop new plant type through crop breeding, deep rooted, low water req. Variety, more effective tillers and high root oxidative activity Increase crop yield instead of area expansion, application of 6-7 t/hac of gypsum reduce 50-70% emission.

### Conclusion

- Climate change is a reality and may constrain attainment of future food production targets.
- From the forgoing it is clear that climate change could impact Soil organic matter and a number of processes that are strong determinant of soil health.
- To mitigate climate change effect, it is imperative that soil health is maintained so that it can sustain physical, chemical and biological function and provide ecosystem resilience.
- Establishing climate smart soil management for cost effective, sustainable climate change mitigation and adaptation.
- The quantitative evaluation of predicted climate change effect on soil health is a difficult task due to uncertainties in weather forecast. Land degradation issues are closely related with adverse effects of climate change.

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# Nutrient Management Approaches for Climate Resilient Agriculture

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## Introduction

Climate change leads to shifts in temperature and precipitation patterns, which directly impact growing conditions. Rising temperatures can disrupt crop growth cycles, reduce yields, and alter the geographic ranges of many crops. In an El Niño year, a warming phenomenon occurs in the central and eastern equatorial Pacific region, which disrupts atmospheric circulation and alters moisture transport and rainfall distribution patterns over the Indian subcontinent. This can result in reduced rainfall and drought conditions in certain areas of India (Kakoti *et al.*, 2023). Increased frequency of extreme weather events, such as droughts, heatwaves, and floods, further complicates the ability of farmers to maintain consistent production. To meet the food needs of an anticipated 9 billion people by 2050 and counter the current decline in agricultural productivity, global food production must increase by approximately 70% (Kakoti *et al.*, 2024). However, climate change, driven primarily by human activities that release greenhouse gases into the atmosphere, presents a profound and pressing challenge. Addressing this issue will require not only boosting agricultural output but also implementing strategies to mitigate and adapt to climate impacts to ensure sustainable food security. As industrialization, deforestation, and the burning of fossil fuels continue to escalate, they increase concentrations of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and other greenhouse gases. These gases trap heat from the sun, leading to the greenhouse effect, which is causing global temperatures to rise a phenomenon known as global warming. This warming trend is altering weather patterns, intensifying the frequency and severity of extreme weather events, such as heatwaves, storms, and heavy rainfall. Consequently, ice caps and glaciers are melting, sea levels are rising, and ecosystems are being disrupted. These changes not only affect natural systems but also have far-reaching impacts on human societies, influencing agriculture, water resources, and overall environmental stability. Addressing climate change is critical to mitigating its effects and ensuring a sustainable future for the planet. Climate change is significantly impacting global food production and agriculture, creating a host of challenges that jeopardize food security and sustainability.

Nutrient management is a critical component of sustainable agriculture, as it influences crop productivity, soil health, and environmental impact. Proper management of essential plant nutrients (such as nitrogen, phosphorus, potassium, and micronutrients) is necessary to optimize crop yields, minimize nutrient losses to the environment, and maintain soil fertility. In the context of climate-resilient agriculture, nutrient management strategies must adapt to the changing climate, ensuring that nutrients are available in the right quantities at the right times, and that nutrient application does not exacerbate environmental challenges like water pollution, greenhouse gas emissions, and soil degradation. The primary goal of nutrient management for climate-resilient agriculture is to develop strategies that enhance agricultural productivity, soil health, and environmental sustainability, while minimizing vulnerability to the impacts of climate change. These strategies aim to support the adoption of

practices that improve nutrient use efficiency, increase the resilience of crops to climate stresses (such as drought, heat, and flooding), and promote long-term soil fertility.

**Role of Fertilizer in Climate Change:** Fertilizers play a significant role in climate change, both as contributors to greenhouse gas emissions and as part of potential solutions. The role of fertilizers in climate change can be understood from the following perspectives:

#### **Greenhouse Gas**

- **Nitrous Oxide (N<sub>2</sub>O) Emissions:** Fertilizers, especially nitrogen-based fertilizers like ammonium nitrate and urea, are a major source of nitrous oxide (N<sub>2</sub>O) emissions. N<sub>2</sub>O is a potent greenhouse gas, with a global warming potential 298 times greater than CO<sub>2</sub> over a 100-year period. The application of nitrogen fertilizers to soil leads to microbial processes that convert nitrogen compounds into N<sub>2</sub>O. Agricultural soils are a significant contributor to global N<sub>2</sub>O emissions. (IPCC, 2019).
- **CO<sub>2</sub> Emissions from Fertilizer Production:** The production of nitrogen fertilizers is energy-intensive, and much of this energy comes from fossil fuels, which emit CO<sub>2</sub>. The Haber-Bosch process, which synthesizes ammonia for fertilizers, is particularly energy-demanding. (Smith *et al.*, 2007), the production of nitrogen fertilizers accounts for a substantial share of agricultural CO<sub>2</sub> emissions globally.

**Soil Degradation and Reduced Carbon Sequestration:** Overuse of synthetic fertilizers can degrade soil quality over time. This reduces the soil's ability to store carbon, as healthy soils are essential for carbon sequestration. (Lal, 2004) emphasized that inappropriate fertilizer use, combined with poor soil management, can lead to a loss of organic matter and a reduced capacity to capture and store carbon in soils.

**Eutrophication and Methane Emissions:** Fertilizer runoff can lead to nutrient pollution in water bodies, causing eutrophication, which promotes the growth of algae. When these algae die and decompose, methane (CH<sub>4</sub>) is released, contributing further to climate change. (Sutton *et al.*, 2013) discuss the relationship between fertilizer use and the subsequent environmental impacts, including the release of methane from aquatic ecosystems.

**Nutrient use Efficiency (NUE):** The nutrient use efficiency is the output of any crop per unit of the nutrient applied under a specified set of soil and climatic conditions. The NUE can be expressed in several ways:

- **Partial Factor Productivity** (kg crop yield obtained per kg input applied).
- **Agronomic Efficiency** (kg crop yield increase per kg nutrient applied).
- **Apparent Recovery Efficiency** (kg nutrient taken up per kg nutrient applied).
- **Physiological Efficiency** (kg yield increase per kg nutrient taken up).
- **Crop Removal Efficiency** (removal of nutrient in harvested crop as a percent of nutrient applied).

	<b>Type</b>	<b>Description</b>
Plant factors	Genetic factor	Species/cultivar/genotype
	Physiological factor	<ul style="list-style-type: none"> <li>• Roots: Length, density of main, lateral and root hairs.</li> <li>• Higher shoot yield, harvest index.</li> <li>• Higher nutrient uptake and utilization</li> </ul>
	Biochemical factors	<ul style="list-style-type: none"> <li>• Enzymes: Nitrate reductase (NR), phosphatase (P), pyruvate kinase (K), phytic phosphate (P) etc.</li> <li>• Metallothionine (trace elements).</li> <li>• Root exudates (citrate, malic acid etc.)</li> </ul>
External factors	Fertilizers	<ul style="list-style-type: none"> <li>• Source</li> <li>• Time/method of application</li> <li>• Interaction among nutrients</li> <li>• Nutrient losses</li> </ul>
	Climate	<ul style="list-style-type: none"> <li>• Soil moisture</li> <li>• Temperature</li> </ul>
	Elements	<ul style="list-style-type: none"> <li>• Toxicities: Acidic soils (Al &amp; Mn), saline (Na, Mg, Cl, SO<sub>4</sub>) and alkaline (Na, CO<sub>3</sub>) soils.</li> <li>• Deficiencies (N, P, K and micronutrients)</li> </ul>
	Others	<ul style="list-style-type: none"> <li>• Arbuscular mycorrhizae and other soil microbes.</li> <li>• Control of weeds, insects and diseases.</li> <li>• Incorporate crop residue, cover crops and crop rotation.</li> </ul>

### **Modern Tools, Techniques and Farming Practices for Nutrient Management in Agriculture**

There are several tools, techniques and farming practices are developed in the present time for the management of nutrients. These tools and technologies can broadly categories in two groups such as: first one is indirect and second is direct nutrient management. Indirect nutrient management includes are conservation agriculture, crop diversification, organic farming etc. and direct managements includes precision agriculture and others.

## Indirect Nutrients Management

### a. Conservation agriculture (CA)

Conservation agriculture (CA) offers a highly effective approach to nutrient management in the context of climate-resilient agriculture (CRA). By focusing on practices that promote soil health, reduce erosion, enhance water retention, and optimize nutrient use efficiency, CA can significantly contribute to sustainable agriculture in the face of climate change. Below are the key ways in which CA helps in nutrient management for climate-resilient agriculture:

#### Soil Health Improvement

- **No-till/Minimal Tillage:** One of the key principles of CA is reducing tillage, which helps maintain soil structure, organic matter, and microbial activity. This creates a more resilient soil system that can store nutrients more effectively and reduce the need for external chemical fertilizers.
- **Increased Soil Organic Matter:** Through practices like crop rotation, agroforestry, and cover cropping, CA increases soil organic matter, which acts as a natural reservoir for nutrients, improving nutrient cycling and availability.
- **Enhanced Soil Fertility:** By maintaining a layer of organic mulch on the soil surface, CA reduces nutrient leaching and erosion, ensuring that nutrients are available for plant growth.

#### Improved Water Management

- **Water Conservation:** CA techniques such as mulching and reduced tillage improve water infiltration and retention, thus reducing nutrient leaching in periods of heavy rainfall and promoting more efficient use of water and nutrients in drought conditions.
- **Better Root Growth:** The practices improve soil structure, allowing plant roots to grow deeper and access nutrients more efficiently, reducing the need for external fertilizers.

#### Sustainable Fertilizer Use

- **Nutrient Cycling:** CA emphasizes nutrient cycling through the use of leguminous cover crops and green manures, which naturally fix nitrogen, a crucial nutrient for plant growth. This reduces dependency on synthetic nitrogen fertilizers, which have environmental and economic costs.
- **Integrated Fertilizer Management:** CA promotes the use of organic fertilizers (such as compost and manure) alongside judiciously applied chemical fertilizers, optimizing nutrient availability to crops while minimizing environmental impact.

#### Climate Resilience

- **Mitigating Climate Change Impacts:** By improving soil structure and organic matter, CA increases the soil's ability to store carbon, making it an effective strategy for climate change mitigation. Improved soil health also helps crops better withstand climatic stresses such as droughts, floods, and extreme temperatures, contributing to climate resilience.

- **Adaptation to Climate Variability:** The diverse crop rotations and intercropping systems promoted by CA allow for greater adaptability to changing climate conditions, which can help ensure stable nutrient availability and food security.

### Nutrient Use Efficiency

- **Reduction in Nutrient Losses:** The practices of CA, such as mulching and crop rotation, help in reducing nutrient losses from the soil through processes like erosion and volatilization, increasing the overall nutrient use efficiency. This results in better crop yields per unit of fertilizer used, promoting sustainable agriculture.

#### b. Laser Land Levelling

Laser Land Levelling is an advanced agricultural technique that involves the use of laser technology to precisely level fields, ensuring uniformity in soil elevation. This practice plays a crucial role in improving water distribution, soil fertility, and overall crop productivity, making it an effective tool for nutrient management in climate-resilient agriculture. It is the process of smoothing the land surface  $\pm 2$  cm from its average elevation by using laser equipped drag buckets to achieve precision in land levelling.



**Fig 1.** Laser Land Levelling

Laser Land Levelling ensures that fields are levelled uniformly, which allows for more even irrigation. This reduces waterlogging in lower areas and ensures that nutrients dissolved in water are evenly distributed across the field. As a result, plants receive adequate water and nutrients, improving their growth.

### Improved Water Distribution

- **Efficient Irrigation:** Laser Land Levelling ensures that fields are levelled uniformly, which allows for more even irrigation. This reduces waterlogging in lower areas and ensures that nutrients dissolved in water are evenly distributed across the field. As a result, plants receive adequate water and nutrients, improving their growth.
- **Reduced Nutrient Loss:** Proper levelling minimizes water runoff, reducing nutrient losses through surface drainage. When water is uniformly distributed, the risk of nutrient leaching, especially in areas with excess water, is reduced.

### Enhanced Nutrient Availability

- **Uniform Soil Moisture:** By ensuring that soil moisture is distributed uniformly across the field, Laser Land Levelling helps in maintaining consistent nutrient uptake by plants. Nutrients are more effectively absorbed when moisture levels are stable, reducing the likelihood of nutrient deficiencies in some areas of the field while avoiding excess nutrients in others.
- **Improved Root Growth:** Laser Land Levelling promotes a more even soil structure, allowing plant roots to penetrate deeper and access nutrients more efficiently. This is particularly important in areas where soil compaction or poor water distribution hinders root development.

## Reduction in Fertilizer Requirements

- **Optimized Fertilizer Use:** With more uniform soil conditions and water distribution, the need for excessive fertilizer applications can be reduced. In uniformly levelled fields, fertilizers are applied more effectively and are better absorbed by crops, minimizing the loss of fertilizers to runoff and volatilization.
- **Enhanced Fertilizer Use Efficiency:** By improving soil conditions, Laser Land Levelling increases the efficiency of nutrient use, reducing the need for large quantities of synthetic fertilizers. This can contribute to a more sustainable nutrient management approach, which is crucial for long-term climate resilience.

## Soil Erosion Prevention

- **Prevention of Soil Erosion:** Laser Land Levelling reduces the potential for soil erosion by preventing water from accumulating in low-lying areas, which would otherwise carry away topsoil and nutrients. By levelling fields, Laser Land Levelling ensures that water flows evenly, preventing erosion and nutrient loss.
- **Protection of Soil Fertility:** Erosion often leads to the loss of the fertile topsoil layer, which contains essential nutrients. Laser Land Levelling helps maintain soil integrity and fertility, which is critical for sustainable farming and long-term agricultural productivity.

## Climate Resilience

- **Adaptation to Climate Change:** In areas facing variable rainfall and irregular water distribution, Laser Land Levelling helps create more resilient agricultural systems by ensuring that water and nutrients are distributed more efficiently. This is especially important in regions experiencing climate change, where erratic rainfall patterns and droughts can severely affect crop production.
- **Improved Crop Yields:** The uniformity created by Laser Land Levelling results in healthier crops that can better withstand climatic extremes such as drought, floods, or extreme temperatures. Higher crop yields and better-quality produce lead to more resilient agricultural systems capable of coping with climate stress.

## Reduction in Labor and Cost

- **Lower Operational Costs:** By improving water distribution and reducing the need for excessive irrigation, Laser Land Levelling reduces the overall operational costs associated with water management and fertilizer application. This not only boosts farm profitability but also reduces the environmental footprint of farming practices.

### c. Organic Agriculture

Organic Agriculture is a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and good quality of life for all involved. (IFOAM General Assembly, 2008). The International Federation for Organic Agriculture Movement's (IFOAM, 1998) definition of Organic agriculture is based on the principle of health, principle of ecology, principle of fairness and principle of care.

**Need of Organic Agriculture:** Growing healthy food and maintenance of soil health is the first criteria. It has been estimated that by 2050, the demand of agricultural products will grow by 1.1% annually as the world's population will reach up to 9 billion (Alexandratos and Bruinsma., 2012). To meet the ever-increasing demand for food of increasing population, farmers are placing excessive pressure on natural resources with a quest to achieve enhanced crop yield. Although as an after effect of green revolution, agricultural production has increased to some extent, but it happens only at the cost of environmental and natural resources degradation (Bazuin *et al.*, 2011). Farmers are also facing different issues like greenhouse gas (GHG) emissions which causes climate change, deterioration in physical, chemical and biological soil health due to excess and imbalanced use of chemical inputs.

**Concept and Importance of Organic Cultivation:** Organic cultivation is a method of farming system, which primarily aims at cultivating the land and raising crops in such a way, as to keep the soil alive maintaining good health. Organic wastes (crop, animal and farm wastes, aquatic wastes) and other biological materials like beneficial microbes (biofertilizers) are generally used to release nutrients for crops in an eco-friendly pollution free environment. So, in simple term, it is a scientific approach, which encourages a shift from intensive use of chemical inputs (inorganic fertilizers, pesticides) to optimize the use of manures-composts, bio-pesticides or beneficial microorganisms and indigenous technologies in agricultural production system. Organic cultivation is far ahead as compared to conventional crop management practices in several ways, such as:

- Maintains long-term soil fertility and genetic diversity of crop production system.
- Positively influences soil carbon and organic matter (OM) status, which in turn directly influence soil physical, chemical, and biological functions more favourably to achieve sustainable food security goal;
- Improves soil physical properties (soil aggregate formation, good tilth, good aeration, easy root penetration and water-holding capacity) and reduces erosion;
- Influences supply and retention of soil nutrients as well as reduces nutrient loss to environment;
- Enhances soil flora-fauna and microorganisms and their associated biological processes;
- Maintains environmental health and quality by minimizing all forms of pollutions;
- Reduces human and animal health hazards by minimizing the bio-accumulation of heavy metals
- Creates harmonious balance between crop production and animal husbandry.

#### **d. Crop Diversification**

Crop Diversification is an agricultural practice that involves growing a variety of crops in the same field or across different fields within a farming system. It is an essential strategy in sustainable farming, helping to improve soil health, enhance biodiversity, reduce risks related to pests and diseases, and improve farm profitability. Diversifying crops allows farmers to take advantage of different market opportunities, reduce the environmental impact of monocropping, and increase resilience to climate change. Here are several definitions highlighting different aspects of crop diversification:

- In agriculture, crop diversification essentially refers to a shift from one crop to another. But in real sense, it is bringing out a desirable change in the existing cropping pattern towards more balanced cropping system to meet ever-increasing demand of food.
- Based on the situations, farmers can adopt intercropping and mixed cropping.
- In climate change scenario, climate smart cropping by altering sowing dates, growing climate resilient varieties can give sustained yield.



**Fig 2.** Crop Diversification

## Direct Nutrients Management

### Precision Agriculture

Precision agriculture is also referred to as site-specific farming or satellite farming. This concept of farming management based on observing, responding to inter and intra- field variability in crops. It is an approach in which inputs are utilised in a precise manner to get increased average yields compared to our traditional practices. Hence it is a very comprehensive system designed to optimize production by using key elements of information, technology and management, to increase production efficiency, improve product quality, enhance the effectiveness of the crop (Shibusawa S. 2002).

#### a. Equipment and Tools Required in Precision Farming

The successful achievement of precision agriculture depends on number factors such as the extent to which the adequacy of input recommendation and the degree of application control. The enabling technologies used in precision agriculture can be grouped in to major categories: Global Positioning System (GPS), Geographic Information System (GIS) and Remote Sensing (RS). Precision agriculture technology makes combination of application of different technologies and all these combinations are mutually inter related and dependable for developments of precision agriculture which are discussed below:

- Global Positioning System (GPS):** GPS makes use of a series of satellites that recognize the location of farm equipment within a meter of an actual site in the field. GPS receiver provides uninterrupted position information in real time while in motion. The precise location information allows soil and crop management to be mapped at any time. The data can be obtained with GPS receiver either carried to the field or ascended on apparatus allowing users to return to specific locations to treat those areas. GPS receiver with electronic yield monitors usually applied to collect yield data across the land accurately (Fig 3). Farm uses include: mapping yields (GPS + combine yield monitor), variable rate planting (GPS + variable rate planting system), variable rate lime and fertilizer application (GPS + variable rate controller). e.g. Locations of soil samples and the laboratory results can be compared to a soil map; irrigation, fertilizers and pesticides can be prescribed to fit soil properties and soil conditions.

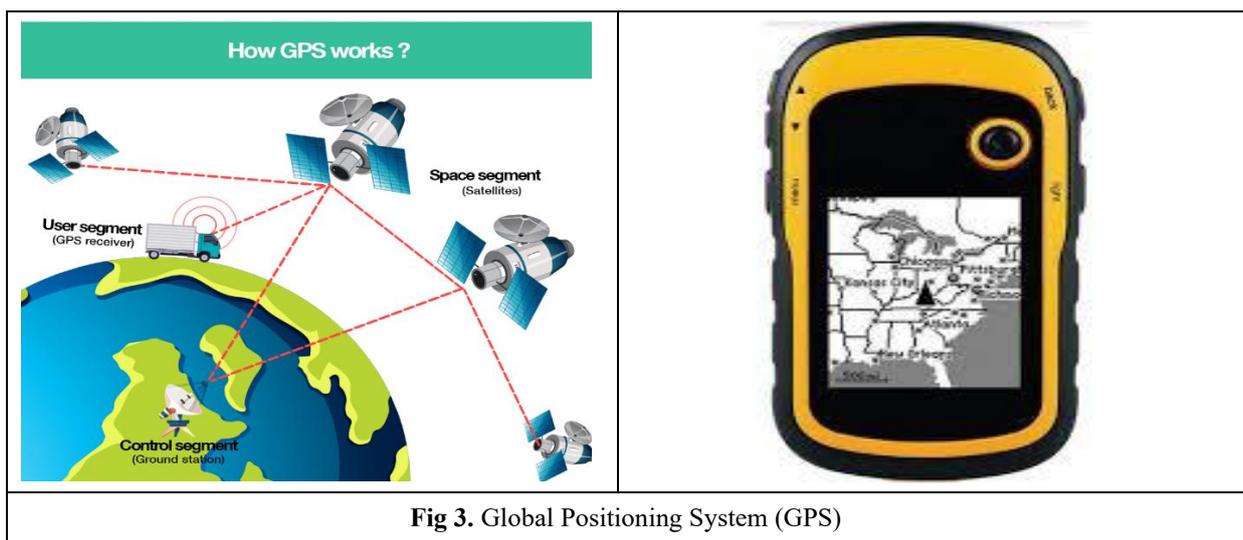


Fig 3. Global Positioning System (GPS)

- Geographic Information System (GIS):** GIS is software that imports, exports and processes spatially and temporally geographically distributed data. GIS systems give farmers a possibility to aggregate data in a visually-rich way.

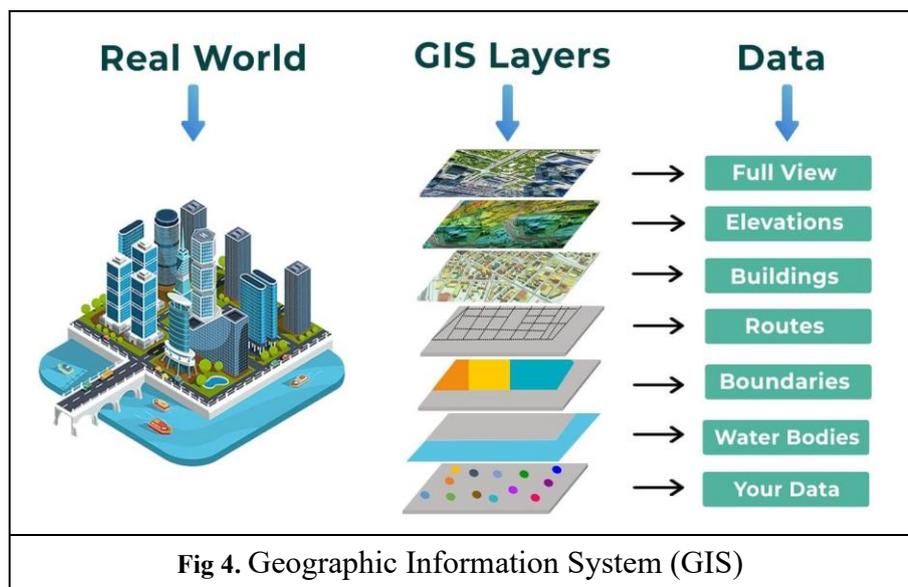
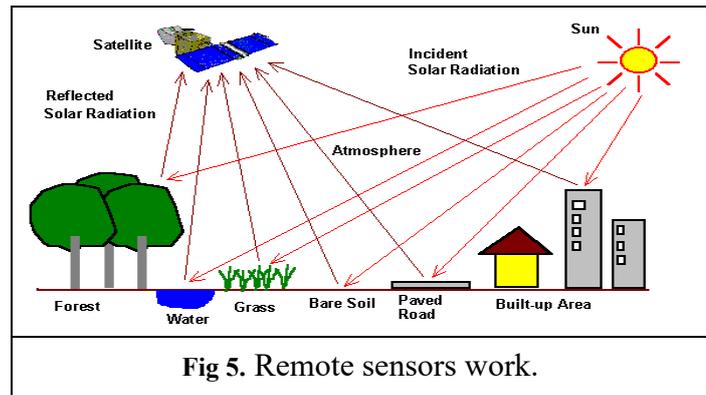


Fig 4. Geographic Information System (GIS)

By generating custom color-coded maps, the tool gives a full view on soil condition, crop fertility, insects or disease pressure (Fig 4).

- **Remote Sensors (RS):** Remote sensors are generally categories of aerial or satellite sensors. They can indicate variations in the colours of the field that corresponds to changes in soil type, crop development, field boundaries, roads, water, etc. aerial and satellite imagery can be processed to provide vegetative indices, which reflect the health of the crop plants (Fig 5).



### b. Need of Precision Farming

The status of Indian environment shows that, in India, about 182 Mha from the total geographical area of 328 Mha is affected by land degradation out of this 141.33 million ha are due to water erosion, 11.50 Mha due to wind erosion and 12.63 and 13.24 Mha are due to waterlogging and chemical deterioration (salinization and loss of nutrients) respectively. So, there is a need in high productivity of each crop, so there is a need for precision farming in today's era. The global food system faces unavoidable challenges that will increase over the next 40 years. Much can be achieved immediately with current technologies and knowledge, given sufficient that will increase in the total productivity (Abdul *et al.*, 2016).

### c. Fertigation

It is the most efficient method of fertilizer application, as it ensures uniform application of the water and fertilizers directly to the plant roots as per crop demand. Since both water and nutrients reaches directly to the rooting zone, it has tremendous effect on resource saving (Fig 6.). Drip fertigation is a good management technique that satisfies the nutrient demand of crops grown on sandy soils and split application of nutrients during the growth season to improve and sustain higher yields.



**Fig 6. Drip Fertigation**

<b>Table 2. Suitable fertilizers used for fertigation</b>	
<b>Nutrients</b>	<b>Fertilizers</b>
N	Urea, Ammonium sulphate, Urea ammonium nitrate (Liquid), Ammonium nitrate
N&P	Mono ammonium phosphate, Urea phosphate
P	Phosphoric acid
P&K	Mono potassium phosphate
K	Potassium chloride, Sulphate of potash, Potassium nitrate, Potassium thiosulphate
Mg & Ca	Magnesium nitrate, Calcium nitrate
(Shukla <i>et al.</i> , 2018)	

### **Advantages of Fertigation**

- The availability of the nutrient is high due to maintenance of soil moisture near root zone under drip irrigation.
- Chances of loss of nutrients through leaching are minimum and are around 10% as compared to 40-55% in the traditional system, which further help in minimizing environmental pollution. It also reduces soil erosion.
- There is about 25-50% reduction in the quantity of fertilizer that leads to higher fertilizer use efficiency.
- Timely as well as precise application of fertilizers directly to the roots zone improves fertilizer use efficiency and reduces nutrient leaching below the root zone.
- Fertigation reduces the cost of labour and saves energy in the application of fertilizers.
- It is a comparatively safer application method, as it eliminates the danger affecting roots due to higher dose.

#### **d. Site-Specific Nutrient Management (SSNM)**

SSNM has been proposed as an approach to tailor fertilizer application to match the field specific needs of crops and to improve the productivity and profitability. Simply it means "feeding of plant as and when needed". This could be done by utilizing available information on indigenous nutrient supplying capacity, nutrient contributions from organic manures, irrigation water, rainfall and crop residue pools and finally crop nutrient demand for targeted yield of crops/cropping systems. Site-specific nutrient management is a component of precision agriculture and can be used for any crop or field. It combines plant nutrient requirements at each growth stage and the soil ability to supply those nutrients and apply that information to areas within a field that requires different management practices. SSNM provides guidance relevant to the context of farmer's fields. SSNM maintains or enhances crop yields, while providing savings for farmers through more efficient fertilizer use (Das *et al.*, 2014).

## Key messages of SSNM

- Site-Specific Nutrient Management (SSNM) optimizes the supply of soil nutrients over space and time to match crop requirements.
- SSNM increases crop productivity and improves efficiency of fertilizer use (Rao *et al.*, 2014).
- SSNM mitigates greenhouse gases emission from agriculture by minimizing fertilizer over use. Greenhouse gas emission can be reduced, in some cases up to 50% (Gill *et al.*, 2008).

**Basic concept of SSNM:** The relatively new approach of nutrient recommendations is mainly based on the indigenous nutrient supply from the soil and nutrient demand of the crop for achieving targeted yield. The SSNM recommendations could be evolved on the basis of solely plant analysis or soil cum plant analysis.

## Principles of site-specific nutrient management (SSNM)

Site-Specific Nutrient Management (SSNM) strives to effectively manage soil nutrient supply across different periods and locations to align with crop needs. This approach is guided by four fundamental principles, commonly referred to as the "4 Rs", which have been recognized since at least 1988 and are credited to the International Plant Nutrition Institute. They are as follows:

**Right product:** Selecting the appropriate fertilizer product or nutrient source tailored to crop and soil requirements ensures a balanced supply of nutrients.

**Right rate:** Adjusting the amount of fertilizer applied to match crop nutrient needs while considering existing soil nutrient levels is crucial. Excessive fertilizer can lead to environmental losses like runoff, leaching, and emissions, as well as unnecessary costs, while insufficient fertilizer can deplete soils and cause degradation.

**Right time:** Timing nutrient applications to coincide with crop nutrient demands ensures effective utilization. This may involve staggered applications of mineral fertilizers or integrating organic and mineral sources for sustained nutrient release.

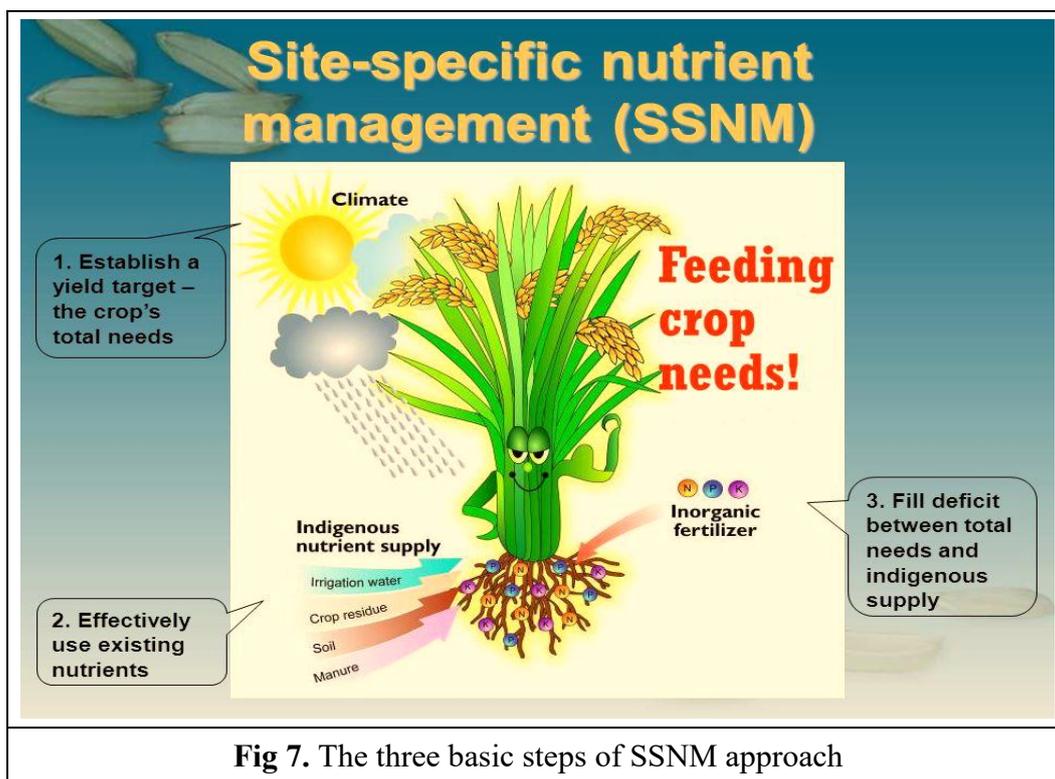
**Right place:** Placing nutrients at optimal distances from crops and within the right soil depth enhances nutrient uptake and minimizes losses. Incorporating nutrients into the soil is generally preferable to surface application, with the method chosen based on soil characteristics, crop type, tillage practices, and fertilizer type.

## Important Features of SSNM

**Step 1. Establish a grain yield target:** Select a yield attainable in a typical season with farmer's crop management and improved nutrient management. It is location and season specific (depending on climate, cultivar and crop management).

**Step 2. Effectively use existing nutrients:** Estimate the supply of existing (indigenous) nutrients from sources other than fertilizers. Use nutrient omission plot technique, fertilizer use history, soil type and residue and crop management to estimate indigenous nutrient supply.

**Step 3. Apply fertilizer to fill the deficit between crop needs and indigenous supply:** Distribute the required fertilizer N in several applications during the growing season to best feed the crop needs for supplemental N. Apply sufficient P and K to overcome deficiencies and maintain soil fertility (Fig 7).



### SSNM Can be

- **Prescriptive N management:** Relies on information generated before the planting of a crop.
- **Corrective N management:** Relies on information generated after the planting of a crop or in the standing crop. E.g. Use of Leaf Colour Chart (LCC) and Chlorophyll Meter (SPAD), Remote Sensing & GIS, Green Seeker, Decision support systems and Nanoparticles.

### Real time 'N' management

It refers to the use of advanced technologies, data, and adaptive strategies to optimize nitrogen application in agricultural systems. Under climate change, effective nitrogen management is critical for improving crop yields, reducing greenhouse gas emissions, and preventing nitrogen loss to the environment. As climate change impacts agricultural productivity and environmental sustainability, managing nitrogen efficiently in real time becomes even more essential. Modern tools like SPAD meter or Chlorophyll meter, Leaf colour chart can be used by the farmers to easily identify leaf N status and apply input accordingly.

- **Soil Plant Analytical Device (SPAD)**

It was originally developed in Japan for nitrogen management in rice (*Oryza sativa*) is now commonly used for rapid and non-destructive estimation of foliar chlorophyll concentration. SPAD meter/Chlorophyll meters are reliable alternatives to traditional tissue analysis as plant N nutritional diagnostic tools. Most widely used chlorophyll meter is the



**Fig. 8** SPAD meter

hand-held Minolta and SPAD-502 (Fig. 8) (Singh *et al.*, 2010). It uses two LEDs (light emitting diodes) which emit red light with a peak wavelength of 650 nm and an infrared radiation with a peak wavelength of 940 nm Hussain *et al.*, (2000). The SPAD meter readings are doesn't have unit and need to be calibrated with chlorophyll or N content and leaf greenness. In the field trials, use of 35 critical SPAD reading resulted in similar yields with less N fertilizer applied (higher agronomic efficiency) compared to fixed split timing schemes or recommended splits (Peng *et al.*, 1996). In South India too, SPAD value of 35 was found to be the appropriate threshold value for guiding need-based N management in transplanted rice. (Hussain *et al.*, 2003). Chlorophyll meter-based N management saved 12.5–25% on the existing fertilizer N recommendation (Singh *et al.*, 2002).

- **Leaf Colour Chart (LCC):**

LCC is a high-quality plastic strip with different shades of green colour ranging from light yellowish green to dark green (Fig. 9). First LCC was developed in Japan. An improved version of six-panel LCC (IRRI-LCC, six-panel) was developed through collaboration of the International Rice Research Institute (IRRI) with agricultural research systems of several countries in Asia IRRI. (Knowledge bank.,2020). Chinese researchers at Zhejiang

Agricultural University developed a LCC (ZAU-LCC) with scale of eight green colour shades (3, 4, 5, 5.5, 6, 6.5, 7 and 8) and it was calibrated for Indica, Japonica and Hybrid rice (Yang *et al.*, 2003).



**Fig. 9** Leaf Colour Chart (LCC)

The leaf colour chart is an innovative cost-effective tool for real-time or crop-need based N management in Rice, Maize and Wheat. LCC is a visual and subjective indicator of plant nitrogen deficiency and is an inexpensive, easy to use and simple alternative to chlorophyll meter/SPAD meter. In this, scheduling of nitrogen fertilizer is done by comparing the leaf colour with panel colour. Thus, it is an eco-friendly tool in the hands of farmers.

- **Remote sensing and GIS**

An improvement in the NUE can be achieved by using modern tools like remote sensing and GIS (geographical information system). The reflectance of near infrared radiation (NIR; 800– 1000 nm) can be measured using remote sensing tools. This reflectance is correlated with plant N status, as shown by the greenness of the leaves (Gill *et al.*,2008). Normalized difference vegetative index (NDVI) based on the in-season sensor reading can predict biomass, plant N concentration and plant N uptake. The NDVI calculates as:  $(F_{NIR} - F_{Red}) / (F_{NIR} + F_{Red})$ , where  $F_{NIR}$  and  $F_{Red}$  are spectral reflectance in near infrared and red (visible) regions, respectively. The NDVI increases with increasing leaf greenness and green leaf area, and can be used as a guide for in-season N applications. Extensive research work through on-farm trials in the Indo-Gangetic Plains (IGP) has clearly demonstrated that these modern tools are effective for site-specific input management (Gill *et al.*, 2008).

- **Green seeker**

Chlorophyll meter and LCC do not take into account the photosynthetic rates or biomass production and the expected yields for working out fertilizer N requirements. Green seeker optical sensors measure spectral response from plant canopies to detect the N stress (Gupta *et al.*, 2006). The use of green seeker, which is also a hand-held instrument (Fig. 10) for measuring the NDVI at various critical growth stages, generates data for crop conditions (Singh *et al.*, 2006). These NDVI data from a standard plot, which has been sufficiently fertilized with N, can be compared with a reference plot for which the N requirement is to be determined. The use of green seeker helps in applying adequate N at specific crop growth stages in various management zones. Experiment clearly showed that optical sensor guided fertilizer N applications resulted in high yield levels and high N use efficiency (Gupta *et al.*, 2011).



**Fig. 10** Green Seeker

- **Decision Support Systems**

Decision support systems have taken various forms and differ in their level of sophistication (Kitchen NR, Goulding KWT 2001). Decision support systems are sophisticated tools, often being driven by computer-simulation models, but usually deal with a single element such as N. The CROPGRO-legume model can simulate N fixation in legumes and its relationship with N uptake by plants (Boote *et al.*, 2009). Nutrient Expert® (NE) is an easy-to-use, interactive, and computer-based decision support tool that can rapidly provide nutrient recommendations for an individual farmer field in the presence or absence of soil testing data (Das *et al.*, 2014). Crop Manager is also a computer- and mobile phone-based application that provides small-scale rice, rice-wheat, and maize farmers with site- and season-specific recommendations for fertilizer application. The tool allows farmers to adjust nutrient application to crop needs based on soil characteristics, water management and crop variety on their farm. Recommendations are based on user-input information about farm location and management, which can be collected by extension workers, crop advisors and service providers. The software is freely downloadable at <http://cropmanager.irri.org/home> (Richards *et al.*, 2015).

- **Soil Test Crop Response (STCR)**

The Soil Test Crop Response (STCR) approach is a fertilizer recommendation system that uses soil test results, crop response data, and other agronomic factors to recommend the optimal amount of fertilizer required to maximize crop yield. This approach considers the nutrient status of the soil and the crop's nutrient needs, aiming to minimize fertilizer usage while maximizing crop productivity. It is particularly useful for maintaining soil fertility and optimizing fertilizer use in a scientifically backed manner. The equations used to recommend fertilizers for STCR approach was developed by All India Coordinated research Project (AICRP) on Soil test Crop response (STCR), Bangalore were used in the study and are as follows (Anonymous., 2007).

$$FN = 3.45 T - 0.093 SN. (KMnO_4 - N)$$

$$FP_2O_5 = 2.00 T - 0.31 S P_2O_5. (Olsen's - P_2O_5)$$

$$FK_2O = 1.04 T - 0.046 SK_2O. (NH_4 OAC - K_2O)$$

Where,

**T:** Targeted yield 80 and 100 q ha<sup>-1</sup> **FN:** Nitrogen supplied through fertilizer (kg ha<sup>-1</sup>), **FP<sub>2</sub>O<sub>5</sub>:** Phosphorus supplied through fertilizer (kg ha<sup>-1</sup>), **FK<sub>2</sub>O:** Potassium supplied through fertilizer (kg ha<sup>-1</sup>), **SN, S P<sub>2</sub>O<sub>5</sub>** and **SK<sub>2</sub>O** are initial soil test value for available N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O, kg ha<sup>-1</sup>, respectively.

**Nano fertilizers:** Nano fertilizers are a new class of fertilizers that utilize nanotechnology to enhance the delivery and efficiency of essential nutrients to plants. By incorporating nanoparticles, nano fertilizers aim to optimize nutrient uptake, reduce environmental losses, and improve crop yields, especially in the context of climate change. As climate change brings challenges such as erratic rainfall, extreme temperatures, and nutrient depletion, nano fertilizers have the potential to play a significant role in increasing agricultural productivity while minimizing environmental impacts. Nano fertilizers are fertilizers engineered at the **nanometer scale** (1-100 nanometers). They contain essential nutrients such as nitrogen (N),

phosphorus (P), potassium (K), micronutrients, or bioactive agents that are encapsulated or coated in nanoparticles. These nanoparticles can improve the release, absorption, and stability of fertilizers, which results in better nutrient utilization by plants. There are various forms of nano fertilizers, including:

- **Nanoscale Nutrient Particles:** Nutrient particles that are smaller than conventional fertilizer particles.
- **Nano capsules or Nanocomposites:** Nutrients are enclosed in nanoparticles or combined with nanomaterials to control the release.
- **Nanocarriers:** Nanomaterials designed to transport and deliver nutrients to plants more efficiently.

### **Benefits of Nano Fertilizers in the Context of Climate Change**

- **Precision Delivery:** Nano fertilizers provide nutrients in a controlled and efficient manner, which helps plants absorb the nutrients more effectively. This is particularly important as nutrient availability may fluctuate under changing climate conditions (e.g., higher temperatures, drought).
- **Reduced Losses:** Traditional fertilizers often result in nutrient runoff, volatilization, or leaching, especially during heavy rains or floods. Nano fertilizers are designed to release nutrients slowly, which minimizes such losses. This efficiency is particularly important as climate change is expected to lead to more intense rainfall and flooding events.
- **Drought Resistance:** Nano fertilizers can help plants cope with drought stress by improving water retention in the soil and enhancing nutrient uptake. By using controlled-release mechanisms, nano fertilizers ensure that plants receive nutrients during dry periods, enhancing their ability to tolerate water scarcity.
- **Heat Stress Mitigation:** Climate change is expected to cause more frequent heatwaves. Nano fertilizers can help plants manage heat stress by providing essential nutrients during periods of high temperature, thus promoting better plant growth and improving crop yields even under extreme heat conditions.
- **Soil Fertility Enhancement:** Nano fertilizers can improve soil fertility by promoting beneficial microbial activity. Certain nanoparticles, such as nano-silica or nano-carbon, can help enhance soil structure and microbial biodiversity. Healthy soils are critical for maintaining productivity in the face of climate variability.
- **Reduced Environmental Pollution:** Since nano fertilizers offer controlled nutrient release and reduce nutrient leaching, they can help mitigate the pollution of groundwater and surface water systems, which is particularly important as climate change exacerbates nutrient runoff problems.
- **Higher Nutrient Uptake:** The efficiency of nano fertilizers allows crops to access more nutrients, resulting in improved plant growth and productivity. This is especially critical in regions where climate change is predicted to reduce arable land or shift growing seasons.
- **Improved Plant Growth:** By providing nutrients in a more bioavailable form, nano fertilizers support better plant growth and resilience, leading to higher yields. This could

be crucial in regions where food security is threatened by climate-related challenges such as drought or flooding.

- **Lower Fertilizer Input:** Nano fertilizers reduce the need for excessive fertilizer application. Since nutrients are more efficiently absorbed by plants, farmers can use smaller amounts of fertilizers while still achieving the same or even better crop yields, which reduces the environmental footprint of agriculture. This is especially important in the context of climate change, where minimizing environmental impacts is critical for maintaining ecosystem health.
- **Reduced Greenhouse Gas Emissions:** By improving nitrogen use efficiency, nano fertilizers help reduce nitrous oxide (N<sub>2</sub>O) emissions, a potent greenhouse gas associated with conventional fertilizer use. Nitrous oxide emissions often increase with excessive fertilizer application, which is a concern in a changing climate.

## Conclusion

India, a tropical country, is facing climate change impacts through droughts, floods, cyclones, heat waves, hailstorms and coastal salinity which have become threats to sustainable development in nutrient management. To manage nutrients sustainably in the context of climate change, farmers can adopt a range of practices that promote soil health, conserve water and reduce nutrient losses effectively. In such scenario, an integration of modern tools and techniques like conservation agriculture, crop diversification strategies, precision farming should be adopted to enhance nutrient use efficiency and to conserve valuable resources for the future generations.

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# Climate Smart Water Conservation Technologies for Enhancing Productivity of Rice-Wheat Cropping System

Himanshu, Amit Kumar, Saurabh Upadhyay and Aniket H. Kalhapure

## Introduction

India accounts for 4% of freshwater resources, 2.4% of the world's land area, and 17% of the world's population. From 3000 m<sup>3</sup>/capita/year in 1951 to 1458 m<sup>3</sup>/capita/year today, India's water supply has drastically decreased. In South Asia, surface water and groundwater account for 60% and 40% of the region's agricultural water use, which surpasses 90%. The agricultural environment is further strained by outdated irrigation techniques and the effects of climate change. Irrigation covers only 48.9% of India's net cultivated land, or 68.5 Mha out of 140 Mha. Furthermore, the irrigation efficiency is low, at approximately 35–40%. The necessity for precision water management systems is highlighted by the fact that 90–98% of all water use is attributed to agriculture. Food security depends on India, which produces 31% of the world's rice and 20% of its wheat. Irrigated agriculture accounts for 55% of India's total food production. 63% of all irrigated land is supported by groundwater, although irrigation frequently depends on subsidies, which causes overexploitation and a decline in the water table. In India, poor irrigation efficiency is caused by free water and inadequate irrigation techniques. Food security is under risk due to the need for reallocation brought on by the rising demand for food in areas with limited water supplies. Climate-smart irrigation techniques can help with these problems. Climate-smart irrigation practices are adaptive and sustainable methods of managing agricultural water resources that take climate change into account. These methods seek to reduce environmental impact, increase resilience to climate-related difficulties, and improve water use efficiency. To solve the problems of water shortage and maximize the efficiency of water usage in agricultural activities, it is crucial to comprehend and apply the right irrigation technology. In the face of shifting climatic patterns and growing water scarcity, climate-smart irrigation uses technologies like precision irrigation, soil moisture monitoring, and better irrigation scheduling to maximize water resources, minimize water waste, and guarantee the sustainable production of crops. About 8% of the world's population depends on rice and wheat as their primary grain source, making these systems vital to the world's food security (Ladha *et al.*, 2003; Timsna and Conor 2001). More than 30% of the rice and 42% of the wheat consumed in South Asia are produced by rice-wheat systems, which span over 13.5 million hectares of arable land (Dhanda, 2022), the majority of which is in India 10.5Mha ( Sarkar, 2015), and the IGP. The rice-wheat farming system in northwest India was made possible by the green revolution. However, existing crop growing methods in rice-wheat systems eventually deteriorate the soil and water resources, endangering the system's viability. Food security is therefore still a problem for the future.

## “Water Saving” in Rice-Wheat Cropping Systems

Depending on the individual, "water saving" might signify several things. Although the amount of water saved might vary greatly depending on the temporal and spatial scales of interest, real water saving happens when losses that cannot be retrieved are minimized or avoided (Seckler 1996; Loeve *et al.*, 2002). Notwithstanding this intricacy, the ultimate goals of "water saving" are unmistakable: to reduce the excessive and unsustainable use of surface and groundwater resources and to expand the amount of water available for non-agricultural uses (such as urban, environmental, and recreational). Therefore, water conservation in Rice-wheat systems aims to increase productivity while utilizing less water than is already being used. Using less irrigation water to cultivate a crop-ideally with the same or higher yield (or eventually profit) is what a farmer often means by "water saving" (g grain/kg irrigation water or \$/kg irrigation water). Saving irrigation water for a single crop in a field does not always translate into a long-term net irrigation or water savings. For instance, it might be feasible to use less irrigation in a field and still maintain production by making a crop like wheat use more of the soil water that has been stored. With no net irrigation or overall water savings over the cropping system, this could also imply that more irrigation water is needed to replenish the soil profile for the following crop. Therefore, it's crucial to take the cropping system as a whole into account when assessing water-saving techniques rather than just specific crops. Scale concerns are also quite significant (Molden 1997).

## Increasing Water Productivity in Rice-Wheat Fields

Reducing water use and/or raising yield are two ways to boost water productivity. Over the past three decades, Rice-wheat systems in Asia and Australia have seen significant increases in irrigation and overall water productivity. This is primarily because improved varieties and management of water, nutrients, weeds, pests, and diseases have led to higher yields of both rice and wheat (Hobbs and Gupta 2000). Techniques like laser land levelling, decreased tillage, raised beds, enhanced germplasm, site-specific nutrient management, stubble mulching, and integrated pest management have the potential to significantly boost yield and, consequently, water productivity of RW systems of the IGP (RWC-CIMMYT 2003). With the help of precision agriculture, improved rice establishment, soil and water management, and improved varieties-particularly those with greater cold tolerance and wheat chosen for irrigation-will continue to boost yields in Australia (Humphreys *et al.*, 2003). Go on to address the necessity to handle the intricate relationships between water management and nutrients, weeds, and environmental implications, as well as solutions for boosting water productivity in irrigated rice.

## State Wise Area Under Rice-Wheat Cropping System

State	Area (Mha)
Utter Pradesh & Uttarakhand	4.52
Bihar & Jharkhand	1.93
Punjab	1.61

MP & Chhattisgarh	1.06
Haryana	0.46
West Bengal	0.27
Jammu& Kashmir	0.22
Assam	0.18
Himanchal Pradesh	0.09
Odissa and Andhra Pradesh	0.04
Total	>10.5
Tiwari <i>et al.</i> , (2022)	

### Water Requirement of Rice-Wheat System

The All India Coordinated Research Project on Water Management has examined the need for irrigation for wheat at several sites in the Indo-Gangetic plains. It has been noted that the amount of water needed for irrigation varies from 180 mm in the plains of Bihar to 360 mm in Haryana. According to estimates, the total amount of water needed for wheat varies from 238 mm in Bihar to 400 mm in Punjab. According to estimates, rice needs between 1144 mm of water in the plains of Bihar and 1560 mm in Haryana. For the rice-wheat system, a total of 1382 mm to 1838 mm of water is needed at various points on the Indo-Gangetic plains.

### How is Water Being Exported Through Argo- Export

Despite the epidemic, India's Agri-exports increased by 17.34%, permanently depleting the nation's supply of irrigation water. Over the past 50 years, the amount of water available per capita has steadily decreased by 60%. Maintaining agricultural exports such as rice (17.7 million tons) and sugarcane (7.5 million tons) is equivalent to exporting 50.4 billion cubic meters of water. Hidden water present in the various product, such as crops, livestock machinery etc. since all these products require water inevitably for their production. thus, along with the commodity, water is also exported. *According to NITI Aayog*, India exported more than 10 trillion liters of embedded or virtual water through the export of nearly 37 lakh tones of basmati rice in 2014-15 alone.

### Problem of Water Use Efficiency

It's possible that our farmers are unaware of the value of water and its requirements. Many farmers still use the same techniques as their forebears to irrigate their crops. This is generating a great deal of garbage. There are water shortages in some places because farmers are unable to use water efficiently in a number of industries besides agriculture. Some regions lack current technologies that allow farmers to maximize water use efficiency, such as sprinkler irrigation systems, drip irrigation systems, zero tillage techniques etc. Many locations have water quality problems; the water is extremely saline, which lowers

production in particular and makes the soil unusable for crop cultivation in a few years. A lot of water is being used since we don't concentrate on WUE, don't work on any other projects related to it, and don't conduct any research on it. Water use efficiency is also being disrupted by climate change. Farmers find it challenging to manage and are unable to water as well as they should because there are years when there is more rain than anticipated and years when there is less. Farmers are unable to fulfil the water consumption efficiency of their crops at will in certain locations due to fragmented ownership that controls the quantity of water that can be provided to people for their crops. Water use efficiency is also being disrupted by climate change.

## **Methods for Improving the Water Use Efficiency**

When paired with on-farm water-harvesting techniques like mixed cropping system or irrigation scheduling and farmers' use of limited resources. Several strategies for improving water productivity and use-efficiency in agricultural production systems are covered here.

### **a. Avoid Over-Irrigation**

Excessive watering of crops wastes water, fertilizer, and soil. Water and mobile nutrients are kept in the root zone where they can be used by plants with the help of frequent, light irrigations. By doing this, soil erosion and irrigation water waste can be prevented. 70% of the world's water is used for irrigation. Much of this is wasted due to irrigation systems watering plants and crops when they don't need it. This can occur in many ways, one being if your sprinklers are on a timer and water your yard after it rains.

### **b. Choose Crops and Cropping Systems According to The Water Supplies That Are Available**

Water availability should be taken into consideration while choosing crops for a given Agro-ecosystem. Aerobic rice cultivars are being produced to use less water as the monsoon varies and the problem of water scarcity continues. The success of conservation agriculture lies on a proper and good crop rotation plan. Different plant species or even varieties have different needs for nutrients, light, water, temperature and air. When one of these basic needs is not met, the plant will be stressed and will not grow properly. Selecting crop rotation varieties is therefore a very important exercise that a farmer needs to undertake (INFONET-BIOVISION 2010). The crop water need (ET crop) is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally. The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and with favourable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment. Crops like rice or sugarcane need more water than crops like millet or sorghum (FAO, 1986).

### **c. Mixed Cropping System**

Mixed cropping is an efficient resource utilization technique through synergistic interactions of biological components; regulate natural entities, reducing the risk of stress, and crop failure under adverse climate. While choosing component crops for mixed cropping,

it must be taken into account that both crops should belong to a different family in rooting and growing behaviour, peak nutrient and water demand, host specificity for pests, different rooting depth, less competitive, shade tolerances, and better leaf orientation (Seran and Brintha, 2010; Meena and Lal, 2018).

**d. Scheduling Irrigation According to Soil Water Content, Soil Water Tension, or Evapotranspiration (ET)**

Crops have different seasonal patterns of water consumption. The soil's ability to retain water, the crops' ability to absorb it, and the ET rate all affect when it best to irrigate a given field. Determining the field soils' water-holding capacity aids in scheduling re-irrigation. A sandy loam soil needs to be irrigated more frequently with less water per irrigation since it cannot retain as much water as a silt loam. Extra water seeps deep into the ground and is lost to runoff. The soil's moisture content can be ascertained with the aid of a tensiometer and moisture meter. When combined with ET charts, these tools offer a reasonably accurate assessment of irrigation requirements.

**e. At Critical Growth Stages, Use Full Irrigation; At other Stages, Use Deficit Irrigation**

Irrigation that uses less water than the crop need is known as deficit irrigation. Crop water productivity rises dramatically under deficit irrigation at non-critical stages, with just a slight yield loss as a result of lower irrigation water input. With deep-rooted crops like wheat and corn, which have minimal test weight and yield loss, deficit irrigation is very effective. Determine how well each crop can withstand drought stress and adjust irrigation accordingly.

**f. Use Conservation Tillage**

Soil moisture conservation basically necessitates the use of contemporary farming techniques such conservation tillage, minimum tillage, no till, and strip till. Crop residue from the preceding crop is at least partially kept on the soil surface and tillage operation is decreased under these practices. Crop wastes are retained, which cools the soil and lessens water loss to the atmosphere. Reducing tillage helps preserve soil water, while increasing tillage exposes the soil to drying. Only cultivate inside the row zone while using strip tillage; do not harm the inter-row zone. After planting, this typically leaves at least 30% of the prior crop residue on the ground. The inter-row zone's soil infiltration ability is enhanced, enabling water to reach its intended location.

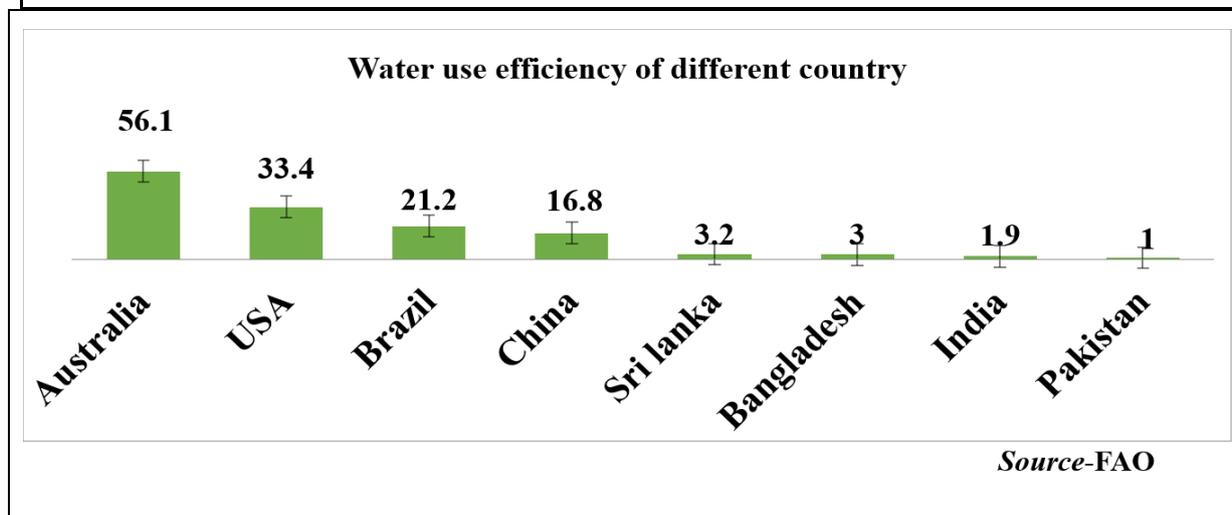
**g. Carefully Manage Surface Irrigation**

Surface irrigation methods have extremely poor irrigation efficiency. Additionally, they dislodge soil particles by bringing a powerful stream of water into direct contact with the soil. The top of the field is frequently over irrigated, and the bottom is under irrigated when surface irrigation is used. Because nitrogen leaks below the root zone, overwatering the top of the field strains the plants and results in a nitrogen shortage. Production losses from somewhat drought stressing the field's bottom are frequently comparable to those from overwatering the field's top. Apply straw mulch to the field's bottom to allow water to seep in. Using straw mulch or polyacrylamide improves the tight soils' ability to retain water and improve water infiltration. Making the switch to micro irrigation techniques, such as drip or sprinkler irrigation, can assist manage water more effectively and frequently boost yields.

Compared to furrow irrigation, micro irrigation can save between 30 and 50 percent of water. Drip and sprinkler irrigation are two types of micro-irrigation techniques that have higher irrigation efficiency. The two most common micro-irrigation systems are sprinkler and drip irrigation.

	Surface irrigation	Sprinkler irrigation	Drip irrigation
Conveyance efficiency (%)	50-70	Not applicable	Not applicable
Application efficiency (%)	40-70	60-80	90
Surface water moisture evaporation (%)	30-40	30-40	20-25
Overall efficiency (%)	30-35	50-70	80-90

NMMI-2017



### Climate-Smart Irrigation:

An excellent irrigation technique tailored to the Agro-climatic and social context, climate-smart irrigation (CSI) takes into account the opportunities and problems that may arise directly or indirectly from many aspects of climate change. Three CSA pillars serve as its foundation, including:

- **Productivity:** Without harming the environment, CSI seeks to raise net agricultural income and productivity. It enhances the sustainability of irrigated farming systems while attempting to protect the interests of farm families.
- **Adaptation:** To address the immediate threats, CSI seeks to fortify the current irrigation system. Maintaining profitability and productivity while enhancing farmers' capacity to adjust to climate change is the major goal.

- **Mitigation:** Up to and beyond the farm gate, CSI seeks to use irrigation techniques that lower greenhouse gas emissions. It emphasizes using green energy to run irrigation systems in order to preserve ecological balance.

## Climate Water Smart Irrigation Practices

**Micro Irrigation:** Sprinklers, surface drips, and subsurface drips are all forms of micro-irrigation. 56 percent of the entire land under micro-irrigation is sprinkler-equipped, whereas 44 percent is drip-irrigated. Sprinkler irrigation has risen at a rate of 6.60 percent over the same time period, whereas drip irrigation is expanding at a quicker rate, with an annual growth rate of 9.85 percent from 2012 to 2015. Andhra Pradesh (1.38 Mha), Maharashtra (1.31 Mha), Gujarat (0.80 Mha), Karnataka (0.72 Mha), and the rest of the country total approximately 5.96 Mha are the main states in India that use drip irrigation (ASG, 2021). Rajasthan (1.68 Mha), Karnataka (1.04 Mha), Maharashtra (0.56 Mha), Andhra Pradesh (0.51 Mha), Gujarat (0.72 Mha), and other states make up the majority of India's 6.57 Mha sprinkler irrigation adoption. By lowering the amount of water input in fields, micro-irrigation helps to increase water production. By saving water, electricity, and labour, this technology lowers overall irrigation costs and increases input usage efficiency. This technology reduces the amount of water lost by evaporation, runoff, and deep percolation. Significant water savings occur because the water is applied where it is needed, such as in the root zone or other specific areas. About 30% of farmers that use micro-irrigation have embraced new crops, demonstrating that farmers have more options to introduce new crops to their fields as a result of lower input costs. The use of micro-irrigation techniques can reduce electricity usage by 30 to 50 percent since they require less power and require fewer hours to irrigate fields. Fertigation is a technique that aids in the prudent use of fertilizer in this system, and applying fertilizer to the root zone increases fertilizer consumption efficiency by 20–30%. Significant amounts of fertilizer and electricity are saved by this system, which eventually reduces the thousands of crores in subsidies given to farmers for this purpose.

### a. Sprinkler Irrigation

Sprinkler irrigation technology, a sophisticated pressurized micro-irrigation technique that mimics rainfall, was introduced to the world almost a century ago but has only recently become widely used. This method uses a system of pipes made of aluminum or high-density polyethylene (HDPE) to distribute irrigation water over the crop canopy. Interestingly, sprinkler systems reduce water loss in conveyance channels, resolving seepage and leak problems. They work effectively even on uneven ground, guaranteeing more even water distribution and drastically cutting down on waste. The use of sprinkler systems for cereals and other field crops has resulted in significant irrigation water savings of between 30% and 70% when compared to traditional flood irrigation. The benefits include increased agricultural sustainability, decreased water waste, and more effective water distribution. As technology develops further, sprinkler irrigation's wider use is expected to make a substantial contribution to resource-efficient and sustainable farming methods worldwide, resolving issues with water conservation and encouraging the best possible crop growth.

### b. Surface Drip Irrigation

One of the most advanced low-volume methods for carefully supplying irrigation water (IW) to plant roots close to the soil surface is surface drip irrigation. Working via a well-planned system of emitters, valves, and pipelines, this system reduces the risk of soil erosion while guaranteeing effective water and nutrient transportation. The integration of fertigation, a technique that reduces nutrient loss through leaching by seamlessly integrating fertilizers with irrigation water, is a noteworthy aspect of surface drip irrigation. Numerous studies covering a wide range of crops, especially cereal systems worldwide, highlight the water-saving potential of drip irrigation systems when compared to traditional flood irrigation methods. These studies have shown that these systems can save up to 50% on water consumption in cereals such as wheat, rice, maize, and other crops. This highlights how surface drip irrigation is a resource-efficient and sustainable substitute that greatly enhances water conservation and agricultural sustainability globally. Drip irrigation for growing wheat and rice MIS (micro irrigation system) has been successfully used to conserve water and achieve the tagline 'More crop per drop'. Water is a precise input for agriculture. Drip irrigation is a tried-and-true MIS technology, particularly for horticultural crops. Drip irrigation in rice and wheat agriculture using the System of Rice Intensification (SRI) and System of Wheat Intensification (SWI) techniques has been successfully demonstrated by the institute. The output of rice and wheat might be raised by 33% and 23%, respectively, by using drip irrigation and plastic mulch in conjunction with traditional cultivation methods.

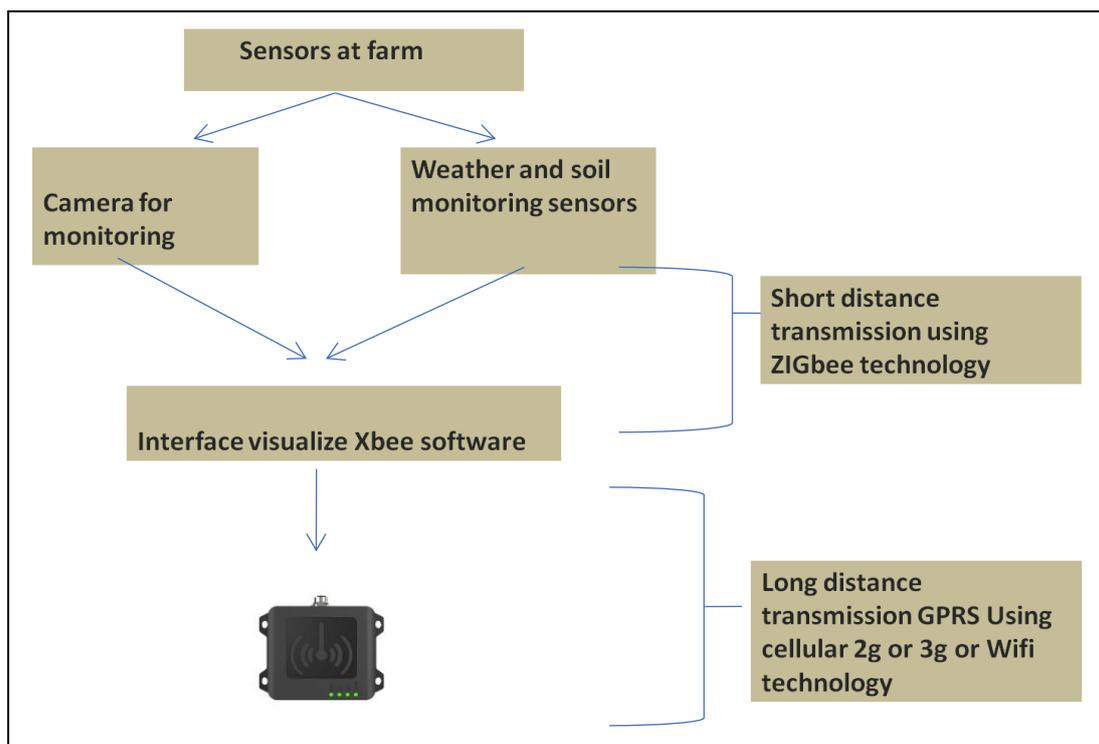
### **c. Subsurface Drip Irrigation**

One of the most advanced low-volume methods for carefully supplying irrigation water (IW) to plant roots close to the soil surface is surface drip irrigation. Working via a well-planned system of emitters, valves, and pipelines, this system reduces the risk of soil erosion while guaranteeing effective water and nutrient transportation. The integration of fertigation, a technique that reduces nutrient loss through leaching by seamlessly integrating fertilizers with irrigation water, is a noteworthy aspect of surface drip irrigation. The water-saving potential of drip irrigation systems is highlighted by numerous studies spanning a variety of crops, especially cereal systems worldwide, which show savings of up to 50% in cereals like wheat, rice, maize, and other crops when compared to traditional flood irrigation methods. This highlights how surface drip irrigation is a resource-efficient and sustainable substitute that greatly enhances water conservation and agricultural sustainability on a global scale. The goal of SSDI is to decrease evaporation-induced water loss from the soil surface. SSDI maximizes fertilizer utilization, reduces weed development, lowers labour expenses, and streamlines cultural operations by enabling the direct administration of water and nutrients to the crop root zone. The efficiency of SSDI is further improved by the incorporation of conservation agriculture techniques. When combined, these interventions reduce evaporation and runoff while improving soil characteristics for greater water retention and storage in the soil profile, which in turn improves irrigation efficiency. The wider implementation of SSDI has enormous potential for sustainable agriculture, supporting international initiatives to alleviate water scarcity and encourage resource-efficient methods. SSDI is a transformative approach that has the potential to revolutionize irrigation strategies and significantly contribute to resilient and sustainable food production systems by reducing

labor inputs, improving nutrient utilization, and mitigating water loss. This is especially true when combined with conservation agriculture practices.

#### d. Automation in Micro-Irrigation

Traditional agricultural methods are being revolutionized by automated drip irrigation systems, which provide accurate and effective water management. Accurate field irrigation is made possible by these systems, which use technology to monitor soil types, climate, and moisture levels. Wireless communication, sensors, and microcontrollers improve automation and enable real-time data analysis for optimal water use. In instance, drip irrigation minimizes waste and conserves resources by delivering water straight to plant roots. By offering clever, sensor-based solutions for higher yield per drop, lower water usage, and enhanced overall agricultural output, this breakthrough tackles the constraints of manpower and water.



Source-Advance in Agronomy 2021,247-300

Flow chart 1. Automated Irrigation System

#### e. Internet of Things (IOT) for Precision Irrigation Systems

Introduced a smart irrigation system that uses Internet of Things applications to increase agricultural efficiency. The system uses a soil moisture sensor to accurately assess the moisture content of the soil and is dependent on real-time soil data. The pumping motor is controlled by an operational amplifier, which automatically turns it on or off in response to changes in the moisture content of the soil. With IoT connectivity, farmers can use a web page or mobile application to check the moisture content of their soil and get information about the condition of their water sprinklers. With its sensor hub and control hub, the model provides useful information for multi-cropping systems. This method improves productivity and efficiency by reducing the amount of physical labour required for irrigation, which is especially helpful in rural areas with little rainfall. An Internet of Things (IoT)-based

irrigation monitoring and control system that uses a variety of sensors and actuators. This intelligent irrigation system shows the possibility for effective and automated irrigation management by delivering a suitable amount of water to crops on its own from a reservoir. The system's goal was to increase agricultural productivity by allowing remote farms to be monitored and operated autonomously. Experimental and simulated results backed the use of soil cost-effectiveness, highlighting the advantages of remote irrigation supply monitoring and control.

## Enhanced Agricultural Methods for Conserving Water

### Laser Land Levelling

Introduced in 2001, laser land levelling modifies fields with a mild slope of 0-0.2%. It accomplishes a smooth ground surface within  $\pm 2$  mm of its average elevation by using drag buckets fitted with lasers. This accuracy lowers nitrogen loss, evaporation, and percolation while saving 20-30% of irrigation water. It provides a precise, graded field for effective water distribution and better agricultural results, saving 6-10% of water, covering 3-4% more land, and increasing yields by 5-15% as compared to traditional approaches.

<b>Technologies</b>	<b>Location, Country</b>	<b>Cropping system</b>	<b>Water savings Over conventional Practices (ha-cm)</b>	<b>Increase in water productivity (kg m<sup>-3</sup>)</b>	<b>Reference</b>
Laser levelling	Meerut, India	Rice-wheat	26.5	0.06	Jat <i>et al.</i> ,(2009) Sidhu (2010)
	Karnal India	Rice-wheat	24.5	-	



**Fig 2. Laser Land Levelling**

### **Furrow Irrigated Raised Beds**

Raised beds with three rows are created using Furrow Irrigated Raised Beds (FIRBs). By facilitating effective water distribution and conveyance, FIRBs shorten the time needed to get from the water source to the lower end. The design of the approach reduces surface area, which in turn lowers water loss during irrigation due to evaporation, contributing to increased water use efficiency in agricultural applications.



**Fig 3. Furrow Irrigated Raised Bed System**

<b>Technologies</b>	<b>Location, country</b>	<b>Crop</b>	<b>Water savings Over conventional Practices (ha-cm)</b>	<b>Increase in water productivity (kg m<sup>-3</sup>)</b>	<b>Reference</b>
Raised-bed planting	Meerut, India	Wheat	16	0.58	Chandra <i>et al.</i> , (2006)

### **Zero tillage**

The two most important cereal crops of India rice and wheat occupying an area of 43.86 million hectare and 29.8 million hectares, respectively. Rice-wheat cropping system is practiced on a large scale in Indo-Gangetic plains. There are issues or problems in rice-wheat cropping system arising due to climate change and variability, emission of greenhouse gases, delayed sowing of wheat, insect pest and diseases, lack of improved production technology, less water use efficiency, less fertilizer use efficiency. These problems can be overcome by adopting zero tillage in rice wheat cropping system. Zero tillage is a type of conservation tillage in which primary tillage is completely avoided, and secondary tillage is restricted to seed bed preparation in the row zone only. In rice wheat cropping system, it can be also called as direct sowing of wheat in rice field. Zero tillage in rice field system has reduced the fuel as well as labour requirement and an overall reduction in cultivation cost. Yield is also more in zero tillage as compared to the conventional tillage.

<b>Technologies</b>	<b>Location, country</b>	<b>Crop</b>	<b>Water savings Over conventional Practices(ha-cm)</b>	<b>Increase in water productivity (kg m<sup>-3</sup>)</b>	<b>Reference</b>
Zero- Tillage	Karnal, India	wheat	2-4	0.10- 0.21	Malik <i>et al.</i> ,(2005)

### **Alternate Wetting and Drying**

Practice of alternate wetting and drying (AWD) technology in rice is a viable option for water saving that has been implemented in various regions of India. However, its effectiveness has been limited due to requirement for more water and inconsistencies in nutrient supply in light textured soil. By adopting such potential water-saving techniques in rice cultivation, not only the crop yield improves, but also carbon sequestration increases, while reducing resource utilization including water, labour, energy and time, and lowering greenhouse gas (GHG) emissions. AWD offers several significant benefits such as utilizing 23–33% less water, enhancing grain quality by reducing arsenic (As) and mercury (Hg)

content, reducing GHG emission, improving water efficiency, maintaining or even increasing grain production. Additionally, intermittent irrigation with AWD method has proven successful in reducing disease and insect pest infestations in lowland rice.

### **Aerobic Rice**

This creative technique, which maximizes water usage and improves overall water efficiency, was created by crossing low-yield upland rice types with high-yielding lowland rice varieties. In contrast to conventional flooded rice fields, aerobic rice cultivation uses a water-efficient method that achieves high Water Use Efficiency (WUE) while saving 30–70% of water (Ghosh, 2003). The main difference is that rice is grown in soil that is neither waterlogged, flooded, or puddled. By keeping soil moisture levels between 0 and 40 KPa, the irrigation technique considerably lowers water losses from evaporation, seepage, and percolation. Usually, irrigation is applied sparingly, allowing floods to only approach the field capacity (FC) of the soil water content in the root zone. Following seeding, light irrigation (30 mm) promotes emergence. Subsequent irrigations are directed by the soil water tension at a depth of 20 cm, initiating irrigation when it surpasses 20 kPa or when leaves start to roll. Throughout the growth stages, it is essential to maintain the ideal soil water conditions, which are about field capacity (30–40 kPa or 0.3–0.4 bar soil moisture potential). The need for watering is indicated by outward manifestations, such as the emergence of hair fissures on the soil's surface or the beginning of tip rolling in the first top leaves. Applications ought to be plenty to fill the field with 20 cm of topsoil. The water management of aerobic rice entails a change from saturated soil moisture regimes, with irrigation planned at 5- to 7-day intervals to augment the crop's water needs. The creation and use of such methods support the overarching objective of attaining food security with the least possible negative impact on the environment.

### **System of Rice Intensification**

With its emphasis on techniques that greatly reduce water consumption (15–30%) and increase water usage efficiency (WUE) to roughly 5.7–5.8 kg/ha.mm, the System of Rice Intensification (SRI) transforms conventional rice farming. Important elements include minimizing flood irrigation, maximizing soil moisture during growth stages, and planting young seedlings (8–10 days old) separately with a wider spacing (20 cm x 20 cm). By just adding 1–2 cm of water to the paddy during vegetative growth, SRI reduces the amount of water used and lets the plot dry out until obvious cracks show. Reducing percolation and switching to alternate wetting and drying methods rather than constant flooding are two ways that SRI saves water.

### **Direct-Seeded Rice**

Compared to more conventional methods like puddled transplanted rice (TPR), direct-seeded rice (DSR) offers substantial water savings. The overall water savings from DSR are a remarkable 35–40% decrease as compared to traditional puddled transplanted rice farming. This highlights how DSR can help maintain or even increase yields while supporting sustainable water management in rice farming.

<b>Technologies</b>	<b>Location/ country</b>	<b>Crop</b>	<b>Water savings Over conventional Practices (ha-cm)</b>	<b>Increase in water productivity (kg m<sup>-3</sup>)</b>	<b>Reference</b>
DSR	Ghaziabad, India	Rice	25	0.08	Jat <i>et al.</i> ,(2006)

### **Ground Cover Rice Production System**

In areas where there are water and temperature constraints for rice growth, the Ground Cover Rice Production System (GCRPS) works well. This novel method entails laying polyethylene before planting on prepared ground. The membrane surface is then punctured to allow for the sowing of rice. Sufficient seeds are sown on each hill using artificial hand dibbling at a depth of 3 cm. The effectiveness of GCRPS has been proven by lowering irrigation water use while simultaneously raising grain yield and water usage efficiency. This approach tackles issues in regions with limited water and temperature, demonstrating its potential for sustainable rice cultivation.

### **Minimization of Evapotranspiration**

Under field conditions, evaporation control principles are used to reduce groundwater depletion. This includes employing techniques like planting plants, erecting windbreaks, and spreading straw mulches to reduce turbulent water vapor movement. By preventing soil moisture from rising through capillary action, soil mulches-which are made by churning the soil to produce a dry soil layer of 5-8 cm-effectively lower evaporation losses. Straw mulches decrease evaporation by reducing movement above the soil and energy absorption. Chemical mulches, such as 5 cm thick hexadecanol, conserve water by reducing evaporation, reducing weed transpiration, and inducing infiltration. Four principles are used to manage transpiration, which is responsible for over 99 percent of water loss received by plants. These include using antitranspirants like PMA or atrazine to increase leaf resistance, using leaf reflectants like kaolin spray to decrease absorbed energy, using growth retardants to slow plant growth, and using windbreaks to increase air resistance. The topic of discussion includes stomatal closing antitranspirants, film-forming antitranspirants like hexadecanol, and leaf reflectants like kaolin spray.

## Polymers

Water-saving techniques, especially in agriculture, heavily rely on polymers like hydrogels (Fig. 4). Superabsorbent polymers called hydrogels may hold onto a lot of water and produce a gel-like material. Hydrogels improve water retention in soil by absorbing and holding onto water during irrigation or precipitation. Hydrogels are used in agriculture as soil water tanks that progressively release moisture to plant roots. This lessens the amount of water wasted and the frequency of irrigation. By providing a consistent supply of water to plants, the polymer's capacity to hold water also helps to mitigate the effects of drought stress.



**Fig. 4** Polymers

## Irrigation Scheduling

In order to maximize crop output and improve water and fertilizer use efficiency, irrigation scheduling is a crucial approach that offers crucial insights into the ideal timing and amount of water application. Soil water regime methods are among the criteria used, which determine soil moisture amounts either directly or indirectly using indicators such as feel, appearance, DASM, soil moisture tension, climatological approaches, cumulative pan evaporation, and IW/CPE ratio. Additionally taken into account are plant indicators including visual symptoms, essential growth stages, plant population, plant water potential, soil cum sand small plots, and relative water content.

## Crop Diversification

Diversification of crops is essential to water-efficient farming methods. Farmers can maximize water consumption and lower the total strain on water resources by growing a range of crops rather than a single monoculture. Due to their different growth patterns and water requirements, different crops enable the effective use of water resources all year long. To further improve water retention and reduce losses, crop diversity might entail planting species with a variety of root systems and drought tolerance.



**Fig 5.** Crop Diversification

Crop diversification reduces the likelihood that water-intensive crops will take over the

agricultural landscape in areas with limited water supplies, hence promoting sustainable water management. It also lessens the need for chemical inputs that could contaminate water sources by breaking the cycles of pests and diseases linked to monocultures.

### Water Harvesting

This method entails gathering and holding onto runoff or precipitation for use in agricultural operations later on. Water harvesting helps diminish reliance on traditional water sources such as rivers and groundwater by collecting and using rainfall. Storage tanks, ponds, and other infrastructure that enables farmers to effectively capture rainfall can be included in water harvesting systems. Rainwater can be stored for use in irrigation by a variety of methods, including check dam construction and rooftop rainwater gathering. Rainwater harvesting reduces the need for excessive groundwater extraction in agriculture by providing an extra supply of water during dry spells. In addition to conserving water, this sustainable strategy enhances groundwater recharge and stops soil erosion. Farmers may improve water-use efficiency, lessen the effects of droughts, and support sustainable water management in the face of shifting climatic trends by including water harvesting into their agricultural methods.

### Saguna Rice Technique

By doing away with conventional methods like ploughing, puddling, and transplanting, the Saguna Rice Technique (SRT) is a unique approach to rice production. Important guidelines include avoiding hoeing and ploughing for weed control, allowing roots and stems to rot slowly, and harvesting eight to ten days sooner. Rice cultivation is revolutionized by SRT, which reduces labour-intensive chores



**Fig 6. Saguna rice technique**

and stops fertility loss. By using permanent elevated beds, this technique guarantees ideal moisture levels and improved oxygen delivery to the root zone. An optimal plant population is promoted by the SRT iron structure, which makes exact planting spacing easier. SRT provides flexibility in farming by reducing reliance on rainfall timing by eliminating transplanting and puddling.

### Case Study on Automated Drip Irrigation in The Rice-Wheat System

A thorough investigation of a novel automated micro-irrigation system in a rice-wheat rotation based on conservation agriculture (CA) was carried out by the Borlaug Institute for South Asia (BISA). In the study, conventional-till (CT) and zero-till (ZT) flood-irrigated systems were compared with surface drip (SD) and subsurface drip (SSD) irrigation systems.

When the soil metric potential (SMP) dropped below threshold levels (15 kPa for rice and 35 kPa for wheat), the electrically powered tube-well and solenoid valve were activated by the automated irrigation system's use of a tensiometer with a magnetic switch. The results showed that automated drip irrigation in conjunction with no-till was preferable, particularly in the ZT-SSD configuration, which produced the maximum rice-wheat productivity. On the other hand, the lowest yield was obtained using flood irrigation in conjunction with conventional tillage. The study found that the no-till rice-wheat system with automated subsurface drip irrigation significantly improved irrigation water productivity. In a CA framework for rice-wheat rotations, this method doubled the irrigation water productivity, demonstrating the potential advantages of automated irrigation in raising crop yields and water-use efficiency. The study demonstrated the usefulness and effectiveness of the sensor-based, real-time irrigation systems that were created for profitable and sustainable farming methods.

## Conclusion

Only 2.4% of the world's territory and 4% of its freshwater resources, India, which is home to 17% of the world's people, is severely affected by water scarcity. The nation faces more difficulties because of the monsoon climate, which causes droughts and floods. In India, irrigated land is approximately 48.9% and irrigation efficiency is 35-40%. To increase water production and efficiency, precision water management technologies are essential. Effective water use requires micro-irrigation, which includes drip and spray irrigation. Significant water savings of 30% to 70% have been shown with sprinkler systems, which mimic natural rainfall. For increased efficiency, surface drip irrigation and SSDI combine with conservation agriculture techniques. Micro-irrigation automation that makes use of wireless connectivity and sensors transforms conventional methods. Wireless sensor networks that use Bluetooth, Wi-Fi, and Zigbee technologies give precision farmers access to real-time data. Precision irrigation systems are further advanced by Internet of Things applications. Laser land levelling, raised beds with furrow irrigation, aerobic rice farming, SRI, Ground Cover Rice Production System, and evapotranspiration reduction are some of the improved Agro-techniques for conserving water. Crop diversification, conservation agriculture, polymers, irrigation scheduling, integrated agricultural systems.

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# Integrated Farming System: An Approach for Climate Resilient Agriculture

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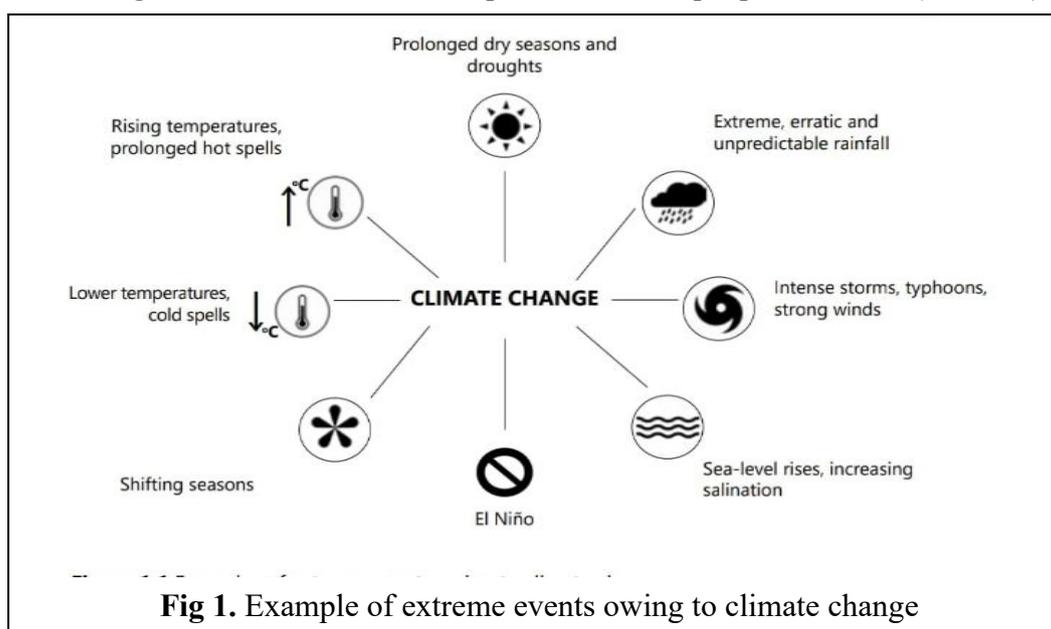
## Introduction

Farmers primarily focus on crop production, which is highly uncertain in terms of income and employment stability. In India, there are 115 million farm holdings, with 80% being small and marginal. The number of operational farm holdings is decreasing, with over 85 million out of 115 million holdings being smaller than one hectare. Due to the growing population and the shrinking per capita availability of land, there is little opportunity for expanding agricultural land horizontally. The only viable option is vertical growth, achieved through integrating crops and allied enterprises that require less space and time while providing reasonable returns for farm families. In this regard, integrating various agricultural activities such as cropping, animal husbandry, fishery, forestry, and backyard poultry offers significant potential for improving the agricultural economy and increasing farm income. These activities not only supplement farmers' income but also create year-round employment for family labor. The integrated farming system offers a viable solution to the challenges of boosting food production, increasing income, and improving the nutrition of small-scale farmers with limited resources. Livestock farming combined with crop production is a traditional practice followed by farmers across the country. Additional activities such as dairy, poultry, fish farming, sericulture, biogas production, edible mushroom cultivation, agroforestry, and agri-horticulture play a crucial role in supplementing farm income. These activities should be compatible with farm-level infrastructure and ensure the full utilization of by-products.

An integrated farming system is a promising strategy for mitigating climate change. Practices such as intercropping, multiple cropping, crop rotation with legumes alternating with non-legumes, conservation farming, agroforestry, and integrated farming are effective for climate mitigation. This system is particularly well-suited to ensuring food security for the growing global population, especially aimed the dual challenges of land degradation and carbon emissions. The primary goal of an integrated farming system is to achieve sustainable crop production with increased productivity, ensure livelihoods and food security, adapt to climate change, and reduce greenhouse gas emissions. Moreover, IFS contributes to climate resilience by improving soil health, conserving water resources, and enhancing biodiversity. Climate-resilient agriculture (CRA) is an approach that focuses on the sustainable use of existing natural resources through crop and livestock production systems to achieve long-term higher productivity and farm incomes, despite climate variability. This practice helps reduce hunger and poverty, ensuring food security for future generations in the face of climate change. CRA practices can transform the current situation and sustain agricultural production at both local and global levels, particularly in a sustainable way (Srinivasarao, 2021).

## Impact of Climate Change on Agriculture

Climate change refers to long-term shifts in average weather patterns, including temperature, wind, and rainfall, in a particular region. It is characterized by rising temperatures, unpredictable rainfall, prolonged droughts, more frequent storms, and hotter days and nights. Earth's surface temperature has increased by 1.5°C since the late 19th century. Changing climate is a tangible reality that has significantly affected land, water, crop production, contribute to desertification and the livelihoods of local communities, particularly farmers in various regions (fig.1). The impacts of climate change vary depending on the specific ecological context of each area, with different regions experiencing unique challenges related to changing environmental conditions. Some examples of serious impacts of climate change on land, water, trees, crops, animals and people are listed (Table 1.) below.



<b>Table 1.</b> Impacts of changes in climate					
<b>Climatic issues</b>	<b>Water</b>	<b>Land</b>	<b>Crops and trees</b>	<b>Animals</b>	<b>Farmers</b>
<b>Rising temperatures</b>	Decreased water availability	Hardened soils Cracked soils	Stunted, slow growth and loss		Declining harvests and income
<b>Prolonged dry seasons, droughts</b>	Lack of water for irrigation and human use	Increased wind-induced soil erosion	Decreased yields		Increased deaths
<b>Intense storms typhoons strong winds</b>	Landslides and floods	Increased run-off and soil erosion	Crops damaged	Increased diseases and deaths	Food shortages Increased malnutrition

<b>Extreme and erratic rainfall</b>	Contaminated. Water	Decreased soil fertility	Growing seasons and cropping patterns changed Decreased yields		Increased occurrence and spread of diseases
<b>Sea-level rises</b>	Saltwater intrusion Decreased freshwater availability	Damaged shorelines Inundation stress, increased salinity	Mangrove ecosystems threatened	Decreased areas for grazing	
<i>Source: Martini et al., (2020)</i>					

## **Need of Integrated Farming Systems (IFS) in Climate-Resilient Agriculture**

### **Challenges posed by Climate change**

The agricultural sector faces numerous challenges due to the changing climate, which directly affects productivity, sustainability, and livelihoods.

#### **a. Rising temperatures**

Rising temperatures pose significant challenges to agriculture, impacting crop and livestock production. Heat stress can reduce productivity and yields, while warmer temperatures can alter growing seasons, leading to mismatches between crop cycles and optimal conditions. Additionally, increased evapotranspiration rates and water requirements can increase water demands, further straining water resources and making it harder to maintain crop health and productivity.

#### **b. Changing precipitation patterns**

Agriculture faces significant challenges due to changing precipitation patterns, including increased drought frequency and severity, which can impact crop yields and livestock productivity. Additionally, more frequent floods can damage crops and infrastructure, disrupting operations. Water scarcity can reduce irrigation availability, further limiting productivity. These shifting weather patterns pose a significant threat to food production systems' stability and sustainability.

#### **c. Increased frequency and severity of extreme Weather events**

The increased frequency and severity of extreme weather events pose significant threats to agriculture. Events like hurricanes and tornadoes can cause extensive crop damage and disrupt infrastructure. Additionally, such extreme weather can lead to livestock mortality, impacting agricultural productivity and the livelihoods of farmers. Moreover, heavy rainfall and flooding associated with these events can result in soil erosion, degrading soil health and fertility, which further compromises long-term agricultural sustainability.

#### **d. Shifts in Pest and Disease dynamics**

Climate change leads to shifts in pest and disease dynamics, with rising temperatures and changing weather patterns altering their distribution. This can negatively impact crop

yields and livestock productivity. To address these challenges, farmers may need to adapt their pest and disease management practices, which could increase costs and further strain agricultural productivity and livelihoods. This underscores the need for adaptive strategies to protect crops and livestock in a changing climate.

**e. Impacts on Agricultural productivity and livelihoods**

Climate change negatively impacts agricultural productivity by reducing crop and livestock yields, threatening food security and farmers' livelihoods. This can lead to income loss and economic instability for rural communities.

**f. Social and Economic impacts**

Climate change contributes to food insecurity, which negatively impacts human health and well-being. It can also lead to migration and displacement of rural communities, disrupting social and economic stability. Additionally, climate change results in significant economic losses for farmers, rural communities, and national economies.

**Integrated Farming Systems (IFS) as a Solution**

- a. Mitigating Risks:** Diversification of agricultural activities reduces dependency on a single crop or enterprise, minimizing the risk of complete failure due to climate variability.
- b. Enhancing Productivity:** Synergistic interactions between different components of IFS improve resource use efficiency, resulting in higher overall productivity.
- c. Improving Livelihoods:** The multi-enterprise approach of IFS generates year-round income, ensuring economic stability for farmers even during adverse climatic conditions.
- d. Enhance Climate Resilience:** Integrated Farming Systems aim to enhance climate resilience by promoting ecological balance, biodiversity, and efficient resource use. This involves diversifying income sources, reducing dependence on single crops, and promoting soil conservation.
- e. Improve Resource Efficiency:** IFS aims to optimize resource use by integrating different farming components, reducing waste, and promoting efficient water and nutrient management. This involves adopting conservation agriculture practices, such as reduced tillage and cover cropping.
- f. Promote Biodiversity:** IFS conserves biodiversity by maintaining ecological balance, protecting natural habitats, and promoting the use of diverse crop and animal varieties. This involves integrating trees into farming systems, promoting agroforestry practices, and conserving genetic resources.
- g. Support Sustainable Livelihoods:** IFS enhances farmers' livelihoods by increasing income, improving food security, and promoting sustainable agricultural practices. This involves providing training and support to farmers, promoting market access, and developing value chains.
- h. Mitigate Climate Change:** IFS contributes to climate change mitigation by reducing greenhouse gas emissions, promoting carbon sequestration, and enhancing soil carbon stocks. This involves adopting conservation agriculture practices, integrating trees into farming systems, and promoting agroforestry practices.

- i. **Improve Water Management:** IFS promotes efficient water management by integrating different farming components, reducing waste, and promoting water conservation practices. This involves adopting conservation agriculture practices, such as reduced tillage and cover cropping.
- j. **Enhance Soil Health:** IFS promotes soil health by integrating different farming components, reducing waste, and promoting soil conservation practices. This involves adopting conservation agriculture practices, such as reduced tillage and cover cropping.
- k. **Support Climate-Smart Agriculture:** IFS supports climate-smart agriculture by promoting agricultural practices that enhance climate resilience, improve resource efficiency, and promote sustainable livelihoods. This involves adopting climate-resilient crop and animal varieties, promoting agro-forestry practices, and conserving genetic resources.

**Goals of Integrated Farming System:** There are four primary goals of IFS (Manjunatha *et al.*, 2014) which summarized as follows:

- a. **Maximization of yield from all component enterprises** to ensure a steady and stable income for farmers by enhancing the productivity of crops, livestock, and other farming activities.
- b. **Rejuvenation and improvement of system productivity** to achieve agro-ecological equilibrium, ensuring that the farming system remains sustainable and balanced over time.
- c. **Prevention of the build-up of insect pests, diseases, and weeds** through natural cropping system management, maintaining their populations at low levels to minimize crop damage and reduce reliance on chemical interventions.
- d. **Reduction in the use of off farm inputs (fertilizers and pesticides),** promoting chemical-free produce to ensure qualitative and healthier food, safer environment for society.

### Advantage of IFS in Climate Resilient Agriculture

The advantages of IFS include pooling and sharing of resources/ inputs, efficient use of family labor, conservation, preservation and utilization of farm biomass including non-conventional feed and fodder resources, effective utilization of manure/ animal waste, regulation of soil fertility and health, income and employment generation for so many peoples and increase economic resources, it improves space utilization and provides diversified products, the IFS is part of the strategy to ensure sustainable use of natural resources for the benefit of present and future generation (Preston, 1995). **i) Productivity:** IFS provides an opportunity to increase economic yield per unit area per unit time by virtue of intensification of crop and allied enterprises. **ii) Profitability:** Use waste material of one component at the least cost. Thus reduction of cost of production and form the linkage of utilization of waste material and elimination of middleman interference in most inputs used. Working out net profit/BC ratio is increased. **iii) Nutritional food security:** Ensures a steady supply of nutritious food for farm families and the community, because the components of varied nature are linked to produce different sources of nutrition. **iv) Pollution free environment:** Reduces environmental pollution by minimizing chemical usage and promoting sustainable farming

practices. **v) Resource recycling:** Promotes the recycling of farm waste and by-products, enhancing resource efficiency and sustainability. **vi) Income generation round the year:** Provides a continuous income throughout the year through diversified farm activities. **vii) Solves the energy crisis:** Integrates renewable energy solutions, such as biogas production, to reduce dependency on external energy sources. **viii) Solves fodder crisis:** Provides adequate fodder for livestock, ensuring a sustainable source of feed. **ix) Solves fuel and timber crisis:** Promotes alternative sources of fuel and timber, such as agroforestry, reducing pressure on natural forests. **x) Employment generation:** Creates year-round employment opportunities for farm families and the local community. **xi) Provides opportunities for agro-based industries:** Supports the growth of agro-processing industries, creating new avenues for rural development. **xii) Increases input efficiency:** Optimizes the use of inputs like water, fertilizers, and labor, reducing waste and costs. **xiii) Improves the standard of living of farmers:** Enhances the quality of life for farmers by increasing income, food security, and overall well-being (Behera and France, 2016).

### Criteria For Selection of Enterprises in IFS

Selection of the IFS for the different regions/locations is depending on the various conditions like; suitability of local **climate** for chosen crops/animals, compatibility of **soil** with the farm's components, farmer's **interest and experience** in specific enterprises that determines scale and integration of activities. Availability of **expertise and technology** is crucial for effective management whereas, access to **infrastructure** enables better post-production handling.

#### Integrated Farming System for Different Agro-Ecosystems

The classification of the farming system may be based on the following criteria:

- **Natural Resource Base:** Availability of essential resources like water, land, grazing areas, and forests that support various farming activities.
- **Climate:** Climatic factors such as temperature, rainfall, and altitude, which influence crop and livestock choices.
- **Landscape:** Topographical features like slope and terrain that affect farm operations and suitability for different enterprises.
- **Farm Size, Tenure, and Organization:** The scale of the farm, land ownership, and how farm operations are organized and managed.
- **Dominant Farm Activities and Household Livelihoods:** This includes field crops, livestock, trees, aquaculture, hunting, gathering, and off-farm activities like processing.
- **Technology:** The use of specific technologies that influence production intensity, efficiency, and the integration of crops, livestock, and other agricultural practices.

These factors together determine the suitability and design of integrated farming systems for diverse agro-ecosystems.

<b>Table 2.</b> Feasible components for integration under different ecosystem		
<b>Wetland</b>	<b>Garden land</b>	<b>Dryland</b>
Cropping	Cropping	Cropping
Fishery	Milch cows	Goat
Poultry	Buffalo	Agroforestry
Forestry	Biogas	Horticulture
Pigeon	Spawn production	Tree
Goat	Mushroom	Pigeon
Duck	Homestead garden	Rabbit
Pig	Silviculture	Farm pond
Mushroom	Sericulture	Fish

<b>Table 3.</b> IFS models for different land use	
<p><b>I. IFS models for wetland</b></p> <p>Crop + dairy + fish + duck + poultry</p> <p>Crop + Livestock+ Fish Farming</p> <p>Crop + poultry/pigeon/goat + fishery</p> <p>Crop + poultry+ fish system</p> <p>Crop + fish + poultry + mushroom</p>	<p><b>II. IFS models for Garden land</b></p> <p>Crop + dairy + biogas</p> <p>Crop + dairy + biogas + mushroom</p> <p>Crop + Milch cow+ Goat + Vermicompost</p> <p>Crop + dairy + biogas + silviculture</p>
<p><b>III. IFS models for dryland</b></p> <p>Crop + goat</p> <p>Crop +Goat + Agro forestry + Farm Pond</p> <p>Crop + silvipasture (Acacia leucophloea + Cenchrus ciliaris + Stylosanthes scabra) + Goat + Vermicomposting</p>	

### **Relation of IFS Component with Climate**

The integration of various components within organic farms and agroforestry systems plays a significant role in mitigating greenhouse gas emissions and enhancing carbon sequestration. Studies have shown that integrated organic farms (IOFs) emit less greenhouse gases, with a reduction in global warming potential compared to conventional systems. Specifically, IOFs emit an average of 2118 t CO<sub>2</sub> equivalent per year or 2.65 t CO<sub>2</sub> eq./ha, with dairy and beef cattle contributing the largest share (45% and 39%, respectively). Crop cultivation and sheep rearing account for 10% and 6%, respectively, of the emissions.

Additionally, the integration of crops and livestock in a no-till system, coupled with moderate grazing intensity, leads to a reduction in net global warming. This is primarily due to substantial soil organic carbon accumulation, which offsets the emissions of nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>) from both the soil and livestock. This method is beneficial for climate change mitigation as it enhances the soil's ability to store carbon and reduce greenhouse gas emissions from agricultural activities (Ribeiro *et al.*, 2020).

Furthermore, integrated farming systems (IFS), which combine field crops, horticultural crops, timber trees, livestock, poultry, fishery, and apiary, provide an efficient use of available space and time, thus optimizing resources and improving farm sustainability. By fostering a symbiotic relationship between different agricultural components, IFS enhance productivity while minimizing environmental impact (Meera *et al.*, 2019).

Agroforestry systems, which involve the integration of trees with crops and livestock, also contribute significantly to carbon sequestration. This is achieved through the combined effects of biomass growth and soil organic matter accumulation within the soil matrix, further enhancing the climate-resilient and sustainable nature of these systems (Meera *et al.*, 2019). The agroforestry component of Integrated Farming Systems (IFS) plays a crucial role in carbon sequestration and the mitigation of greenhouse gas (GHG) emissions. By incorporating biomass and manure into the soil, these systems effectively act as carbon sinks, reducing atmospheric carbon. The integration of perennial trees, especially in boundary plantations, alongside horticultural crops such as fruit trees, further enhances soil carbon storage and biomass accumulation, which helps mitigate climate change effects through increased carbon sequestration in both the soil and tree biomass (Ravisankar *et al.*, 2019). Studies have demonstrated the significant environmental benefits of IFS. For example, Salton *et al.*, (2014) reported that, while conventional farming systems resulted in positive net greenhouse gas emissions, IFS showed a net negative emission due to higher levels of soil carbon sequestration. This indicates that IFS can act as a climate change mitigation strategy by enhancing soil organic carbon storage. Bell *et al.* (2014) also highlighted the effectiveness of combining perennial forages with agro forestry practices like alley cropping and intercropping, which further promotes carbon sequestration and improves nutrient availability, making these systems environmentally sustainable.

IFSs are also beneficial for reducing carbon losses, with predictions indicating a 25% reduction in carbon emissions by 2050 when integrating crop-livestock-forestry components in a farm. Despite moderate soil compaction caused by the presence of cattle, IFS enhances soil quality, soil organic carbon dynamics, and crop yields, making it a sustainable farming practice (Bell *et al.*, 2014). Moreover, IFS contributes to biodiversity conservation by promoting diverse cropping systems (e.g., mixed or intercropping), raising a variety of livestock (ruminants and non-ruminants), and cultivating different trees, shrubs, and herbs. These practices, along with integrated pest management and the improvement of soil microbial diversity through organic matter addition, support the ecological balance on the farm. Beyond environmental benefits, IFS plays a vital role in improving food and nutrition security. By increasing agricultural output and providing diversified, nutritious food sources, IFS supports the livelihoods of farmers, encourages investment and innovation in the agricultural sector, and enhances the sustainability of food production systems. Thus, IFS

offers a comprehensive approach to climate change mitigation, biodiversity conservation, and improved food security.

## Climate change mitigation advantage of IFS with respect to the equivalent specialized production system

### Agro-forestry vs Crop production Systems

Global climate change, driven primarily by human activities such as the burning of coal and oil, has led to a warming of the earth due to an increase in heat-trapping gases, notably carbon dioxide (CO<sub>2</sub>). This warming is causing significant changes in weather patterns, which are already impacting human health, ecosystems, and agricultural productivity. In response to these challenges,



**Fig. 2** Agro-forestry vs Crop production system

agroforestry has emerged as an effective strategy to combat climate change, both by reducing CO<sub>2</sub> emissions and enhancing carbon sequestration. Agroforestry offers a unique opportunity to address both climate change adaptation and mitigation. By integrating trees with crops and livestock, agroforestry systems can improve the resilience of farming systems to cope with the adverse effects of climate change. This land-use approach combines food crops (annuals) with tree crops (perennials) and/or livestock on the same unit of land, thus maintaining ecological sustainability while increasing overall farm productivity (**fig.2**). Tree species such as *Acacia catechu*, *Dalbergia sissoo*, *Mangifera indica*, *Zizyphus mauritiana*, and *Gmelina arborea* are commonly retained in farmland, where they provide multiple benefits. For example, in a 6-year-old *Gmelina arborea*-based agri-silvicultural system, a total of 31.37 tons of carbon per hectare (t C/ha) was sequestered. Carbon sequestration rates also vary among species, with *Alnus nepaliensis* sequestering 0.256 tC/ha/year and *Dalbergia sissoo* sequestering 0.141 tC/ha/year when intercropped with wheat and paddy. These findings highlight the potential of agroforestry systems to significantly enhance carbon sequestration. In addition to their climate change mitigation benefits, agroforestry systems are economically and ecologically sound. They enhance overall farm productivity, improve soil quality through the addition of organic matter from litter fall, and provide essential environmental services, including carbon sequestration, phytoremediation (the removal of pollutants from the environment), watershed protection, and biodiversity conservation. By fostering a diverse and sustainable agricultural landscape, agroforestry systems contribute to both the health of the environment and the livelihoods of farmers, making them an important tool in the fight against climate change (Reddy *et al.*, 2020).

Agro forestry systems enhance soil health by providing more biomass for ground cover and mulching, which improves soil structure and fertility. These systems also promote greater carbon sequestration, both in the aboveground biomass and within the soil. Carbon storage in agroforestry systems ranges from 0.29 to 15.21 Mg ha<sup>-1</sup> yr<sup>-1</sup> aboveground and 30 to 300 Mg C ha<sup>-1</sup> at depths up to 1 meter in the soil. Additionally, the increased ground cover boosts the soil's water infiltration rate and retention capacity, helping to conserve water and improve moisture availability for crops.

<b>Region</b>	<b>Agroforestry model</b>	<b>Carbon storage capacity</b>	<b>Reference</b>
<b>Semi-arid region</b>	Agri-silviculture system	26.0 tC/ha	NRCAF(2005)
<b>Himachal Pradesh</b>	Silvopasture	31.71 tC/ha	Verma <i>et al.</i> ,(2008)
<b>Central India</b>	Block Plantation	24.1-31.1 tC/ha	Swamy <i>et al.</i> , (2003)
<b>Himachal Pradesh</b>	Agrisilviculture	13.37 tC/ha	Verma <i>et al.</i> , (2008)
<b>Kerala</b>	Silvipastoral	6.55 Mg/ha/yr	Kumar <i>et al.</i> , (2002)
<b>Himachal Pradesh</b>	Agri-Horticulture	12.28 tC/ha	Vermak <i>et al.</i> , (2008)
<b>Sumantra</b>	Indonesia Home-gardens	8.00Mg/ha/yr	Roshetko <i>et al.</i> , (2002)

### **Integrated Crop Production Systems**

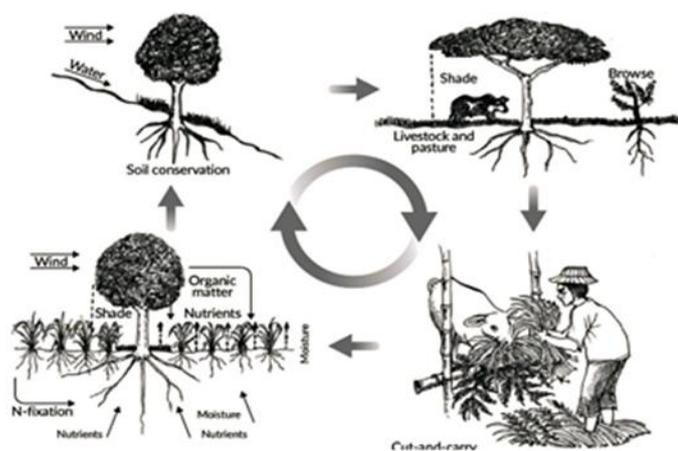
Integrated Crop Production Systems (ICPS) are a sustainable approach to farming that integrates various agricultural components such as crops, livestock, and sometimes agroforestry into a unified system. This holistic approach not only enhances farm productivity but also provides significant environmental benefits, especially in terms of reducing greenhouse gas (GHG) emissions and improving soil health. One of the key benefits of ICPS is the use of manure for crop production, which leads to a reduction in greenhouse gas emissions. The application of manure, a natural fertilizer, significantly reduces the need for synthetic fertilizers, whose production and transportation are responsible for substantial GHG emissions. By replacing or reducing the use of synthetic fertilizers, ICPS help decrease the environmental footprint of agriculture. Furthermore, manure contains valuable nutrients such as nitrogen, phosphorus, and potassium, which improve crop yields without the harmful side effects of chemical fertilizers. Another major advantage of ICPS is the increase in Soil Organic Matter (SOM) through manure restitution. Manure serves as an organic input that enhances soil structure, fertility, and microbial activity. Over time, this increases the SOM in

the soil, which is essential for soil health. Higher SOM improves water retention, reduces soil erosion, and enhances nutrient cycling, leading to better crop growth and resilience to climatic stressors such as drought or heavy rainfall. Additionally, increased SOM is a vital carbon sink, helping sequester carbon dioxide from the atmosphere and mitigating climate change.

The reduced land area required for the production of feed crops is another benefit of ICPS. In conventional farming systems, large areas are dedicated solely to growing feed for livestock, often leading to deforestation, land degradation, and increased GHG emissions due to land-use changes. In contrast, ICPS optimize the use of available land by integrating crop production with livestock and other farming components, reducing the need for additional land for feed production. This efficient land use helps avoid GHG emissions associated with land-use changes such as deforestation and soil degradation. Moreover, ICPS systems foster diversified agricultural production, which enhances resilience against climate change impacts. For example, by combining crops with livestock, farmers can buffer against climate variability—if one component (such as crops) suffers from drought, the livestock may still provide a source of income, or vice versa. This integrated approach allows for better risk management and long-term sustainability. Additionally, ICPS promotes biodiversity, both above and below ground. Diverse cropping systems and the integration of livestock and other practices, such as agro forestry, support a wide range of beneficial organisms, from pollinators to soil microbes. These organisms contribute to ecosystem services like pest control, soil fertility, and pollination, which in turn enhance the productivity and sustainability of the farming system.

### Agroforestry vs Livestock production systems

Agroforestry is a land-use system that integrates trees with crops and/or livestock on the same plot of land, offering numerous environmental, economic, and social benefits. This system can significantly improve the sustainability and resilience of agricultural practices, especially in the context of livestock production. One of the key advantages of agroforestry in livestock systems is the longer and higher availability of fodder. By



**Fig. 3** Agroforestry vs Livestock Production System

integrating trees and shrubs on farms, agroforestry systems provide a continuous and diverse supply of fodder for animals, especially during dry seasons when traditional grazing lands may be scarce. Trees such as *Leucaena*, *Gliricidia*, and *Acacia* offer high-quality, nitrogen-rich fodder that can supplement the diet of livestock, ensuring better nutrition and enhancing

livestock productivity. Agroforestry also improves the thermal comfort of animals, which can have a direct impact on their welfare and productivity. The shade provided by tree canopies helps protect livestock from extreme heat, which can reduce stress and the risk of heat-related illnesses. In addition to cooling, tree cover can help protect animals from strong winds, which can be detrimental to their health and performance. This improved microclimate can lead to better feed intake, growth rates, and reproductive performance of livestock.

Furthermore, agroforestry systems contribute to enhanced biodiversity and soil health, as the presence of trees and shrubs helps to reduce soil erosion, improve water retention, and increase soil organic matter (fig.3). This results in healthier land, which in turn benefits livestock and crop production.

In contrast, conventional livestock production systems, especially those relying on monoculture grazing or intensive confinement, can lead to land degradation, reduced soil fertility, and increased vulnerability to climate change impacts. These systems may also require higher inputs of external resources, such as synthetic fertilizers and pesticides, which can contribute to environmental degradation and higher production costs. Thus, agroforestry offers a more holistic and sustainable alternative to traditional livestock production systems. By promoting biodiversity, enhancing animal welfare, and improving the resilience of farming systems to climate variability, agroforestry plays a critical role in addressing the challenges of modern agriculture, particularly in the face of climate change.

### Integrated rice-fish farming systems

To improve the livelihoods of small and marginal farmers, the Rice-based Integrated Farming System (IFS) model for irrigated areas has been developed at NRRI, Cuttack. This model incorporates rice-fish farming, a centuries-old practice, offering a sustainable solution to the challenges faced by modern agriculture. By integrating rice cultivation with fish farming in the same ecosystem, it promotes ecological balance, enhances productivity, and contributes to food security. Additionally, this system reduces the need for synthetic fertilizers and pesticides. Rice-fish farming also has environmental benefits, including the reduction of methane and other greenhouse gas (GHG) emissions (fig.4). Aquatic creatures, particularly bottom feeders like crabs and carps, disturb soil layers as they search for food or move, which impacts the methane production processes in the soil (Poonam *et al.*, 2019). Their activity increases oxygen levels in both the water and soil, shifting anaerobic digestion processes to aerobic conditions, thus reducing methane emissions.

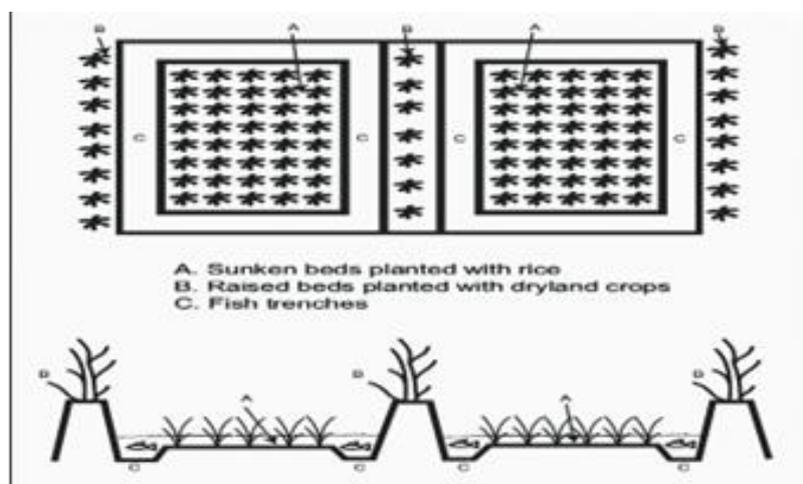


Fig. 4 Integrated rice-fish farming systems

Methane emissions from the rice-fish cultivation system are 34.6% lower than those from monoculture rice cultivation systems, making it environmentally-friendly farming practice.

Treatment	CH <sub>4</sub> emission (kg ha <sup>-1</sup> )	N <sub>2</sub> O-Nemission (kg ha <sup>-1</sup> )	Rice yield t ha <sup>-1</sup>	Fish yield (kg ha <sup>-1</sup> )	Rice straw yield(t ha <sup>-1</sup> )
<b>R</b>	109.3	0.89	4.1	0.0	7.7
<b>RF-A</b>	125.6	0.78	4.6	195.1	9.3
<b>RF-B</b>	136.0	0.79	4.1	207.3	9.35
<b>RF-C</b>	148.5	0.825	5.1	238.4	8.3
<b>RF-D</b>	141.5	0.81	4.3	226.3	8.4

*Source: Bhattacharyya et al., (2013)*

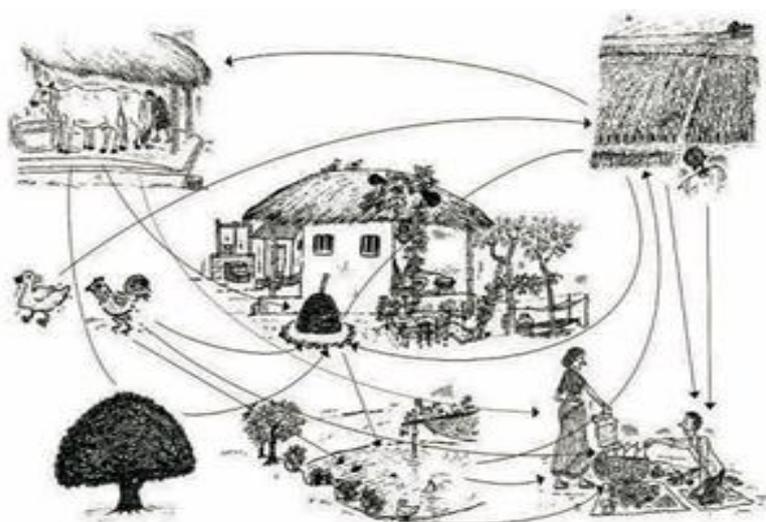
R= Rice only; RF-A= Rice + Fish (mrigal); RF-B= Rice + Fish (rohu); R-F C = Rice + Fish (common carp); RF-D= Rice + Fish (catla), Rice, Varshadhan (transplanted, NPK 50:25:25)

### Nutrient Change in Soil Under Rice Fish System

The rice-fish farming system in rainfed lowlands leads to improvements in soil nutrient content. Specifically, it increases the organic carbon content of the soil by 7%, exchangeable ammonium by 25%, and available P<sub>2</sub>O<sub>5</sub> by 6% (Sinhababu *et al.*, 1998). The continuous addition of fish excreta in this system likely plays a significant role in enriching soil nutrients, further enhancing soil fertility.

### Integrated Food Production Systems

Integrated Food Production Systems (IFPS) leverage sustainable practices such as the use of manure or slurry for crop production, which helps mitigate greenhouse gas emissions. By substituting synthetic fertilizers with manure or slurry, emissions related to the production, transport, and application of synthetic



**Fig. 5** Integrated Food Production Systems

fertilizers are either reduced or avoided. This practice also enhances soil carbon sequestration, as the organic matter in manure/slurry improves soil structure and promotes carbon storage. Additionally, IFPS encourage the recycling of crop residues and by-products, which not only reduces emissions associated with their disposal but also avoids the environmental impact of

feed production (fig.5). These practices collectively contribute to more sustainable and environmentally friendly food production systems.

### **Integrated Livestock production systems**

Integrated Livestock Production Systems (ILPS) play a significant role in improving the sustainability of both agriculture and livestock sectors, especially in the face of climate change. The agriculture and livestock sectors are vital to a country's economy, but changing climate patterns and erratic rainfall distributions can negatively impact both areas. Climate change has already been shown to reduce crop yields by about 5%-10% since the 1980s, as observed in various regions (Iizumi and Ramankutty, 2016). ILPS can help mitigate some of these negative effects while improving overall farm productivity.

#### **Key climate change mitigation advantages of ILPS include**

##### **a. Higher-Quality Diets for Livestock**

By integrating livestock with crop production, animals can consume crop residues and by-products, improving the quality of their diets. Efficient use of land in ILPS reduces the need to dedicate large areas to the production of feed crops. This avoids the greenhouse gas emissions associated with land-use change, such as deforestation or conversion of natural habitats into agricultural land, and helps conserve biodiversity. need for additional feed inputs. This also results in lower emissions of enteric methane from ruminants and reduces manure emissions, both of which contribute to greenhouse gas emissions.

##### **b. Reduced Land Use for Feed Crop Production**

##### **c. Improved Grassland Management**

Through periodic renovation, grasslands can be maintained in optimal condition, improving the quality of grazing land for livestock. These renovations can be performed every 5-10 years on permanent grasslands by activities such as over seeding, removing undesirable plants or bushes, and adding fertilizers and scarifying the soil. These practices increase pasture productivity, which leads to more efficient land use and reduced environmental pressures.

##### **d. Enhanced Soil Fertility**

The integration of livestock with crop and grassland systems also helps improve soil fertility. Manure from livestock acts as an organic fertilizer, enriching soil organic matter and supporting healthier, more productive soils that are better equipped to cope with climate impacts.

### **Energy Production Systems**

Biogas systems utilize a process known as anaerobic digestion, which takes place in an oxygen-free environment, often referred to as an anaerobic digestion reservoir. During this process, bacteria decompose organic matter without the presence of oxygen. Biogas production involves the breakdown of organic materials through biochemical transformations, where large molecules are broken down into smaller ones. The key bacteria involved in biogas production are methanogenic bacteria, which carry out anaerobic decomposition reactions to produce biogas. These bacteria are capable of breaking down both complex and

simple organic materials, leading to the production of biogas. There are two main types of methanogenic bacteria: mesophilic and thermophilic. Mesophilic bacteria thrive at temperatures between 37 to 45°C, while thermophilic bacteria operate at higher temperatures, ranging from 50 to 52°C.

<b>Table 6. Different processes of converting biomass into biogas</b>				
<b>Zero phase (Input)</b>	<b>First phase (Hydrolysis)</b>	<b>Second phase (Acidification)</b>	<b>Third phase (Acidification)</b>	<b>Fourth phase (Methanogenesis)</b>
<b>Carbohydrates</b>	sugars	Carbonic acid	Acetic acid	methane
<b>fats</b>	Fatty acids	Alcohols	hydrogen	Carbon dioxide
<b>proteins</b>	Amino acids	Carbon dioxide	Carbon dioxide	Carbon dioxide
<i>Source: Jameel et al., (2024)</i>				

Lowering greenhouse gas emissions in agri-food chains can be achieved by replacing fossil fuels with bioenergy. This transition reduces the reliance on fossil fuels, which are major contributors to carbon emissions. Additionally, bioenergy production helps mitigate deforestation and forest degradation, as it reduces the demand for unsustainable wood fuel harvesting, promoting more sustainable energy practices. Livestock manure can be effectively utilized to produce biogas through anaerobic digestion, providing a renewable energy source. This biogas can serve as an eco-friendly and sustainable energy solution for household needs such as cooking and lighting, reducing the dependence on traditional, polluting energy sources. This approach not only lowers emissions but also contributes to a circular economy by recycling organic waste into valuable energy.

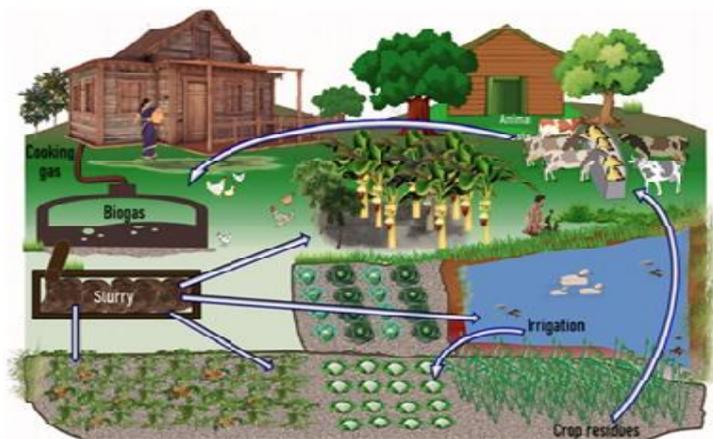
### **IFS as climate-resilient model**

Sole commodity-based farming is highly vulnerable to natural hazards such as floods, droughts, diseases, and epidemics. Relying on a single farm enterprise is a risky approach for farmers, as it offers limited resilience to climate variability. In contrast, diversified agricultural systems, which include both crops (annual and perennial) and livestock, are an ideal strategy to enhance resilience in agricultural systems (Sahoo *et al.*, 2019; Gill *et al.*, 2009). Crop diversification within Integrated Farming Systems (IFS) helps farmers adapt to erratic weather conditions, such as early-season droughts, late-season droughts, and dry spells during the growing season. Developing climate-smart agriculture through an integrated approach is an effective solution to ensure food security for the growing global population, particularly at a time when land degradation and carbon emissions pose significant challenges (Bhatt, 2016). Integrated Farming Systems (IFS), through diversified crops and other agricultural enterprises, provide a stable and sustainable production system that minimizes risks and enhances resilience to climate change (Ayyappan and Arunachalam, 2014; Behera and France, 2016). The nature of Integrated Farming Systems (IFS) enhances the model's resilience to climate change. If one component of the farm is negatively impacted by adverse weather conditions, other components may remain unaffected or experience less impact, acting as a buffer against climate-related risks and ensuring the livelihood security of farmers

(Bonaudo *et al.*, 2014). IFS create a stable and sustainable production system that minimizes risks while simultaneously enhancing resilience to climate change (Singh *et al.*, 2020).

### Effective recycling of resources

In Integrated Farming system, crop by-products are repurposed as fodder for livestock, while animal manure and by-products such as milk and dung contribute to increasing income and enhancing soil fertility. Additionally, the resources available on the farm serve as valuable manures, promoting systemic recycling within the farming process. This integrated approach ensures more efficient use of farm resources and supports a sustainable agricultural system. By recycling organic nutrient sources from the various components of the farm, IFS models can enhance farm output, increase farmer income, and maintain soil productivity. This approach not only preserves the environment but also generates sustainable income for farmers; ensuring long-term agricultural viability (Dar *et al.*, 2018). Nutrient recycling in an Integrated Farming System (IFS) involves the efficient reuse and redistribution of nutrients within the system. (fig.6) This practice includes utilizing organic waste, residues, or by-products from one component of the farming system as inputs for another, creating a more sustainable and resource-efficient farming



**Fig.6** Effective recycling of resources

process (Kumar, Singh, *et al.*, 2012; Kumar, Subash, *et al.*, 2012).

### Conclusions

Integrated Farming Systems (IFS) serve as a comprehensive and sustainable approach to mitigate the challenges posed by climate change in agriculture. Through the integration of various farm enterprises such as crops, livestock, aquaculture, agro forestry, and renewable energy systems, IFS enhances resource-use efficiency, diversifies farm income, and reduces the vulnerability of farming communities to climatic extremes. The synergistic interactions between farm enterprises ensure optimal utilization of natural resources while minimizing environmental footprints. Additionally, the resilience of IFS is attributed to its ability to buffer against climate variability, improve soil health, conserve water, and enhance biodiversity. These systems also contribute significantly to carbon sequestration and mitigation of greenhouse gas emissions, making them a pivotal strategy for sustainable agricultural intensification. In conclusion, adopting IFS can transform agriculture into a more adaptive, productive, and climate-resilient enterprise.

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# Smart Farm Mechanization: An Option for Mitigating the Effects of Climate Change in Agriculture

Shikha Jaiswal, Devrani Gupta, Vasudha Sharma and Arun Kumar

## Introduction

Climate refers to the long-term statistical data of meteorological elements, such as temperature, precipitation and wind, in a specific geographical area. On the other hand, the IPCC defines climate change as observable alterations in the climate system, often identified through statistical analysis, by changes in the average and/or variability of its characteristics. These changes persist over long periods, typically decades or more, and involve significant modifications in climate parameters like temperature, precipitation, or wind patterns. These alterations can result from natural variability or human activities. Climate change has become a critical global challenge, profoundly influencing both the environment and human society. One of the most significant consequences is its effect on agriculture, which is vital for global food security, economic stability, and livelihoods. This section explores the various effects of climate change on agriculture, supported by credible sources and scientific research. The Intergovernmental Panel on Climate Change (IPCC) emphasizes the undeniable reality of climate change, highlighting human activities, such as burning fossil fuels and combustion and deforestation, have significantly increased greenhouse gas concentrations in the Earth's atmosphere (IPCC, 2021). The impacts of climate change on agriculture are complex and deeply interconnected, influencing various aspects of this crucial sector. Rising temperatures contribute to increased heat stress, which negatively impacts both crop production and livestock health. Higher temperatures can result in lower crop yields, compromised livestock health, and shifts in crop distribution patterns. Additionally, changing precipitation patterns and prolonged droughts due to climate change leads to water scarcity, jeopardizing the availability of water for irrigation and livestock. One of the most noticeable impacts of climate change on agriculture is the uncertainty and disruption it causes in planting and harvesting schedules. Changes in temperature and rainfall patterns make it increasingly difficult for farmers to make informed decisions about when to plant and harvest. This unpredictability not only affects crop quantity and quality and also facing greater challenges. Smallholder farmers, especially those in low-income regions, often lack the resources and access to adaptive technologies needed to mitigate the adverse effects of climate change. Sustainable adaptation strategies should be central to agricultural policies and practices. This includes developing and distributing climate-resilient crop varieties, implementing efficient water management practices, and investing in improved agricultural infrastructure. Additionally, international cooperation is crucial in addressing the root causes of climate change (Annappa N. N. *et al.*, 2023).

The Paris Agreement, established under the United Nations Framework Convention on Climate Change (UNFCCC), represents a global collaborative effort to address climate change. It sets a framework for countries to collectively reduce greenhouse gas emissions and

limit global warming to well below 2°C above pre-industrial levels. As the global population continues to grow, the urgency of tackling these challenges becomes increasingly clear. The effects of climate change on agriculture extend beyond national borders, impacting global food security, economic stability, and social well-being. Therefore, proactive, scientifically informed, and internationally coordinated actions are essential to protect global food security, ensure the sustainability of agriculture, and support the well-being of farming communities worldwide (UNFCCC, 2015).

## Variabilities of Climate Change

Climate change variability is defined as the way climate fluctuates yearly above or below a long-term average value. The climate extremes include drought, untimely rainfall, floods, heat wave, cold wave, frost, hailstorm and cyclones. These weather aberrations are likely to impact not only crop sown area, particularly during rainy season (kharif), but also impact the crop stand, performance and yield ultimately, influencing over all agricultural production and productivity. A brief description of these events are presented here.

### Dry Spell

A dry spell is defined as a period of consecutive rainless days, with the specific duration varying based on soil type

- **In light soils:** A dry spell occurs when there is no rainfall for more than 10 days, as these soils have low water-holding capacity and dry out quickly.
- **In heavy soils:** A dry spell is identified after 15 days without rain since these soils retain moisture for longer durations due to their higher water-holding capacity.

### Drought

Drought is a climatic anomaly, characterized by deficient supply of moisture resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of all the three factors. Drought is different from other hazards in that it develops slowly, sometimes over years, and its onset can be masked by a number of factors. Drought can be devastating: water supplies dry up, crops fail to grow, animals die and malnutrition and ill health become widespread.

### Famine

Famine is an extreme outcome of prolonged drought, where the lack of rain and water leads to severe food shortages and widespread hunger. Crops fail, livestock die, and communities face malnutrition, illness, and even death. It often worsens due to poor resources and delayed relief efforts.

### Erratic Rainfall

In the recent past, continuous high rainfall in a short span leading to waterlogging and heavy rainfall coupled with high-speed winds, long dry spells, or uneven rainfall across regions, making it difficult for crops and ecosystems to adapt. Erratic rainfall often disrupts agriculture, affects water availability, and increases the risk of droughts and floods.

## **Flood**

Floods are common in river basins and coastal areas of the country leading to physical loss of crops, human and livestock population. Serious land degradation is an after-effect of flood which requires considerable effort to reclaim the land for cultivation. Heavy rainfall results in flash floods in streams and rivers breach of embankments leading to transient waterlogging and continuous submergence of crop lands and entry of sea water into cultivated fields and intrusion of seawater into groundwater in coastal districts.

## **Heat Wave**

In regions where the normal maximum temperature is more than 40°C, if the day temperature exceeds 3°C above normal for 5 days it is defined as heat wave. Similarly, in regions where the normal maximum temperature is less than 40°C if the day temperature remains 5°C above normal for 5 days, it is considered to be experiencing heat wave.

## **Cold Wave**

In regions where normal minimum temperature remains 10°C or above, if the minimum temperature remains 5°C lower than normal continuously for 3 days or more it is considered as cold wave. Similarly in regions where normal minimum temperature is less than 10°C if the minimum temperature remains 3°C lower than normal it is considered as cold wave. The adverse impacts observed are on growth, flowering, fruiting, delay in ripening and mortality of young and aged orchard plants.

## **Frost**

It is a condition that exists when the temperature of the earth's surface and earthbound objects falls below zero degree (freezing).

## **Hailstorm**

A hailstorm is a type of storm where pellets of ice, called hailstones, fall from the sky instead of raindrops. It causes significant loss in agricultural crop lodging, break plant stems, leaves, fruits and flowers leading to reduce yield and quality.

## **Cyclone**

Cyclone starts as a tropical low-pressure depression, created by oceanic temperature rising above 26°C and usually occurs between April and May and also between October and December in the country. The entire coastal is affected by cyclones with varying frequency and intensity. Inundation of cropped areas and sea water intrusion are associated with cyclonic events.

## **Climate Change Challenges**

Climate change poses numerous challenges globally, impacting various aspects of human societies, ecosystems, and the environment. Here are some key challenges:

**Increasing Temperatures:** Global warming is causing a rise in average temperatures worldwide, leading to heatwaves, heat stress, and heat-related health issues, particularly in urban areas.

**Extreme Weather Events:** Climate change is associated with more frequent and severe extreme weather events, such as hurricanes, cyclones, droughts, floods, and wildfires. These events can cause significant damage to infrastructure and disrupt communities.

**Rising Sea Levels:** As global temperatures increase, polar ice caps and glaciers are melting, resulting in rising sea levels. This threatens coastal communities, infrastructure, and ecosystems, with low-lying island nations being especially vulnerable.

**Ocean Acidification:** Increased levels of carbon dioxide (CO<sub>2</sub>) in the atmosphere are absorbed by the oceans, causing ocean acidification. This negatively impacts marine life, especially organisms with calcium carbonate shells or skeletons, such as coral reefs and shellfish.

**Loss of Biodiversity:** Climate change disrupts ecosystems and habitats, leading to changes in the distribution and behaviour of plant and animal species. Many species may struggle to adapt or face extinction.

**Water Scarcity:** Altered precipitation patterns and increased evaporation due to higher temperatures can lead to water shortages in many regions. This affects agriculture, drinking water supplies, and industrial processes.

**Food Insecurity:** Climate change can disrupt crop and livestock production due to changes in temperature, rainfall patterns, and the increased prevalence of pests and diseases. This can result in food shortages and price spikes, affecting global food security.

**Human Health Disaster:** Climate change can worsen health issues through heat stress, the spread of vector-borne diseases (like malaria and dengue), and deteriorated air quality, leading to respiratory problems.

**Displacement and Migration:** Rising sea levels, extreme weather events, and food insecurity can force people to leave their homes and communities, leading to climate-induced migration and displacement.

**Economic Depression:** The costs of climate change are significant, including damage to infrastructure, increased healthcare expenses, and disruptions to industries like agriculture and tourism.

**Security Risks:** Climate change can exacerbate existing conflicts and create new ones by intensifying resource scarcity, migration, and competition for limited resources.

**Social Inequality:** Vulnerable and marginalized communities often bear the brunt of climate change impacts, leading to increased social inequality.

**Loss of Cultural Heritage:** Rising sea levels and extreme weather events can threaten cultural heritage sites and indigenous communities, leading to the loss of cultural knowledge and traditions.

**Global Cooperation:** Addressing climate change requires international cooperation and agreements, like the Paris Agreement, to reduce greenhouse gas emissions. However, challenges in reaching consensus and enforcing commitments persist.

## Impacts of Climate Change on Indian Agriculture

Climate change can affect agriculture through their direct and indirect effects on the crops, soils, livestock and pests. Increase in atmospheric carbon dioxide has a fertilization effect on crops with C<sub>3</sub> photosynthetic pathway and thus promotes their growth and productivity. Increase in temperature can reduce crop duration, increase crop respiration rates, alter photosynthesis process, affect the survival and distributions of pest populations and thus developing new equilibrium between crops and pests, hastens nutrient mineralization in soils, decrease fertilizer use efficiencies, and increase in evapo-transpiration.

The classified impacts on crops, water, livestock, fisheries and pest and diseases are presented below (Aggarwal *et al.*, 2009).

### Crops

- Increase in ambient CO<sub>2</sub> is beneficial since this leads to increased photosynthesis in several crops, especially crops with C<sub>3</sub> mechanism of photosynthesis such as wheat and rice, and decreased evaporative losses. Despite this, the yields of major cereals crop especially like wheat is likely to be reduced due to decrease in crop growth duration, increased respiration, and /or reduction in rainfall/irrigation water supplies due to rise in atmospheric temperature.
- Enhanced frequency and duration of extreme weather events such as flood, drought, cyclone and heat wave that adversely affect agricultural productivity.
- Reduction in yield in the rainfed areas due to increased crop water demand and changes in rainfall pattern during monsoon season.
- Declined quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants.
- Alteration of agricultural pests and diseases because of more pathogen and vector development, rapid pathogen transmission and increased host susceptibility.
- Threatened agricultural biodiversity by rainfall uncertainty and temperature increase, sea level rise, and increased frequency and severity of drought, cyclones and floods.
- Contrary to all the above negative impacts, predictions have been made for decreased cold waves and frost events in future due to the atmospheric temperature rise, which would lead to a decreased probability of yield loss associated with frost damage in northern India in crops such as mustard and vegetables.

### Water

- Increased irrigation demands with increased temperature and higher evapo-transpiration. This may also result in lowering groundwater table at some places.
- Melting of glaciers in the Himalayas may lead to increased water availability in the Ganges, Brahmaputra and their tributaries in the short run but in the long run the availability of water would decrease considerably.

- A significant increase in runoff is projected in the wet season that may lead to increase in frequency and duration of floods and also soil erosion. However, the excess water can be harvested for future use by expanding storage infrastructure. The water balance in different parts of India is predicted to be disturbed and the quality of groundwater along the coastal track will be more affected due to intrusion of sea water.

### **Soil**

- Reduced quantity and quality of organic matter content, which is already quite low in Indian soil.
- Under elevated CO<sub>2</sub> concentration, crop residues have higher C:N ratio, which may reduce their rate of decomposition and nutrient supply.
- Increase of soil temperature will increase N mineralization but its availability may decrease due to increased gaseous losses through processes such as volatilization and denitrification.
- Change in rainfall volume and frequency and wind intensity may alter the severity, frequency and extent of soil erosion.
- Rise in sea level may lead to salt-water ingression in the coastal lands turning them less suitable for conventional agriculture.

### **Livestock**

- Climate change has pronounced effect on feed production and nutrition of livestock. Increased temperature results in enhanced lignification of plant tissues and reduced digestibility. Increased water scarcity would also decrease food and fodder production.
- In cooler areas, climate change has major impact on vector-borne diseases of livestock by the expansion of vector population. Changes in rainfall pattern may also influence expansion of vectors during wetter years, leading to large outbreaks of disease.
- Global warming would increase water, shelter, and energy requirement of livestock for meeting projected milk demand.
- Climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance.

### **Fishery**

- Increasing sea and river water temperature is likely to affect fish breeding, migration, and harvest.
- Impact of increased temperature and tropical cyclonic activity would affect the capture, production and marketing costs of the marine fish.
- Coral bleaching is likely to increase due to higher sea surface temperature.

### **Insects and diseases**

- Extension of geographical range of insect-pests and pathogens
- Changes in population growth rates of pathogens and insect-pests
- Changes in relative abundance and effectiveness of biocontrol agents

- Changes in pathogen/insect-pest × host × environment interactions, and loss of resistance in cultivars containing temperature-sensitive genes
- Emergence of new diseases/pest problems and increased risk of invasion by migrant diseases and pests
- Reduced efficacy of different components of disease and insect-pest management

## Mitigation

Climate change mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behaviour. Climate change mitigation generally involves reductions in human (anthropogenic) emissions of greenhouse gases (GHGs). Mitigation may also be achieved by increasing the capacity of carbon sinks i.e, through reforestation. Mitigation is achieved through

**Reducing emissions:** Agriculture releases to the atmosphere significant amounts of CO<sub>2</sub>, CH<sub>4</sub> N<sub>2</sub>O (IPCC, 2001). The fluxes of these gases can be reduced by more efficient management carbon and nitrogen flows in agricultural ecosystems. For example, practices that deliver added N more efficiently to crops often reduce N<sub>2</sub>O emissions and managing livestock to make most efficient use of feeds often reduces amounts of CH<sub>4</sub> produced. The approaches that best reduce emissions depend on local conditions, and therefore vary from region to region.

**Enhancing removals:** Agricultural ecosystems hold large carbon reserves (IPCC, 2001), mostly in soil organic matter. Historically, these systems have lost more than 50 Pg, but some of this carbon lost can be recovered through improved management, thereby withdrawing atmospheric CO<sub>2</sub>. Any practice that increases the photosynthetic input of carbon and/or slows the return of stored carbon to CO<sub>2</sub> via respiration, fire or erosion will increase carbon reserves, thereby 'sequestering' carbon or building carbon 'sinks'. Many studies, worldwide, have now shown that significant amounts of soil carbon can be stored in this way, through a range of practices, suited to local conditions. Significant amount of vegetative carbon can also be stored in Agroforestry systems or other perennial plantings on agricultural lands.

**Avoiding (or displacing) emissions:** Crops and residues from agricultural lands can be used as a source of fuel, either directly or after conversion to fuels such as ethanol or diesel. These bio- energy feedstock still release CO<sub>2</sub> upon combustion, but now the carbon is of recent atmospheric origin (via photosynthesis), rather than from fossil carbon.

## Agronomic Approaches to Mitigating Climate Change

Agronomic strategies to mitigate climate change involve adopting agricultural practices that reduce greenhouse gas emissions, enhance carbon sequestration, and promote sustainable land management. These approaches are crucial for addressing agriculture's role in climate change.

**Agroforestry:** Agroforestry integrates trees with crops or livestock on the same land, offering multiple advantages. Trees sequester carbon, provide shade, improve microclimates,

and can increase overall farm productivity. This approach is valuable for climate change mitigation and sustainable land management.

**Cover Cropping:** Planting cover crops during fallow periods or between cash crops helps build soil organic matter, reduce erosion, and mitigate nitrogen losses. Cover crops are an effective agronomic tool for enhancing soil health and mitigating climate change.

**Crop Diversification:** Expanding crop diversity can enhance resilience to climate change, reduce vulnerability to pests and diseases, and improve overall farm sustainability. Diversified cropping systems can reduce greenhouse gas emissions and improve agricultural sustainability while minimizing environmental impacts.

**Improved Nutrient Management:** Effective nutrient management can significantly reduce greenhouse gas emissions in agricultural systems. Precision application of fertilizers and efficient nutrient use are crucial for sustainable and climate-friendly farming practices. This approach can lower nitrous oxide emissions and improve crop nutrient uptake.

**Livestock Management:** Sustainable livestock practices, such as rotational grazing and enhanced feed efficiency, can reduce methane emissions from enteric fermentation. Implementing these practices is essential for reducing methane emissions, a major contributor to greenhouse gas levels, and promoting a more climate-resilient agricultural system.

**Improved Mechanization:** Improved mechanization in terms of climate resilience refers to the adoption and use of advanced agricultural machinery and technologies that enhance the efficiency and sustainability of farming practices, particularly in the context of adapting to and mitigating the impacts of climate change.

## Understanding how mechanization can mitigate climate change effects

Agricultural mechanization is an important symbol of agricultural modernization. The agricultural equipment is the carrier of agricultural modernization and thus an important tool used to promote agricultural mechanization.

“Mechanization covers all levels of farming and processing technologies, from simple and basic hand tools to more sophisticated and motorized equipment. It eases and reduces hard labour, relieves labour shortages, improves productivity and timeliness of agricultural operations, improves the efficient use of resources, enhances market access and contributes to mitigating climate related hazards. Sustainable mechanization considers technological, economic, social, environmental and cultural aspects when contributing to the sustainable development of the food and agricultural sector.”

### Smart Farming

Smart farming is a management concept using recent technologies such as precision agriculture and digital agriculture to improve quality and quantity of farm produce as well as input use efficiency. These techniques are well supported by artificial intelligence for weather prediction, detection of pest and diseases, site specific application of water and nutrients, optimize crop planning for maximizing yield and profit.

The applications of new technologies *viz*; precision agriculture, digital agriculture and artificial intelligence (AI) are heralding the start of a new revolution in agricultural production. The recent and emerging technological development such as Internet of Things (IoT), drones and robots, are accelerating changes around the agricultural mechanization.

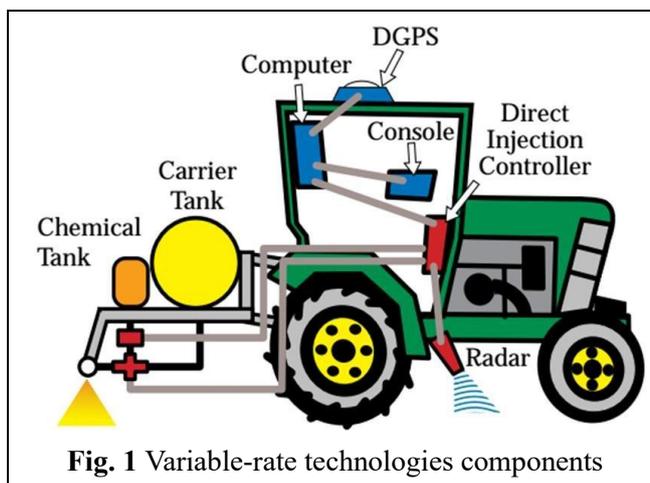
#### a. Precision agriculture (PA)

Precision agriculture technologies can help to meet new challenges by applying the right Inputs (seeds, fertilizers, chemicals, water, etc.), In the right amount, at the right place, at the right time, and in the right manner. The Importance and success of precision agriculture lies in these five "R". Presently, research on precision agriculture is at initial stage and developed technologies are in laboratories in India. The PA technologies such as sensors (soil nutrient, temperature, fertility, and moisture gradients), guidance systems (often enabled by GPS, GNSS, RFID), variable-rate input technologies (VRTs), automated machinery (automatic control and robots) and advanced imaging technologies (including satellite and drone imagery) have been developed to map the variability and manage at field level. A few potential precision agricultural technologies such as fixed rate seed drill, low cost SPAD meter, spectral reflectance (NDVI) based fertilizer applicator, uniform rate sprayer, real time soil moisture -based sprinkle irrigation system, automatic irrigation system for rice and automatic yield monitor for indigenous combine harvesters have been developed and tested at ICAR- Central Institute of Agricultural Engineering (CIAE), Bhopal (Chandel and Agrawal, 2019).

The low cost SPAD meter has been developed for indirect measurement of chlorophyll content of leaves in the field crops (Anonymous, 2017). It is a compact hand-held and portable unit and can be plugged to OTG enabled android smartphone for display data logging of SPAD values. Two row- on- the-go variable rate spectral reflectance-based urea applicator for top- dressing has been developed for rice and wheat crops (Fig. 1). It is 5.5 kg in weight and has swath width of 4 m.

The NDVI based variable rate fertilizer application system resulted in 8-15% savings in application of urea fertilizer in wheat and rice crops in areas with spatial nitrogen variation (Anonymous, 2016). The GPS based variable rate fertilizer applicator has also been developed. The application accuracy of the applicator ranged from 89.3% to 98.1% at various discharge rates for 8×8 m size grid (Mehta, 2015; Chandel *et al.*, 2016).

An ultrasonic sensor based spraying system, sensor-based system for sugarcane bud cutting and planting, tractor-implement monitoring system, automatic depth and draft control for fuel economy and image based herbicide applicator have been developed and tested at IIT, Kharagpur. The percentage saving of chemical by tractor operated ultrasonic sensor-based pomegranate sprayer was 25-30% and 45-50% with turbo nozzles and hollow cone



nozzles, respectively as compared to whole field spraying system (Mehta. 2015). Further, Punjab Agricultural University (PAU). Ludhiana has developed an optical sensor (Yara) based fertilizer application system, an automatic EC and pH mapping system and a batch type yield monitoring system for indigenous combine harvesters. The real-time uniform rate spraying system has been developed at ICAR CIAE, Bhopal, It helped in uniform application of chemical and reduced loss of chemicals during turning at head lands. The results of these precision technologies are encouraging, however, their adoption on large scale is lacking due to high cost of these machinery.



**Fig. 2** Sensor based real time uniform rate spraying system

### **b. Digital Agriculture**

Digital agriculture (DA) consists of a wide range of technologies, most of which have multiple applications along the agricultural value chain. These technologies include cloud computing/big data analysis tools including block chain and smart contracts, the Internet of Thing (IoT), digital communications technologies (mobile phones) and digital platforms (e-commerce, agro advisory apps, e-extension websites). The government of India



**Fig. 3** Digitalisation in agriculture

has planned to digitize farming system for sustainable agriculture productivity. Agricultural research institutions, universities, and other organizations are working on digital farming to solve various agriculture related problems. IIT Bombay in collaboration with Japan has developed a Geo-ICT and WSN based DSS for agriculture/environment assessment. Under the Information Technology Research Academy (ITRA) project at IIT Kharagpur, work has been carried out on applications of IoT and UAVs in smart farming.

The Coordinated Programme on Horticulture Assessment Management using geoinformatics (CHAMAN) was initiated in 2014 for area assessment and production forecasting of 7 major horticultural crops on pilot basis using sample survey methodology and remote sensing technology across 12 states. The project "Forecasting Agricultural Output using Space, Agrometeorology and Land (FASAL)" based observations is one of the successful initiations under digital agriculture and is an AI-powered IoT-SaaS platform for horticulture crops. It has raised \$1.6 million in seed funding to build a world-class solution for two core problems of horticulture farmers to manage irrigation and diseases/pests.

### c. Precision Irrigation

Globally, agriculture accounted for 90% of freshwater consumption for irrigating 20-30% of agricultural land of which contribution of surface water and ground water was 60% and 40%, respectively (Chaturvedi *et al.*, 2013; Smilovic *et al.*, 2015). India has 18% of world population, and 4% of world's fresh water, out of which 80% is used in agriculture. Of the net sown area of 140.1Mha, only 68.4Mha is net irrigated area (DARE-ICAR Annual Report 2018-19). With advent of climate change and increase in demand of water for other competitive uses such as domestic and industrial use, water available for irrigation will be limited in future. The conventional surface irrigation methods such as border, check basin and furrow have low efficiency (30-60%). In addition, they have limitations of uniform distribution of irrigation water in terms of space and time, higher seepage and percolation losses and affected by soil type and topography of the land.

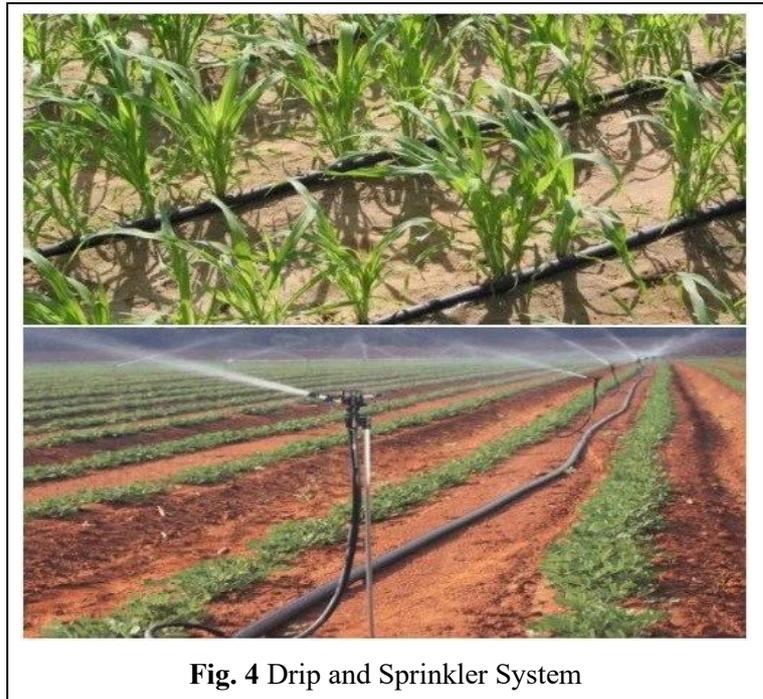


Fig. 4 Drip and Sprinkler System

Precision irrigation methods such as drip and sprinkler irrigation minimize water loss as water is carried through closed pipelines and delivered at desired rate resulting in higher conveyance and application efficiency. Therefore, there is a huge potential to bring more area under irrigation in India. The Government of India implemented the National Mission on Micro-Irrigation (NMMI) scheme to enhance water use efficiency in the agriculture sector by promoting appropriate technological interventions like drip and sprinkler-irrigation systems and encouraging the farmers to use water saving and conservation technologies. The scheme in this form continued up to 2013-14 and is being continued as centrally sponsored scheme on Micro irrigation under Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). The scheme has benefitted the farmers in term of enhanced productivity and reduced cost of electricity and fertilizers consumption. The average productivity of fruits and vegetables increased by about 42- 52% and fertilizer usage reduced by 28%. Besides, the scheme has also succeeded

in reducing the irrigation cost by 20-50% and electricity consumption by 31%. Moreover, this led to increase in water use efficiency. by 50-90% and farmer's income by 42%. Given its higher efficiency and ease of implementation within months as compared to conventional irrigation projects which need years to create infrastructure to implement, micro-irrigation system can go a long way in addressing the issues faced by country and agriculture sector. The integration of micro-irrigation with watershed projects particularly for utilization of harvested water as aimed under PMKSY too are likely to result in an efficient utilization of available water resources in agriculture with significant savings of water for extending the irrigation facilities to un-irrigated areas.

The sensors available for monitoring of different soil and climatic parameters such as soil moisture and temperature for automated irrigation system are costly and not robust. The number of sensors per unit area and their placement are also important and provide soil moisture data at a particular point at a depth. The wetted area of different micro-irrigation system needs to be considered to provide representative data to decide about number of sensors per unit area for irrigation scheduling. The variable rate irrigation application can be designed considering soil heterogeneity. The yield mapping and/or traditional soil sampling can help to identify different soil zones according to their physio-chemical properties. However, electro-magnetic induction (EMI) or near-infrared (NIR) system can be used on a field to map spatial soil variability. The biotic as well as abiotic stresses of plants can be assessed using high resolution imagery. Satellite data, use of unmanned aerial vehicles and drones can be used for procuring high resolution thermal and RGB images for spatial soil moisture mapping/plant water stress monitoring which can be used as inputs for activating an automated irrigation system. These techniques can lead to precision and site-specific irrigation overcoming field variability and soil heterogeneity. The potential of near-surface remote sensing as a scalable platform for collecting high-resolution plot-specific data in addition to local images captured using smart phones can be used in supporting crop damage insurance, crop modelling, and extension for building resilience to yield risk and maintaining sustainable food security in smallholder agricultural systems (Madramootoo and Morrison, 2013).

The real time irrigation scheduling using sensors can be achieved using Wireless Sensor Network (WSN), IoT and AI based technologies. Currently, automation is being practiced using embedded system and micro-controller with the help of solenoid valves in a few Indian farms. However, these are limited to research level and/or small scale. The research in future should focus on development of irrigation scheduling using techniques such as machine learning, deep learning and artificial intelligence. The compact and robust sensors can also be developed using nano-technology having high accuracy.

#### **d. Conservation Agriculture**

Conservation agriculture (CA) has emerged as a sustainable farming practice designed to increase crop productivity minimizing while environmental impacts. Rooted in three core principles—minimal soil disturbance (no-till), maintaining soil cover (cover crops), and crop rotation. CA aims to protect natural resources, improve soil health, and reduce agricultural emissions. Mechanization, or the application of machinery in agriculture, plays a pivotal role

in making these practices scalable and efficient. Initially, mechanization focused on maximizing crop yields through intensive tilling and chemical inputs. While this boosted food production, it also led to soil degradation, erosion, loss of biodiversity, and increased greenhouse gas emissions. As awareness grew about these environmental consequences, conservation agriculture began to gain traction, seeking to balance productivity with ecological stewardship. Mechanized tools were adapted or created specifically to support the core principles of CA, revolutionizing farming methods by reducing the need for excessive tillage and chemical inputs. Mechanization in CA involves several innovations and modifications to conventional machinery. Each is aligned with the principles of reduced soil disturbance, efficient planting, and minimizing the need for synthetic fertilizers and herbicides. Below are the major mechanized systems used in CA:

**e. Residue management for surface mulch and soil incorporation**

- **Residue burning**

Traditionally, rice straw is removed from the fields for use as cattle feed and for other purposes in India. Recently, with the advent of mechanised harvesting, farmers have been burning in-situ large quantities of crop residues left in the field as crop residues interfere with tillage and seeding operations for the subsequent crop, causing loss of nutrients and soil organic matter. When burnt, the residues instantly generate as much as 13 tonnes of CO<sub>2</sub> per ha, contaminating the air and killing of beneficial soil insects and microorganisms. This practice also kills soil borne deleterious pests and pathogens. One of the advantages of burning is that it clears the land quickly of residues before the next crop is established, thus facilitating seed germination and establishment. So, there is a need to adopt ways and means to manage this valuable resource.

<b>Table.1</b> Nutrient content of rice straw and amounts removed with 1 tonne of straw residue					
	<b>N</b>	<b>P<sub>2</sub>O<sub>5</sub></b>	<b>K<sub>2</sub>O</b>	<b>S</b>	<b>Si</b>
Content in straw, % dry matter	0.5-0.8	0.16-0.27	1.4-2.0	0.05-0.10	4-7
Removal with 1 tonne straw, kg/ha	5-8	1.6-2.7	14-20	0.5-1.0	40-70

- **Surface retention and mulching**

Direct drilling in surface mulched residues is a practice that leaves straw residues from a previous crop on the soil surface without any form of incorporation. Surface retention of residues helps in protecting the fertile surface soil against wind and water erosion. The large volume of residues remaining on the surface often leads to machinery failures, thus affecting sowing of seeds of the following crop. Farmers usually follow this method where no till or conservation tillage practices are prevalent. Surface retention of some or all of the residues may be the best option in many situations. Residues decompose slowly on the

surface, increasing the organic carbon and total nitrogen in the top 5-15 cm of soil, while protecting the surface soil from erosion. Retention of residues on the surface increased soil nitrate concentration by 46%, nitrogen uptake by 29% and yield by 37% compared to burning. Retention, however, provides habitat for both harmful as well as useful organisms in one hand and also it provides carbon substrate for heterotrophic nitrogen fixation, increase microbial activity, soil carbon and nitrogen and reduce fertilizer nitrogen requirements for rice. The faster decomposition and release of nitrogen to soil is possible if it is treated with urea and applied during field preparation.

- **Straw incorporation**

Crop residues may be incorporated partially or completely into the soil depending upon methods of cultivation. Ploughing is the most efficient residue incorporation method. Incorporation of the remaining stubble and straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long term. Short-term effects on grain yield are often small (compared with straw removal or burning) but long-term benefits are significant. Where mineral fertilizers are used and straw is incorporated, reserves of soil N, P, K, and Si are maintained and may even be increased. Incorporation of straw and stubble into wet soil results in temporary immobilization of N and a significant increase in methane emission from paddy, a practice that contributes to greenhouse gases. Incorporation of large amounts of fresh straw is either labour-intensive or requires suitable machinery for land preparation and may result in the build-up of disease problems. Transplanting should be carried out two to three weeks after straw incorporation. Recent research results from experimental farms indicate that early, dry shallow tillage at 5 to 10 cm depths to incorporate crop residues and enhance soil aeration during fallow periods has beneficial effects on soil fertility in intensive rice-rice systems. Shallow tillage of dry soil should be carried out up to two to three weeks after harvest in cropping systems where the dry-moist fallow period between two crops is at least 30 days.

#### **f. Residue Management Equipment**

Managing crop residues is a fundamental principle of CA. Equipment like mulchers, choppers, and combine harvesters with residue spreaders are designed to manage the crop remains left after harvest. This residue is crucial for maintaining soil cover, which protects against erosion, retains soil moisture, and promotes the activity of beneficial microorganisms.

- **Zero Tillage**

A Zero tillage technique means that, without prior land preparation and disturbance to soils where previous crop residue is present, seed has been sown on the ground through drillers. It is good for early sowing, saving water and labour costs, improving the efficiency of use of fertilisers, reducing soil erosion that improves organic carbon in soils, increasing yield by up to 20 per cent. The soil properties have been substantially altered by the use of Zero tillage systems, which retain a high surface cover and particularly in the area over several centimetre (Anikwe and Ubochi, 2007). According to Lal, Reicosky, and Hanson (2007) the technologies of the Zero tillage have a considerable effect on controlling soil and crop residues disturbance, limiting soil evaporation as well as minimizing erosion losses. Zero tillage reduce soil moisture loss which helps in saving

irrigation (Gozubuyuk *et al.*, 2020). Moreover, by reducing the oxidation of organic matter since soil is not stirred and more plant residues remain on the ground surface, a zero-tillage technique contributes to maintaining or increasing land organic matter stocks (Yerli *et al.*, 2022). Moreover, zero tillage is directly reducing greenhouse gas emissions through the conversion of CO<sub>2</sub> to O<sub>2</sub> in the atmosphere by enriching ground organic matter (Venkateswarlu and Shanker, 2009). However, the potential of Conservation agriculture for storing Carbon depends on antecedent soil Carbon concentration, cropping system, soil texture, slope and climate (Luo *et al.*, 2010).



**Fig. 5** Zero till drill

- **Laser Land Levelling**

It is the process of leveling the land surface at an accuracy level of  $\pm 2$  cm from its mean elevation by using laser-equipped drag buckets (Fig. 6). Besides, this method creates a constant slope of 0-0.2% throughout the field, for which, irrigation water spreads uniformly in every part of the field with negligible loss in action from run-off or waterlogging. Large horsepower tractors and soil movers equipped with global positioning systems (GPS) and/or laser-guided instrumentation are used in this method. The soils are moved either by cutting or filling to make the land surface well leveled. Laser leveling increases water saving by approximately 20-25%, increases approximately 3 to 5% of cultivable land area, reduces GHG emission and increases the yield of crops (Nayak *et al.*, 2020).



**Fig. 6** Laser land leveller

- **Strip-Till Equipment:** Strip-till is a hybrid approach that disturbs only narrow strips of soil, where seeds are placed, leaving the rest of the field undisturbed. Strip-till machinery helps balance the benefits of both tillage and no-till systems by improving seedbed conditions and enhancing root development, while still preserving soil health and reducing erosion in between crop rows.
- **Cover Crop Seeder and Roller Crimpers:** Cover crops are essential to CA because they provide year-round soil cover, improve soil structure, and fix nitrogen, reducing the need

for synthetic fertilizers. Mechanization has simplified cover crop management with seeders and roller crimpers. Seeders allow farmers to sow cover crops quickly and efficiently, while roller crimpers flatten and terminate cover crops without disturbing the soil, making them easier to manage in the planting cycle.

#### **g. Crop Residue Cover**

The part or parts of the plant or crop left in the field after harvest, or the part of the crop which is not used domestically or sold commercially or discarded during processing, are crop residues. A prerequisite and an integral part of conservation agriculture is a fixed or permanent crop cover with the recycling of crop residues. However, the problem is sowing a crop in which residues of an earlier crop are present. But new variants of zero-till seed-cum-fertilizer drill such as Turbo Seeder, Happy Seeder, and rotary-disc drill have been developed for direct sowing of seed by drilling into the soil even in the presence of surface residues. The vast potential is available for efficient recycling of crop residues, especially in the rice wheat belt of Punjab, Haryana, and western Uttar Pradesh, where they are burned at ground level. In order to protect the soil from weather aggression and water erosion, a key level of crop residues is required in CA practices so as to preserve soils moisture (Lal 1997). The RCTs in residue management has potential for reducing burning of straw, increase soil organic carbon, and also have the potential to reduce Greenhouse gases emission (Pathak *et al.*, 2011)

#### **h. Happy Seeder**

Punjab Agricultural University, Ludhiana in association with Australia has successfully developed Happy Seeder machines which facilitate sowing of wheat in the standing paddy stubble, while retaining the straw as surface mulch. Happy seeder is compact and lightweight and is tractor mounted. It consists of two separate units a straw management unit and a sowing unit. The straw management unit comprised a forage harvester with modified chute that would cut, lift and throw the standing stubble and loose straw. This was backed by a no-till seed drill with inverted T type furrow openers (the sowing unit), which followed the straw management unit and conducted the sowing activity concurrently.

#### **i. Combo Happy Seeder**

To overcome the problems of poor man euverability and visibility the seeding unit of happy seeder, the straw management and sowing units were combined into a single compact unit that could be lifted on the three-point linkage of a 45hp tractor. The machine has the same sowing configuration as the standard zero-till drill with 9 rows inverted T-tynes spaced 20 cm apart. This reduces the straw load on the germinating wheat seeds and power requirement of the tractor. The “Combo Happy Seeder” unit includes strip tillage in front of the inverted T-tynes to improve establishment and was tested and found that considerable dust generation and difficulty in lining up adjacent sowing passes accurately. The sown rows were difficult to see, especially with partial cutting of standing straw.



**Fig. 7** Happy Seeder Machine



**Fig. 8** Combo + Happy Seeder Machine

#### **j. Turbo Happy Seeder**

Turbo Happy Seeder has no chute that greatly reduces the amount of dust. Instead, the straw is chopped finely with the inclusion of fixed blades on the inside of the rotor volute and concave rotor blades in front of the improved design inverted-T sowing tynes. All the furrow openers (tynes) are now on the same bar and are curved so that there is only a very small clearance (15 mm) between the rotating flails and tynes, which are swept clean twice with every revolution of the rotor and the straw is fed between the tynes. As a result, the sowing lines are now more exposed, and visible. The rotor speed is only marginally higher than in Combo Happy Seeder (1300- 1500 rpm). Moreover, the Turbo Seeder does not have a strip-till mechanism and the tynes are on a single toolbar.

#### **k. Rotary disc drill**

This machine is based on the rotary-till mechanism. The rotor is a horizontal transverse shaft having six to nine flanges fitted with straight discs for a cutting effect similar to that of the wooden saw while rotating at 220 rpm. The rotary disc drill is mounted on a three-point linkage system and is powered through the power take off shaft of the tractor. The rotating discs cut the residue and simultaneously make a narrow slit into the soil to facilitate placement of seed and fertilizer. The machine can be used for seeding under conditions of loose residues as well as anchored and residue free conditions.

If the machine is to be used under loose residue conditions, it is better to use an offset double disc assembly for placement of seed and fertilizer. Otherwise, an inverted T-type or chisel type opener can be used. The rotary disc drill can also be easily converted in to a rotary till drill by replacing the discs with L- shaped or J shaped blades on the rotor. The rotor completely pulverizes the soil leading to a clean and fine tilth. Direct seeded rice using a rotary disc drill was successfully established in 6 t/ha of loose residues.

#### **l. Efficient harvesting and storage Reaper**

Harvesting of cereal crops especially wheat and rice is a serious problem. There is a tremendous crop loss when untimely rain is experienced. Delayed harvesting causes grain shattering due to over maturity. The standing crop in the field can be harvested with the use of reapers. A reaper may be classified as animal-drawn reaper, animal-drawn engine operated reaper, tractor rear mounted PTO operated reaper, power tiller operated or tractor front mounted vertical conveyer type reapers and tractor mounted reaper binder.



**Fig. 9** Rotary disc drill



**Fig. 10** Reaper

### **m. Renewable energy integration**

Renewable energy sources such as wind, solar, small hydro, and biomass are receiving increased attention in developed as well as developing countries. Long term sustainable development not only in agriculture but also in all other sectors, requires implementation of renewable energy technologies that are more equitably distributed and environmentally friendly. The cost of renewable energy technologies has declined significantly and further reduction of cost is also projected in the next few years. The applications of various renewable energy technologies are discussed below.

### **n. Solar Energy**

Our country is blessed with abundant supply of solar radiation. By adopting suitable gadgets solar energy can be use in agricultural sector. In the industrial sector, solar thermal energy is utilized for preheating boiler feed water and also for supplying direct process heat. These techniques are helpful in agricultural related industries like, food processing industries, agro-based industries etc. According to an estimate, the potential for the deployment of solar water heaters is around 30 million square meters of collector area, of which around 7 million square meters has already been installed. Semiconductors based solar cells provides one of the most environmentally friendly routes for power production. Solar cells are connected together into a module as per the requirement of the appliance. Module becomes the basic building block of a PV power system and required numbers of modules are suitably interconnected in a series and parallel combination to form a PV panel or an array. About 1700 MW of power production has been achieved through solar photovoltaic systems.

Solar street lights, solar lantern, solar water pumps etc are some of the solar electrical appliances, which have been successfully developed. In agriculture, photovoltaic systems are widely used in water pumping for irrigation and in rural domestic households for lighting. These systems have higher installation cost with added advantages of environment friendly and lesser operation and maintenance cost.

### **o. Wind Energy**

Wind energy has a potential of 45000 MW in India. Wind mills are commercially used for power generation, which is technically and economically viable and is a suitable alternate for fossil fuel power generation. Out of the potential energy sources about 40 – 45 per cent

has already been installed i.e. India has about 19000 MW of wind mill installations. Apart from power generation, water pumping is one of the applications of wind mills, which helps for irrigating water from shallow deepwater sources.

#### **q. Biomass Energy**

Biomass provides the possibility of conversion into liquid, solid or gaseous fuels through various conversion routes which provides more opportunities for its use in different applications. Biomass could become a central part of future sustainable energy supply, due to its economic and technical feasibility. Biomass power generation potential is vast in a predominantly agricultural country like India. With an annual biomass availability of about 500 million tonnes, the power generation potential is in the order of 17,000 MW. With the available biomass conversion technologies, the installed power generation is about 500 MW. Varieties of technologies are available for the conversion of biomaterials to useful energy forms. The major classification is thermochemical and biochemical conversion technologies. In biochemical conversion processes, microorganisms play major role in energy generation. Whereas in thermochemical conversion processes, heat will be introduced during the process.

#### **r. Biodiesel**

Biodiesel is a chemical process, by which vegetable oils can be converted into biodiesel. This is the best alternative to diesel and can be used in engines and automobiles. The raw vegetable oils are subjected into chemical and thermal processes and by removing the by product (glycerol), biodiesel is segregated. The suitable crops for the production of biodiesel are oil bearing seeds producing trees such as Jatropha, Pongamia etc. Thus, various forms of energy like chemical, mechanical, electrical and thermal can be generated efficiently and effectively from biomaterials, which is otherwise unutilized or underutilized. The selection of process for various biomaterials is the key factor in efficient biomass energy conversion. These end use forms of biomass based energy can be substituted well in various industrial and domestic applications, in the place of conventional energy sources. This not only provides energy conservation but also safe, clean and greener environment to the mankind.

Our country is well endowed with renewable sources of energy. But, the exploitable potential depends upon the availability of resources, the status of technology, and the end-use patterns. The application of these technologies is dependent on the degree of R&D, development of consumer satisfied appropriate products, as well as their commercialisation. Widespread information dissemination and awareness campaigns need to be launched to apprise people of the benefits of renewable energy technologies and their advantages over other technologies.

#### **s. Artificial Intelligence in Agriculture**

Using artificial intelligence (AI) platforms, one can gather large amount of data from government and public websites. Presently, artificial intelligence (AI) based on machine learning (ML) is not extensively used in Indian agriculture for automatic data collection, analysis, decision making and controlling the various tasks using different algorithm and mathematical models. The AI offers vast opportunities for advance application in agriculture.

The use of AI with computer vision and robotics is able to build next- generation agriculture equipment those can identify defects in fruits and vegetables, detect stresses in crops, assess nutrient deficiencies in soil, reduce chemical application and harvest high value crops. There is a growing interest in applying AI to develop smart farming practices to minimize yield losses in crops by early warning. AI based agricultural machinery is becoming more and more intelligent. AI based sensors have become basic components on autonomous tractors, self-propelled machinery and implements. Within PA and digital agriculture-based applications, AI based automated data acquisition will have the highest priority. Microsoft in collaboration with the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad has developed an AI Sowing App powered by Microsoft Cortana Intelligence Suite including Machine Learning and Power BI. The App sends sowing advisories to participating farmers about the optimal date to sow. The best part is that farmers do not need to install any sensors on their farms or incur any capital expenditure. They only need a feature phone capable of receiving text messages. These AI- based sowing advisories led to 30% higher yield per hectare (Microsoft News Center India, 2017).

## **Conclusion**

Smart farm mechanization is an agricultural development paradigm extensively promoted in developed countries to transform agriculture under a changing climate. Adopting climate smart equipment i.e., zero till drill, No-till drill, laser land leveller, combined tillage practice and controlled traffic system for seedbed preparation will decrease the GHC, remove carbon from the atmosphere and store it in the soil, reduce soil disturbance and reduce use of all agricultural inputs. Mechanization in sowing or transplanting is highly required. It brings timeliness in operation, precision, cost effectiveness, resources and inputs use efficiency and resource conservation of soil and water. In spite of many challenges in implementing mechanical weed management, there is tremendous scope for exploring robotic weed control system. More research is needed on inter and intra row weeding for various old crops. Micro and mechanized farming systems help to reduce water wastage, as the market is experiencing tremendous demand from emerging nations. Irrigation system can also be automated using real-time clock, moisture sensor, temperature sensor and humidity sensor along with irrigation supply system and system controller. The negative consequences on environment corresponding to excessive N fertilizer, need new technological interventions to improve nutrient management. The use of remote sensing to control dose and timing of N fertilizer can protect environment and permit best management of crops to enable sustainable agriculture. The new state of art technologies allows farmers to ensure the efficiency of crop inputs such as water or chemical fertilizers which can lead to enhanced productivity with better product quality. The harvesting and threshing operation is most important and critical in farm operations. Combine harvesting gives lesser carbon footprint than harvesting and threshing of crops when done separately. Addition of Straw Management System (SMS) or other mechanical components improve the performance of combine harvesting of crops resulting in slight increase in carbon emissions that are offset or nullified by the high-quality threshed grain from the combine and finer straw output from the combine that is decomposed in the field rapidly. Management of crop residue needs attention on a priority basis and awareness

among the farmers need to be created. Farm machinery developed need limited initial handholding by the government to enable ready acceptance and quick adoption by the farmers in order to tackle the crisis of climate change.

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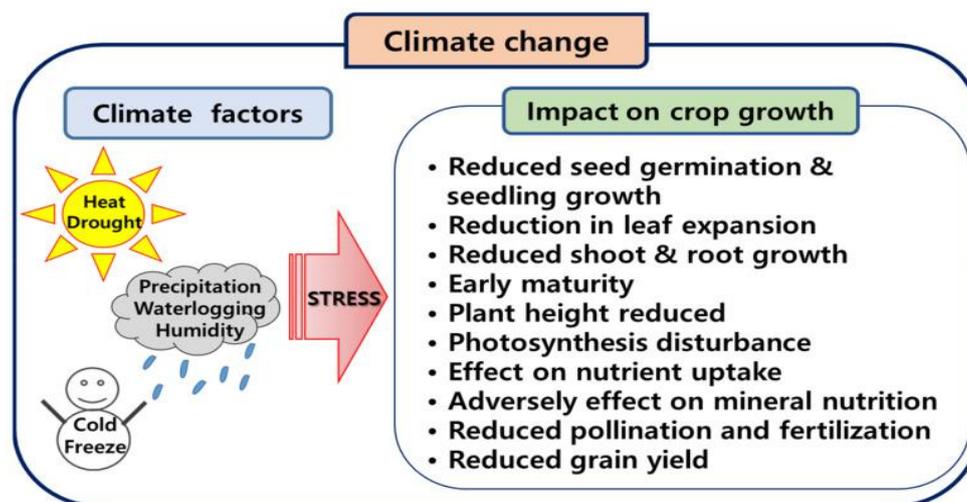
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# Cereal Crops under the Climate Change Scenario: Impact, Adaptation and Mitigation

Pramod Kumar, Rinku Kumar, Sanjay Kumar, Amit Kumar and Dinesh Sah

## Introduction

Climate change is refers to the long-term shifts in weather parameters such as temperature and rainfall. Changing climate is an inevitable phenomenon and its effects are felt worldwide. This is alarming considering variations in meteorological parameters, impact crop production. This is even more concerning considering that cereal production needs to be increased by 70–100% to ensure food security for the 9.8 billion people by 2050 (Neupane *et al.* 2022). Cereal crops including wheat, maize, and rice are considered primary crops as they are staple foods to most of the population across the globe (Wang *et al.* 2018). These crops play a crucial role in global food systems, providing essential nutrients and energy for billions of people. More than half of the world's calories come from these staple crops, highlighting their significance in tackling issues related to food security. Cereals are essential for providing nutrition, employment, and economic stability, especially in developing nations.



**Fig.1** Effects of climate change on crops. *Source: Kim and Lee (2023)*

Human intervention via the use of fossils, deforestation, and land cover alteration, lead to increased production of greenhouse gases, which is the main cause of global temperature increase. Furthermore, throughout the twenty-first century, the duration and intensity of drought have become severe, reducing agricultural water reserves fivefold (Neupane *et al.*, 2022). Unabated, global average temperature is expected to rise by 1.50 °C through 2050 (IPCC, 2018). By the end of the twenty-first century, this increase could be as much as 3–5 °C at certain locations. Moreover, the pace of global climate change over the next 20–70 years is expected to be more rapid and intense than in the previous 10,000 years (Reddy *et al.*, 2000).

The effects of climate change on cereal crops are already visible in many parts of the world, where prolonged droughts, unseasonal rainfall, and heat waves are seriously disrupting

crop growth cycles and yields. For instance, maize production, which is primarily grown in tropical and subtropical regions, is especially susceptible to heat and drought stress, with predictions showing a sharp decline in yields in equatorial regions. Similar to other crops, rice, which needs a lot of water, is having trouble producing as a result of growing water shortages. On the other hand, an extension of acceptable growing zones into higher latitudes may help wheat output, although these increases are anticipated to plateau by the middle of the century as other environmental limitations become more severe. Complexity is further increased by the physiological reactions of grains to climatic stresses. Reduced grain formation and shorter growing seasons can result from crops developing more quickly due to rising temperatures. Furthermore, elevated atmospheric carbon dioxide (CO<sub>2</sub>) concentrations, while potentially enhancing photosynthetic rates and water-use efficiency in crops like wheat, often lead to a reduction in grain protein and micronutrient content. As the global population approaches 10 billion by 2050, the demand for cereals is expected to rise substantially, intensifying the need for resilient agricultural systems (Alfonso *et al.*, 2023). Mitigation and adaptation strategies offer pathways to address these challenges.

This chapter explores the relationship between climate change and cereal crop systems, focusing on the impacts of climatic variability, adaptive innovations, and successful case studies. It offers insights for policymakers, researchers, and farmers to ensure sustainable cereal production.

## Conditions That's Required to Grow Different Cereal Crops

### Paddy

Paddy is a staple cereal food crop, is normally grown in water-flooded fields in more than 95 countries and plays a crucial role in feeding large portion of the world's population, especially in India and China (Coats 2003). Cultivation of paddy required a huge amount of water (around 800-1500 mm) for rice production. However, as rice production accounts for 34–43% of the world's irrigation water demand, the water problem in rice-growing nations is a serious worry. The optimal temperature for growth was reported to be between 22 and 31 °C, and requires 5 to 6 hrs of sunshine per day (Yao *et al.* 2012). In various studies it has been reported that the climatic conditions like- rainfall, irrigation, temperature can have a significant effect on the yield of crops.

**Table 1.** The requirements of rainfall, irrigation, temperature, and duration of growth for various cereal crops.

Species	Water requirement (mm)	Temperature (°C)	Duration of Growth (d)	Photosynthesis Pathway
Paddy	800-1500	21–37	100–135	C3
Millet	0*	20–40	60–100	C4
Maize	500-800	11–32	90–110	C4
Wheat	450-650	3.5–25	120–180	C3

\* Minimal use of water

Source: Hunsigi and Krishna

**Table 2.** The requirement of soil condition, and fertilizer, of various crops.

Species	Soil pH	Soil Type	N (kg/ha)	P (kg/ha)	K (kg/ha)
Paddy	5.5–6.5	Clay or clay loam	120	60	40
Millet	4.5–8.0	Saline, sandy, clay loams	No *	No *	No *
Maize	5.5–7.5	Sandy loam to silt loams	120–180	60–80	40–60
Wheat	5.5–6.5	Clay loam or loam	120–150	60	40–60

\* Minimal use of fertilizers and pesticides compared to other cereals. Source: **Hunsgi and Krishna (1998)**

## Millet

Millets have been cultivated for thousands of years as a staple food crop in India, China, and Africa, primarily because of their exceptional nutritional value, including a high content of protein (11 g per 100 g), carbohydrates, fiber and minerals. The commonly grown millet species worldwide include proso-millet, pearl millet, finger millet, kodo millet, and foxtail millets. Millets are low-input cereal crops that require minimal resources for cultivation and contribute to reduced greenhouse gas emissions compared to other cereal crops. Millet is a drought-resistant cereal crop with a short growth duration that varies between 60 to 100 days (Habiyaremye *et al.* 2017). Millet crops typically range from 30 to 100 cm in height and possess a robust rooting system, making them well-suited to challenging environmental conditions. They generally thrive without the need for fertilizers. Being C<sub>4</sub> plants, millets exhibit an efficient carbon fixation mechanism, which enables them to perform well under high-temperature and low-nitrogen conditions. Additionally, their low transpiration rate contributes to their drought tolerance, making them a resilient choice for cultivation in arid and semi-arid regions.

The optimal growing temperature for millets is 20 to 35°C with 4 to 6 hours of sunshine per day (Table 1). Millet can be grown in sandy, salty, alkaline, and acidic soils; thus, the optimal pH ranges widely between 4.5 and 8.0 (Table 2). Moreover, the nutrient requirement for millets is minimal, and a few millet varieties can be grown in soils (sandy loam, slightly acidic soils) with low fertility (Changmei and Dorothy, 2014). Furthermore, most millet are pest free due to their strong disease resistance traits, which could be a key to reducing the use of pesticides and the consequent pollution caused by pesticide use.

## Maize

Maize (*Zea mays* L.), also referred to as corn or Indian corn, is a cereal crop belonging to the Poaceae (Gramineae) family. Globally, maize ranks as the third most cultivated cereal after wheat and rice (Zamir *et al.*, 2013). It serves as a staple food and feed crop in both developed and developing nations, valued for its rich nutrient profile: carbohydrates (76–88%), protein (6–16%), fat (4–5.7%), and minerals (1.3%) (Woldesenbet and Haileyesus, 2016). It thrives in warm climates with an ideal temperature range of 11 to 30°C and requires 5 to 7 hours of daily sunshine (Table 1). The crop performs well in nutrient-rich, moist soils with a pH of 5.8 to 7.0, and its optimal rainfall requirement during the growing period is 200 to 450 mm (Yin *et al.*, 2014). The crop matures within 90 to 110 days.

Maize grows best in silt loam soils and is a C4 plant, similar to millets, which enhances its water-use efficiency compared to C3 plants such as soybean and wheat. This characteristic makes maize more resilient to high temperatures and increases its carbon fixation efficiency. The commonly recommended dose of fertilizers per hectare for maize cultivation is 125-160 kg N, 55-80 kg P<sub>2</sub>O<sub>5</sub> and 85-110 kg K<sub>2</sub>O.

### **Wheat**

Wheat (*Triticum spp.*) belongs to the family of poaceae. It is one of the most widely grown cereal crops and is a staple food for many people of the world. According to growing season there are two types: winter wheat and spring wheat. Usually, winter wheat is planted in October or November and harvested in June or July. Spring wheat, on the other hand, is sown between March and May and harvested from July to September. Spring wheat has a growing cycle of four months, which is considerably shorter than that for winter wheat. The growing temperature for wheat is 3.5 to 25 °C with a 120 to 180 day growing period, and it requires 6 to 8 hours sunshine per day. It can be grown in sandy loam soils and the optimum soil pH range is from 5.5 to 6.5 (Table 2).

### **Impact of Climate Change on Cereal Crops**

Climate change and increasing extreme weather events pose serious threats to crop yields and their stability worldwide (Reyes *et al.*, 2021). The increase in atmospheric CO<sub>2</sub> level and the predicted climate change could impact the future of agriculture worldwide by changing the plant growth and development, respiration, transpiration and photosynthesis rate (Wang *et al.*, 2013; Crawford *et al.*, 2012; Rezaei *et al.*, 2015; Mall, 2017). Declining soil fertility, water quality, changes in groundwater table and increasing salinity in some parts of the world are now major concerns of existing agriculture. Short growing season, water scarcity, high temperature and heat stress at important reproductive phases of crops can cause massive yield reduction (6-18%) in arid and semi- arid regions of the world (Ullah *et al.*, 2017).

### **Paddy**

It has been evident from the various research studies that the growing conditions which required by the crop (e.g., irrigation, temperature, fertilizer supply) play a crucial role in the final yield of paddy. The global warming can have a negative impact on the yields of paddy produced around the world. Over the past century, the average global temperatures have increased by 0.5 to 0.6°C (Hansen *et al.*, 2010). The increase in temperature has resulted in increased respiration in the plant and a subsequent increase in carbon metabolism and a decrease in the yield of paddy. The higher temperatures can also cause the flowers of the paddy to become sterile, disrupting the reproduction process. Recently, the International Food Policy Research Institute (IFPRI) reported that climate change could reduce the paddy yield by 10 to 15%, which can result in a rise in market price by 32 to 37% (Vaghefi *et al.*, 2011). Matthews *et al.*, (1997) simulated the impact of increased atmospheric carbon dioxide on the productivity of rice in various parts of Asia and found that on average the yields will go down by 4%. While certain regions with cooler climates may experience yield increases due to

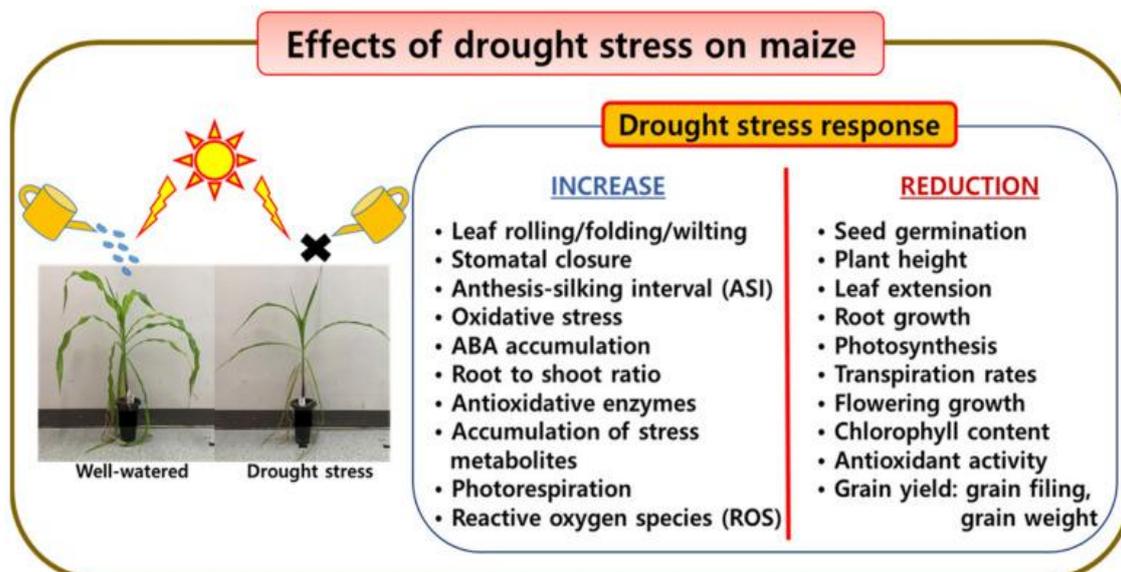
rising global temperatures, enabling double-cropping, these gains are unlikely to compensate the overall decline in yields across much of Asia, which is the world's primary rice-producing region.

## **Millet**

Millet crops have a deep-rooted system that is beneficial and can utilize the residual nitrogen, phosphorus, and potassium in the soil. Hence, this deep-root system does not require a high quantity of fertilizer in comparison with other crops. Pearl millet (*Pennisetum glaucum*) accounts for more than 50% of the global millet production (Singh *et al.*, 2017). Compared to traditional cereal crops, pearl millet requires lower amounts of resources for its growth and can grow in adverse conditions (e.g., water and fertilizer shortage) due to its physiological characteristics. Moreover, millet is one of the most drought-resistant crops due to its strong root system, which allows them to grow in areas that experience frequent periods of dry weather (Hadebe *et al.*, 2017). Drought and heat tolerance together showed an increase in millet yield which amounts to 14% under climate change. Furthermore, millets also possess the ability to grow in hilly terrain and mountainous regions where cultivation of other cereals is difficult (Rasul *et al.*, 2018). This shows that millets possess the potential to be a vital crop that could grow with limited nitrogen input in drought, high-temperature and hilly regions around the world. This is one crop that clearly has the potential to reduce the carbon footprint as it has the least global warming potential, and at the same time is resistant to the global warming effects such as increased frequency in droughts and increased average temperatures.

## **Maize**

Climate change, driven by increased greenhouse gas emissions, poses a significant threat to crop yields and food security by raising temperatures and altering precipitation patterns (Legg, 2021). Rising temperatures accelerate moisture loss from plant tissues and soil surfaces, leading to drought, while excessive heat can directly damage crops (Wahid *et al.*, 2007). Drought and heat stress, whether occurring individually or in combination, have severe implications for agriculture and are critical challenges to ensuring food security. In maize, prolonged drought and extreme climate variability during critical growth and developmental stages significantly reduce crop yields and result in crop losses (Naveenkumar *et al.*, 2018). Irregular rainfall patterns have contributed to a steady decline in maize production, with farmers reducing maize cultivation areas under drought conditions. Additionally, abiotic stresses such as drought and heat, when occurring simultaneously during crop growth stages, exacerbate the impact on production. These stresses not only affect plant health but also promote the emergence and spread of pathogens, insects, and weeds, potentially increasing the risk of dangerous pests (Duveiller *et al.*, 2007).



**Fig.2** Effect of drought stress on maize growth and development.

*Source:* Kim and Lee (2023)

Drought stress directly affects crop growth and yield by impairing photosynthesis (Schussler and Westgate, 1991) leading to symptoms such as wilting, slowed growth, delayed leaf emergence, and reduced leaf area, particularly during the seedling stage. In maize, the flowering period is critical, as the release of pollen and the development of maize silk are closely linked to yield determination. Drought stress during this stage delays silk development and reduces yields, highlighting the importance of the anthesis-silking interval (ASI) in determining final crop productivity (Ribaut *et al.*, 1996). Among the various factors affecting maize production, drought and heat stress are the most significant. Furthermore, increasing atmospheric carbon dioxide concentrations and rising temperatures adversely affect photosynthesis, reducing crop growth rates and water-use efficiency, which directly impacts productivity. Globally, maize suffers an estimated 15% yield loss due to drought stress, underscoring the urgent need for climate-resilient agricultural practices.

## Wheat

Global climate changes and extreme weather events will have a huge impact on the production of wheat, one of the most widely consumed cereals. Changing climate affects crops mainly through elevated CO<sub>2</sub>, temperature increase and erratic rainfall. In India, wheat is grown during the winter season. The sowing starts in November and crop is harvested by the early half of April. Since more than 85% of the wheat land area is irrigated, the influence of rainfall is not significant. But elevated CO<sub>2</sub> levels increase grain yield due to an increase in leaf area duration, straw yield, number of ears per m<sup>2</sup> and kernel weight (Rawson 1995, Pleijel *et al.*, 2000). The reported gain in yield has ranged from 17 to 19% at 550 μmol CO<sub>2</sub> mol<sup>-1</sup> to ~31% at 700 μmol CO<sub>2</sub> mol<sup>-1</sup> (Chakrabarti *et al.*, 2012).

Heat stress is considered to be the major climatic factor affecting wheat yield in the IGP region of India (Ortiz *et al.*, 2008). A substantial area is under late and very late-sown conditions (until the third week of December), exposing the crop to heat stress. This results in considerable yield reduction in central and eastern India. The crop is sensitive to high temperature, which affects photosynthesis, growth and development, number of grains and

grain yield. Wheat crops exposed to temperatures  $>34^{\circ}\text{C}$  have significantly low yields because of accelerated senescence (Asseng *et al.*, 2011, Lobell *et al.*, 2012). The optimum temperature range is 17 to  $23^{\circ}\text{C}$  during the entire growth period, with maximum temperatures not exceeding  $37^{\circ}\text{C}$  (Porter and Gawith 1999). Temperature optima are  $\sim 22^{\circ}\text{C}$  for vegetative development and  $21^{\circ}\text{C}$  for reproductive development, while  $\sim 35.4^{\circ}\text{C}$  is the maximum limit for grain filling (Porter and Gawith 1999). More than  $31^{\circ}\text{C}$  temperatures just before anthesis induce pollen sterility and reduced grain number and yield. Lobell *et al.*, (2012) reported wheat yield reductions of up to 20% in some areas of the IGP, due to a  $2^{\circ}\text{C}$  increase in seasonal temperature. On the other hand, low temperatures can be problematic for seed set. Projected increases in temperatures and frequency of weather extremes (IPCC 2007a) could therefore significantly constrain wheat production in a future climate.

In France, Gammans *et al.*, 2017, were analyzed winter wheat yields with the help of modeling approach based on historical yield and gridded weather data available from 1950 to 2015. The model predicted that due to climate change, the wheat yield would be reduced by 3.5 to 12.9% in the medium term from 2037–2065, and it further predicted that winter wheat productions would decrease by 14.6 to 17.2% by the end of the century. In China, researchers reported that wheat production rates would be reduced by 3 to 10% due to a  $1^{\circ}\text{C}$  increase in temperature during the growing period based on the historical data between 1970- 2000 (Wang *et al.*, 2018).

## Adaptation Strategies under Changing Climate

Adaptation strategies for cereal crops under climate change are critical for ensuring food security and agricultural sustainability. These strategies aim to mitigate the adverse effects of changing climatic conditions such as rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events. Adaptation efforts, such as developing heat-tolerant and drought-resistant crop varieties, early-maturing varieties of crops (Table 3.), crop diversification, optimizing irrigation practices, planting of cover crops, and shifting planting schedules, are critical to maintaining productivity (Federal Ministry of Environment 2014; Achike and Onoja 2014). Some important adaptation strategies are explained as under:

**Crop Breeding and Biotechnology:** including (i) development of climate-resilient varieties that are drought-tolerant, heat-resistant, and resistant to pests and diseases, (ii) Use of genetic engineering: Incorporating traits such as early maturity enhanced photosynthetic efficiency, and stress tolerance.

By many scientists and researchers, it is estimated that the average temperature worldwide will increase by  $2.5\text{-}4.5^{\circ}\text{C}$  by the end of this century (Solomon, 2007). The maintenance of an appropriate temperature during the growth period is vital for cereal crops in different stages of cultivation since most of the cereal crops are highly sensitive to environmental and climatic variations. For example, high temperatures can reduce pollen viability and result in reduced kernel numbers and ultimately the yield during the heading and flowering periods (Stratonovitch and Semenov, 2015). Traditionally, crop breeding has focused more on enhancing yield than on developing tolerance to high temperatures. However, there is an increasing need to breed new varieties of crops that can cope with

extreme weather events and increasing annual temperatures with stable production rates (Fita *et al.*, 2015). Studies have been carried out on exploiting and extending the existing genetic variability to develop new heat-tolerant and high-yielding crop genotypes. For example, new varieties of cereal crops have been developed that have higher average grain yields when grown under high temperatures.

**Table 3** Climate- Resilient Crop Varieties

Crop	Varieties	State	Varieties feature	Source of seed availability	
<b>1. Rice</b>	Pant Dhan 16, Barani, Dhan-1, Aditya, Kalinga-3	Uttarakhand, Chhattisgarh	Suitable for Cultivation under Drought Stress	GBPUA&T, Pantnagar; IGKV, Jabalpur	
	DRR Dhan 50 (IET 25671)	Andhra Pradesh, Telangana, Tamilnadu, Karnataka, Bihar, Odisha, Chhattisgarh, Uttar Pradesh and Madhya Pradesh		IIRR, Hyderabad	
	DRR Dhan 46	Bihar, Madhya Pradesh and Maharashtra		IIRR, Hyderabad, Telangana	
	DRR Dhan 44 (IET 22081)	Uttarakhand, Haryana and Bihar		IIRR, Hyderabad	
	Sahbhagi dhan, Sushak Samrat	Bihar		BAU, Sabour	
	Pusabasmati-1121	Punjab		Short duration Crop Varieties	IARI, New Delhi
	PR-124	Punjab	IARI, New Delhi		
	Sahbhagi	Bihar	BAU, Sabour		
	IR-64 Drt I (IET 22836) (DRR Dhan 42)	Telangana, Andhra Pradesh, Tamilnadu, Madhya Pradesh, Chhattisgarh, Jharkhand	IIRR, Hyderabad and BAU, Ranchi		
	DRR Dhan 44 (IET 22081)	UK, Haryana and Bihar	IIRR, Hyderabad		
	DRR Dhan 46	Bihar, Madhya Pradesh and Maharashtra	IIRR, Hyderabad		
	VNR-2111 PLUS (IET 24075) (VNR 212)	Punjab, Uttarakhand, Haryana, Odissa, Bihar, West Bengal, Uttar Pradesh, Jharkhand, Madhya Pradesh, Chhattisgarh and Maharashtra	VNR Seeds Pvt. Ltd., Raipur		
	Sushak Samrat	Bihar	Suitable for Cultivation under Delayed Monsoon		BAU, Sabour/RAU, Pusa
	Govind	Uttarakhand	GBPUA&T, Pantnagar		
	Swarna Mahsuri, Sada Swarna, Kalinga, Latat, 1001, Sahbhagi dhan	West Bengal	BCKV, Kalyani, WB		

	DRR Dhan 47 (IET 23356)	Telangana, Andhra Pradesh, Karnataka, Kerala and Pudducherry	Suitable for Cultivation under Heat Stress	IIRR, Hyderabad, Telangana.
	DRR Dhan 52 (IET 23354) (RP5125-12-5-3-B-IR84898-B)	Haryana, Gujarat and Odisha.		ICAR-IIRR, Hyderabad
	Basmati CSR 30, CSR 36, CSR 27	Haryana	Suitable for Cultivation under Salinity Stress	CSSRI, Karnal
	CSR 23	Uttar Pradesh		CSSRI, Karnal
	CSR-46 (CSR 2K 262)	Uttar Pradesh		CSSRI, Karnal
	CSR 56 (IET 24537)	Uttar Pradesh & Haryana		CSSRI, Karnal
	Swarna Sub1	Orissa, WB, AP		NRRI, Cuttack
	DRR Dhan 50 (IET 25671)	A P, Telangana, TN, Karnataka, Bihar, Odisha, Chhattisgarh, UP and MP	Suitable for Cultivation under Flooding or Submergence	IIRR, Hyderabad, Telangana.
	CR Dhan 802 (SUBHAS) (IET 25673) (CR3925-22-7).	Madhya Pradesh and Bihar		ICAR-NRRI, Cuttack
<b>2. Wheat</b>	HD2888, K8027	Bihar, Eastern UP, WB	Suitable for Cultivation under Drought Stress	BAU, Sabour
	Raj 3077, Raj 3765, KRL-1-4	Rajasthan		RSSC, Rajasthan
	PBW 527, PBW 644, PBW 396	Punjab, Haryana, UP, Rajasthan		PAU, Ludhiana
	DBW-17	Uttar Pradesh		IIW&BR, Karnal
	HUW 669 (Malviya 669)	Uttar Pradesh		BHU, Varanasi
	PBW-677	Punjab	Short duration Crop Varieties	PAU, Ludhiana
	HD-2967	Punjab MPKV, Niphad;		IARI New Delhi
	DBW17	Bihar		IIW&BR, Karnal
	DBW-14	Bihar	Suitable for Cultivation under Delayed Monsoon	DWR, Karnal
	WH 1124		Suitable for Cultivation under Heat Stress	CCSHAU, Hisar
	DBW 107	Eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal, Assom and plains of North Eastern States		IIWBR, Karnal
	AAI-W9 (SHIATS-W9),	Uttar Pradesh		SHUAT&S, Naini, Allahabad
	AAI-W10 (SHIATS-W10)	Uttar Pradesh		
UP 2338, UP 2425, UP 2526, UP 2565	Uttarakhand	Suitable for Cultivation under Flooding or Submergence	GBPUA&T, Pantnagar	
<b>3. Maize</b>	KMH-7148 Hybrid	Punjab, Haryana, Delhi and Uttar Pradesh	Suitable for Cultivation under Drought	Kaveri Seed Company Limited, Secundrabad
	Candy (KSCH-333) Hybrid 84.)	All India		

	D2244 (DASMaharashtra-501) Hybrid		Stress	DOW Agro Sciences India Pvt Ltd., Mumbai
	GK 3150 Hybrid Punjab,	Haryana, Delhi and Uttar Pradesh		Ganga Kaveri Seeds Pvt.Ltd., Hyderabad
	Candy (KSCH333) Hybrid	All India	Short duration Crop Varieties	KSCL, Secundrabad, Telangana
	D2244 (DASMaharashtra-501) Hybrid			DOW Agro Sciences India Pvt Ltd. Mumbai.
	JVM-421	Madhya Pradesh	Suitable for Cultivation under Delayed Monsoon	RVSKVV, Gwalior
	GK 3150 Hybrid	Punjab, Haryana, Delhi and Uttar Pradesh	Suitable for Cultivation under Heat Stress	Ganga Kaveri Seeds Pvt.Ltd., Hyderabad
	PMH 7 (JH 3956) (Hybrid)	Punjab		PAU, Ludhiana
	Pragati	Uttarakhand	Suitable for Cultivation under Flooding or Submergence	GBPUA&T, Pantnagar
	Jawahar Maize 218	Madhya Pradesh		JNKVV, Jabalpur
	Pusa Jawahar Hybrid Maize-1	Madhya Pradesh		IARI, New Delhi & JNKVV, Jabalpur
<b>4. Pearl millet</b>	HHB-234, HHB-226, HHB-216, Bio 70 (MH 1632), RHB-177, RHB-154, GHB-757, GHB-719, GHB-538, CZP 9802	Western Rajasthan, Gujarat & Haryana	Suitable for Cultivation under Drought Stress	CCS HAU, Hisar; Bioseed Pvt Ltd; ARS Durgapura; AICPMIP MRS Jamnagar; CAZRI Jodhpur
	PB 1705 (MH 2008)	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Madhya Pradesh and Uttar Pradesh		Hybrid Bayer Bio Science Pvt. Ltd. Hyderabad
	HHB-67(I), RHB-177	Rajasthan		RSSC, Rajasthan
	WCC-75	Karnataka		GKVK, UAS(B)/KSSC / NSC
	PB 1705 (MH 2008) Hybrid	Rajasthan, Gujarat, Haryana, Punjab, Delhi, Madhya Pradesh and Uttar Pradesh	Short duration Crop Varieties	Bayer Bio Science Pvt. Ltd. Hyderabad
	B H B - 1 2 0 2 (Bikaner Hybrid Bajra-1202) (MH 1831)	Rajasthan		RRS, SKRAU, Bikaner (Raj.)
	HHB-67	Rajasthan	Suitable for Cultivation under Delayed Monsoon	RSSC, Rajasthan
	HHB-67 (I), RHB-177	Rajasthan		RSSC,GSSC, NSC
	WCC-75	Karnataka		GKVK, UAS(B)/KSSC / NSC
		GHB-558, GHB732 and GHB538	Gujarat	Suitable for Cultivation under Heat Stress

<b>5. Sorghum</b>	CSH-5, CSH-9, CSV-4, DSV-2	Karnataka	Suitable for Cultivation under Drought Stress	GKVK, UAS(B)/ KSSC / NSC
	Pant Chari 5, Pant Chari 7	Uttarakhand		GBPUA&T, Pantnagar;
	CSV-17	Rajasthan		ARS, Udaipur
	RVICSH 28 (Hybrid)	Madhya Pradesh		All India Coordinated Sorghum Improvement Project, Indore
	CSV 32F (SPV 2128)	Maharashtra, Tamil Nadu and Karnataka	Short duration Crop Varieties	IIMR, Hyderabad
	Phule Rohini(RPASV3)	Maharashtra		MPKV Rahuri, Maharashtra
	Phule Madhur (RSSGV 46)			AICSIP, Indore, MP
	RVICSH 28 (Hybrid)	Madhya Pradesh		
	JJ-983, JJ-1041, CSH-18	Madhya Pradesh	Suitable for Cultivation under Delayed Monsoon	RVSKVV, Gwalior
	Parbhani Moti	Maharashtra		VNMKV, Parbhani
	M35-1 (Muguthi-5-4-1)	Karnataka		GKVK, UAS(B)/ KSSC / NSC
	<b>Source: Maheswari et al., (2019)</b>			

## Improved Agronomic Practices

### a. Conservation Agriculture

Conservation Agriculture (CA) is a concept of resource- saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production level while concurrently conserving the environment” (FAO 2007). It can prevent losses of arable land while regenerating degraded lands. It promotes maintenance of a permanent soil cover (retention of adequate levels of crop residues on the soil surface), minimum soil disturbance (zero tillage), and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

### b. Irrigation and Fertilizer Efficiency

Efficient water and fertilizer application is crucial for optimizing crop yields, but excessive use has limited benefits. Developing countries like China, India, and others face water scarcity due to climate change, population growth, and industrial demands. Improving irrigation efficiency is essential for sustainable agriculture. The International Food Policy Research Institute (IFPRI) estimates a 21% increase in crop yields with improved irrigation efficiency. Studies in California highlight water use efficiency of 60–85% in surface irrigation, 70–90% in sprinkler systems, and 88–90% in drip irrigation. Thus using a drip irrigation system could effectively control water usage and help improve yields and reduce the quantity of water usage by more than 50% (Brouwer *et al.*, 1998). Furthermore, the use of fertilizer is another vital factor that directly impacts crop production. Over the past few decades, increase in crop production was reported because of the use of fertilizers. Currently, the usage of fertilizer is increasing in both developed and developing countries. However, long-term excessive application of fertilizers has been shown to have a negative effect on the soil and on the quality of cereal crop. Several studies revealed that over-fertilization can lead

to soil acidification. Furthermore, nitrogen leaching and ammonia volatilization also contribute to environmental issues in areas where urea and nitrogen-fertilizers are applied. Therefore, an emphasis has to be placed on using fertilizers at appropriate levels, which can save resources and avoid environmental pollution.

#### **c. Agro-ecological approaches**

Agroecological approaches offer sustainable solutions to enhance agricultural resilience and productivity. Agroforestry systems, which involve integrating trees with cereal crops, help provide shade, reduce temperature stress, and enhance biodiversity. Similarly, crop diversification, by cultivating a mix of cereal crops and legumes, spreads risk and improves the resilience of farming systems. Additionally, the use of cover crops plays a vital role in reducing soil erosion, improving moisture retention, and suppressing weed growth, thereby contributing to overall soil health and sustainable crop production.

#### **d. Alteration in sowing time**

Adjustment of sowing dates is also one of the important crop adaptation strategies. Adjustment of sowing times is facilitates to avoid heat or water stress during critical growth stages. Sowing time adjustment for a specific area or region could be fixed according to a changing climatic condition of this specific region or area. Furthermore, optimization of harvesting times reduces losses due to untimely rainfall or temperature fluctuations.

### **Water Harvesting**

Water harvesting refers to conservation of rainwater under unirrigated condition, by collecting runoff of precipitation in order to supplement soil moisture in an adjacent area. This technique of water conservation can help to mitigate water scarcity and improve crop yields. Some water harvesting techniques are Check dams, farm well, Rooftop harvesting, Watershed conservation.

### **Mitigation Strategies**

FAO (2012) suggested some obvious measures that governments could pursue for mitigation viz. reduction of GHGs (at the source) of the use of fossil fuels (clean coal technology, renewable energies), Capture of methane from landfills and rice paddies, Creation of sinks for storing carbon through natural resource management (carbon sequestration) with reducing tropical deforestation and increasing tree planting. The agricultural sector has a substantial potential for mitigation; as about 24% of the global greenhouse gas emissions is due to agriculture activities and deforestation.

The key mitigation technologies and practices suggested by IPCC (2007) are-

- ✓ Improved crop and grazing land management to increase soil carbon storage;
- ✓ Restoration of cultivated peaty soils and degraded lands; improved rice cultivation;
- ✓ Techniques and livestock and manure management to reduce CH<sub>4</sub> emissions;
- ✓ Improved nitrogen fertilizer application techniques to reduce N<sub>2</sub>O emissions;
- ✓ Dedicated energy crops to replace fossil fuel use; improved energy efficiency;
- ✓ Improvements of crop yields

- ✓ Afforestation; reforestation; forest management; reduced deforestation;
- ✓ Harvested wood product management;
- ✓ Use of forestry products for bioenergy to replace fossil fuel use;
- ✓ Tree species improvement to increase biomass productivity and carbon sequestration;
- ✓ Improved remote sensing technologies for analysis of vegetation/ soil carbon
- ✓ Sequestration potential and mapping Land-use change;
- ✓ Emissions from agriculture come mainly from nitrous oxide from soils, methane from ruminant livestock digestion, burning of living and dead vegetation, rice production and manure management. Land use, land-use change and forestry are responsible for GHG emissions; largely through tropical deforestation. However; the agriculture sector has also a relevant potential to absorb GHG from the atmosphere through carbon sinks. Carbon sinks can be created through carbon sequestration and conservation. Carbon sequestration refers to enhancing carbon storage in soils and biomass above and below ground- e.g. through afforestation, reforestation and re-vegetation, such as restoration of degraded lands, agro-forestry, crop land and grazing management. Whereas; carbon conservation refers to the conservation of carbon stocks in forests and agricultural systems, through improving management practices (e.g. selective felling, reduced impact logging), or conservation/ protection measures (forest conservation, soil conservation, fire protection), within forest and agricultural systems.

## Case Study

Wang *et al.*, (2018) reviewed from various research studies that the GWP and CEE is lowest from millets followed by sorghum field compared to other cereals (Table 4). Therefore, to reduce greenhouse emissions from agricultural activity, cultivating millets will be a better option, which in turn could be beneficial in reducing global warming. Furthermore, a comprehensive life cycle analysis must be performed on millets to confirm the lower GWPs when transportation and other factors are also included.

Table 4. Seasonal flux of global warming potential and carbon equivalent emission from soil under different crops.		
Crop	Global Warming Potential (Kg CO <sub>2</sub> eq. ha <sup>-1</sup> )	Carbon Equivalent Emission (Kg C ha <sup>-1</sup> )
Rice	2890–17,000	956–4600
Millet	3218	878
Wheat	2000–18,000	545–4900
Maize	3427–17,600	935–4800
Sorghum	3358	916
Rice-Wheat *	7137–18,000	2000–4900
Wheat-Maize *	12,880–18,850	3512–5100
* Values presented are for the cropping system (2 seasons). (Wang <i>et al.</i> , 2018)		

## Conclusion

Improved agricultural practices and advanced irrigation techniques have been proposed as solutions to address the challenges posed by global warming. Climate change, particularly the rise in ambient temperatures, is projected to reduce the yields of major cereal crops. To achieve global food security, millets emerge as a promising alternative due to their tolerance to high temperatures and their ability to thrive in marginal and suboptimal soil conditions. Moreover, millet production contributes to climate change mitigation as it emits fewer greenhouse gases compared to other major crops. Therefore, efforts must be directed toward promoting millet cultivation, enhancing its market value, and supporting farmers—particularly in developing countries—through policies, incentives, and improved market access.

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# Dynamics of Methane Emission in Agriculture

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## Introduction

Methane (CH<sub>4</sub>) is a powerful greenhouse gas, though it exists in the atmosphere in very low concentrations. It is the second most significant greenhouse gas after carbon dioxide (CO<sub>2</sub>). CO<sub>2</sub> accounts for roughly 50% of the enhanced greenhouse effect, while CH<sub>4</sub> contributes around 15–20% and nitrous oxide (N<sub>2</sub>O) about 6%. As a saturated hydrocarbon and the main component of natural gas, methane plays a major role in climate change due to its potency and abundance, particularly over a short time frame of 10–15 years. Methane is released during the extraction and transport of coal, natural gas, oil and also from livestock, agricultural activities, the decomposition of organic waste in landfills, and certain wastewater treatment processes. The total amount of methane emitted into the atmosphere is estimated to be 566 Tg per year (Thakur *et al.*, 2021).

Methane is generated in soil through the microbial decomposition of organic matter in anaerobic conditions. Submerged rice fields, therefore, serve as potential sources of methane. Prolonged water coverage, higher organic carbon content, and the application of organic manure in puddled soils all increase methane emissions. The burning of crop residues also contributes to the global methane budget. Another significant source of methane is enteric fermentation in ruminants (Pathak *et al.*, 2010). Methane is colorless, odorless, flammable, and explosive when present in the air at a carbon-to-air ratio of 1:10. The methane molecule has a tetrahedral structure, with weakly polarized bonds and no free electron pairs, contributing to its chemical stability. Lighter than air, methane's density at room temperature and 1 atm pressure is 0.657 kg/m<sup>3</sup> (Stępniewska *et al.*, 2004). A key environmental aspect of methane is its ability to absorb infrared radiation. Methane has a relatively short atmospheric lifetime of around 10 years (Stern *et al.*, 2007).

## Source and Sink of Methane Worldwide

Methane is emitted from a variety of natural and human-made sources. Anthropogenic emissions primarily stem from biogenic sources, including agriculture, livestock enteric fermentation, waste from cattle breeding, human waste in landfills and sewage treatment plants, rice fields, and biomass burning. Fossil fuel extraction and use are also significant contributors to methane emissions. Naturally, methane is released from wetlands, termites, wild ruminants, oceans, freshwater reservoirs, and from the decomposition of CH<sub>4</sub>-hydrate particles during glacier melting and volcanic eruptions (Minami and Takata, 1997). Human activities contribute around 70% of global methane emissions, while natural sources like wetlands, oceans, and termites were the dominant contributors until the 20<sup>th</sup> century. The rise in livestock production and fossil fuel consumption are the primary causes of the recent increase in atmospheric methane levels (IPCC, 2019).

The main sources of methane emissions are biological processes in soil and near the soil surface, with additional emissions from fossil fuel energy production and biomass burning. Natural sources, such as wetlands and lakes, account for nearly one-third of global methane emissions. The remaining two-thirds come from human activities, including fossil fuel use (~20%), paddy

rice cultivation (~10%), enteric fermentation in ruminants (~15%), biomass burning (~7%), and waste from landfills, animals, and domestic sewage (~5% each). Soils act as a minor sink for methane, oxidizing approximately 6% of it through microorganisms in aerobic conditions. The primary removal process for atmospheric methane is oxidation by hydroxyl (OH<sup>-</sup>) radicals in the upper atmosphere, particularly in the troposphere, which accounts for around 94% of methane removal. This process converts methane into carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O) (Fowler *et al.*, 2009). In anaerobic environments with low sulfate and nitrate concentrations, the complete breakdown of organic matter occurs through methanogenic fermentation, producing methane and carbon dioxide, as represented by the equation:  $C_6H_{12}O_6 \rightarrow 3 CO_2 + 3 CH_4$ .

#### a. Role of Methane in Global warming

The atmospheric warming potential of methane is 28-36 times greater than that of carbon dioxide (CO<sub>2</sub>). In 2021, atmospheric methane levels averaged 1.89 ppm, and by June 2024, they had increased to 1.92 ppm. Methane is one of several gases which act as a sort of blanket between the earth and the stratosphere. By trapping the energy from the sun's rays, they retain heat and warm the atmosphere. Methane is responsible for around 30% of the rise in global temperature. Methane emissions contribute to global temperature rise 1.5°C from 1900 AD (IPCC).

### Methane Emission from Soil

Methane (CH<sub>4</sub>) emissions from soil are a significant contributor to the global methane budget. Methane is a greenhouse gas that is produced in soil when organic matter is reduced in the absence of oxygen. Methane is produced from the soil by activity of methane forming bacteria called methanogens (example – *Methanosarcina barkeri*, *Methanococcus marisnigri*) through the application of fertilizer in anaerobic condition of soil. Methanogens bacteria produce methane as a byproduct of anaerobic decomposition. In the high nitrogenous soil nitrate can be reduced by microbial processes and enhancing the production of methane.

### Factors Affecting Methane Emission from The Soil

#### a. Anaerobic Conditions and Redox Potential

The anaerobic decomposition of organic matter generates organic substrates for methanogens. Significant methane (CH<sub>4</sub>) emissions occur when soil redox potentials fall below approximately -100 mV (Hou *et al.*, 2000). Under these anoxic conditions, such as in flooded soils, Fe<sub>3</sub><sup>+</sup> is reduced to Fe<sub>2</sub><sup>+</sup>, creating a strong correlation between CH<sub>4</sub> emission rates, soil redox potential, and Fe<sub>2</sub><sup>+</sup> concentrations in anaerobic environments (Mohanty *et al.*, 2001). Adding organic carbon substrates like plant residues to flooded soils further lowers the redox potential, leading to increased CH<sub>4</sub> emissions. For example, Bossio *et al.*, (1999) observed that incorporating rice straw into soil lowered the redox potential by 50 mV (to -275 mV), compared to burning it (-225 mV). After four years of straw incorporation, CH<sub>4</sub> emissions were five times higher (92 kg CH<sub>4</sub> per hectare) than in the burned straw treatment (19 kg CH<sub>4</sub> per hectare) during the rice growing season.

## **b. Substrate Availability**

Carbon (C) substrates for methanogens are derived from the anaerobic decomposition of soil organic matter, microbial biomass, roots and root exudates, as well as organic matter introduced to the soil from aboveground sources like leaf litter and plant biomass. Under anaerobic conditions, methane (CH<sub>4</sub>) production is influenced by the availability of C substrates from organic matter mineralization, the reduction of terminal electron acceptors (such as Fe<sub>3</sub><sup>+</sup>, Mn<sup>4+</sup>, SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub><sup>-</sup>), and the activity of methanogens (Segers 1998). Generally, CH<sub>4</sub> production and methanogenic activity are recognized in four phases.

In the first phase, CH<sub>4</sub> production is low due to the low concentration of acetate, although CO<sub>2</sub> production is high. In the second phase, terminal electron acceptors deplete hydrogen (H<sub>2</sub>), which limits CH<sub>4</sub> production due to H<sub>2</sub> scarcity, while acetate concentration increases and CO<sub>2</sub> production stabilizes or slows. In the third phase, with terminal electron acceptors depleted, concentrations of acetate and H<sub>2</sub> rise, leading to an increase in CH<sub>4</sub> production and a decrease in CO<sub>2</sub> production. In the fourth phase, carbon mineralization restricts the production of acetate and other C substrates, causing CH<sub>4</sub> and CO<sub>2</sub> production rates to decrease and stabilize (Segers 1998).

## **c. Temperature**

In anaerobic soil conditions, methane (CH<sub>4</sub>) production increases as temperature rises. The Q<sub>10</sub> value for CH<sub>4</sub> production ranges from 1.1 to 28.0, with an average of about 4.0, depending on factors such as substrate type, available electron acceptors, and the specific thermal and temporal conditions of the measurement (Park *et al.*, 2005). The optimal temperature for CH<sub>4</sub> production is approximately 35°C (Rath *et al.*, 2002), although this can vary based on factors like the type of carbon substrate, vegetation, plant cultivar, stage of plant growth, soil composition, soil moisture, and pH.

## **c. Diffusion**

The diffusion of oxygen to the site of methane (CH<sub>4</sub>) production is the main factor controlling methanogenesis. This process is influenced by the soil matrix (structure and texture), soil moisture or water-filled pore space (WFPS), and, conversely, air-filled pore space and bulk density, which impact the path of O<sub>2</sub> diffusion. CH<sub>4</sub> emissions from soil to the atmosphere primarily occur through the aerenchyma of aquatic and wetland plants (over 80%) with the remaining emissions coming from diffusion and ebullition (less than 20%) (Cheng *et al.*, 2006). In unvegetated systems, however, diffusion and ebullition contribute to more than 90% of total CH<sub>4</sub> emissions (Whalen 2005). A significant portion of the CH<sub>4</sub> produced is oxidized as it diffuses through the soil, across the soil-water interface and at the soil-root interface (Le Mer and Roger 2001).

## **d. Water Availability and Water Table**

Water availability controls the microbial activity, C mineralization and substrate availability, and oxygen diffusion and hence the extent of anaerobic conditions and redox potential. Height of the water table also has significant effect on the rate of CH<sub>4</sub> emission from submerged soils. In general, CH<sub>4</sub> emission is positively correlated with the height of the water table.

#### **e. Soil pH and Salinity**

Methanogenic activity and methane (CH<sub>4</sub>) production can occur across a wide range of pH levels, from pH <4 to pH >9. However, optimal CH<sub>4</sub> production takes place within a narrower pH range of 5–7.5, and within this range, CH<sub>4</sub> production is positively correlated with soil pH, except in acidic soils with a pH <5. Generally, as salinity increases, the rate of CH<sub>4</sub> emission decreases, as seen in intertidal coastal wetlands in subtropical Australia and India. Similarly, in paddy rice fields, an increase in salinity from 0.8 dS/m to 4 dS/m led to a 25% reduction in CH<sub>4</sub> emission rates (Denier van der Gon and Neue 1995).

#### **f. Vegetation, Plant Species and Cultivars**

Vegetation growing in and around aquatic habitats, particularly plants with aerenchyma, can serve as an essential pathway for transporting methane (CH<sub>4</sub>) from the soil and water to the atmosphere. CH<sub>4</sub> primarily enters the plant roots through diffusion across the epidermis and then into the aerenchyma, with a smaller contribution from water uptake. As CH<sub>4</sub> moves from the soil into the root system, oxygen diffuses from the roots into the soil, creating a relatively oxygen-rich zone in the rhizosphere. Methane produced by methanogenic archaea in the soil is partially oxidized to carbon dioxide (CO<sub>2</sub>) by methanotrophic bacteria in the rhizosphere. As a result, the total CH<sub>4</sub> production in the soil may be much higher (50–200%) than the amount emitted to the atmosphere (The *et al.*, 2005).

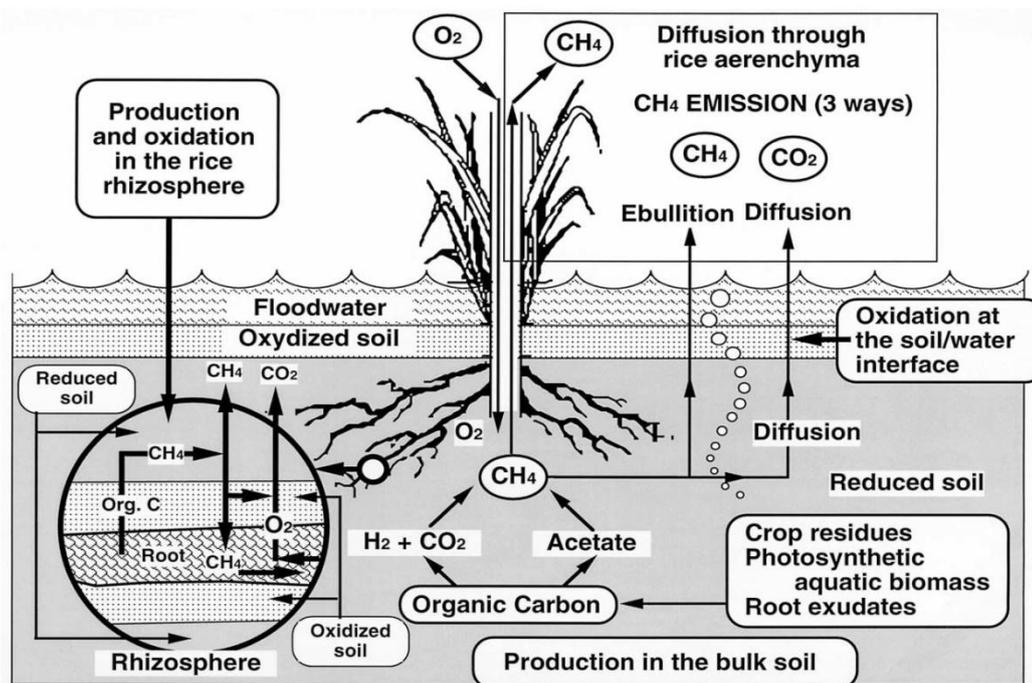
#### **g. Methane Oxidation and Consumption in Soil**

Into the soil various kind of microorganism founds that consume and oxidize atmospheric methane. Methane (CH<sub>4</sub>) oxidizers and consumers need oxygen (O<sub>2</sub>) to oxidize methane (CH<sub>4</sub> + 2O<sub>2</sub> → CO<sub>2</sub> + 2H<sub>2</sub>O; ΔG° = -818 kJ/mol). These microorganisms are generally classified into two main groups: methane-assimilating bacteria and autotrophic ammonium-oxidizing bacteria. These bacteria is very helpful for reduction of methane level into atmosphere as well as helps in low methane emissions from different processes.

### **Methane Emission from Rice Field**

Rice fields were first recognized as sources of atmospheric methane (CH<sub>4</sub>) in the 1960s. In 2000, global CH<sub>4</sub> emissions from rice fields were estimated at 25.6 Tg per year. According to the latest summary from the IPCC, rice fields now emit between 31 and 112 Tg of CH<sub>4</sub> annually (1 Teragram, Tg = 10<sup>12</sup> g) (D.C. Uprety *et al.*, 2011). Methane is produced during the growing season in paddy soils through the activity of methanogenic bacteria, particularly when the fields are flooded. Methane escapes the soil through bubbling, diffusion, and also through the rice stems. Therefore, the variety of rice and soil type plays a significant role in emissions. Draining the fields halts methane production due to aeration. Additionally, the presence of sulfate and gypsum reduces methane formation. Consequently, methane emissions from rice depend on factors such as the duration of flooding, climate, soil type, management practices, and the type, amount, and method of fertilizer application. Minami (1994) reported that emissions increase when rice straw is applied to fields. Estimating global methane emissions from rice fields has been challenging due to the lack of data on the area of irrigated, rainfed, deep-water, and upland rice. However, rainfed and irrigated rice fields contribute significantly to emissions, while other types contribute less. The IRRI (1988) provides data on the area of wetland rice, indicating that

about 80 million hectares of harvested wetland rice are a potential source of methane. Based on this data and experimental results, Neue *et al.*, (1990) estimated average emissions of 200-500 mg/m<sup>2</sup> during an average growing season of 130 days (Fig.-1).



**Fig.1** Production, consumption and transfer of CH<sub>4</sub> to the atmosphere in rice fields (Mer Roger, 2001)

<b>Table-1. Methane emissions from rice fields accounted by various authors (Rice emissions are in unit of Tg CH<sub>4</sub>/yr).</b>				
<b>Base Year</b>	<b>Life Time of Methane</b>	<b>Type of Estimates</b>	<b>Rice</b>	<b>Reference</b>
1980s	8.6	Top down	60	IPCC(1996)
1990	8.3	Top down	88	Hein <i>et al.</i> , (1997)
1992	7.9	Top down	115-175 (including wetland)	Lelieveld <i>et al.</i> , (1998)
1993	-	Top down	80	Houweling(1999)
2003	-	Top down	48.7	Bergamaschi(2007)
2000	-	Top down	54	IPCC(2007)
2010	-	Bottom up	29	Van Amstel(2012)

\*Top Down- Atmospheric methane measurement emissions from large areas or regions by satellites & aircraft.

\*Bottom up- methane measurement at source level such as on-site monitoring and surveys.

Water management is one of the key factors influencing methane emissions. The emission pattern from rice fields shows that peaks in methane flux are closely linked to soil moisture content. Continuously saturated rice fields produce higher methane emissions compared to fields with intermittent wetting and drying conditions (Pathak *et al.*, 2003). On average, methane emissions in saturated soils ranged from 0.3 to 0.6 kg ha<sup>-1</sup> d<sup>-1</sup>, while in intermittently wet and dry soils, emissions ranged from 0.1 to 0.4 kg ha<sup>-1</sup> d<sup>-1</sup>. Saturated soils create anaerobic conditions favorable for methane production, as methanogens are strict anaerobes. When these soils dry out and become aerobic, methane production nearly ceases.

The application of manure, such as farmyard manure (FYM), increases methane emissions by supplying organic carbon and nitrogen, which are essential for microbial activity and act as a source of electrons. Replacing 50% of inorganic nitrogen with FYM increased methane emissions by 172% compared to applying the full amount of nitrogen through urea (Pathak *et al.*, 2003). In another study, methane emissions were lowest (28.4 kg ha<sup>-1</sup>) in unfertilized fields and highest (41.3 kg ha<sup>-1</sup>) when the entire nitrogen amount was applied through organic sources (Bhatia *et al.*, 2005). However, the use of biogas slurry reduced methane emissions by 2.3 times compared to FYM, suggesting that biogas slurry is a more effective option for mitigating methane emissions (Debnath *et al.*, 1996).

Other factors that significantly influence methane emissions include organic carbon content, total nitrogen content, soil texture, and cation exchange capacity. The topsoil (0–15 cm layer) is responsible for the majority (99%) of methane emissions, with the subsoil contributing much less (Mitra *et al.*, 2002). Different rice cultivars exhibit substantial variation in methane emissions. For instance, the seasonal methane emissions were highest for Pusa 933 (27.2 kg ha<sup>-1</sup>) and lowest for Pusa 169 (15.6 kg ha<sup>-1</sup>), with intermediate values for other cultivars in descending order of Pusa 1019, Pusa Basmati, Pusa 834, and Pusa 677 (Mitra *et al.*, 1999). Additionally, nitrification inhibitors, such as neem-coated urea, coated calcium carbide, neem oil, and dicyandiamide (DCD), which slow down nitrification in soil, have been shown to reduce methane emissions by 10–15% (Malla *et al.*, 2005).

### **Methane emissions from rice residue burning**

Crop residues from agricultural fields include materials such as stalks, stubble (stems), leaves, and seedpods, while agro-industrial residues like sugarcane bagasse, husk, and molasses are also generated (Hoorweg and Bhada-Tata 2012). Typically, crop residues are used in various ways, including as animal feed, in mushroom production, as industrial feedstock, bedding for livestock, mulching material, construction materials, fuel for industrial/domestic purposes, and in composting or green manuring. The reasons for burning crop residues are varied and include: (a) insufficient facilities for proper management and disposal, (b) low fodder value of some residues, (c) interference with the tillage process, (d) it being a cost-effective and quick method to prepare land for the next crop, (e) labor shortages, (f) poor degradability of certain crop residues, (g) weed control, (h) pest and disease management, (i) lack of awareness of the environmental impacts, and (j) limited time between harvesting Kharif crops and sowing Rabi crops. Burning one ton of straw results in the emission of 3 kg of particulate matter (PM), 60 kg of carbon monoxide (CO), 1460 kg of carbon dioxide (CO<sub>2</sub>), 199 kg of ash, and 2 kg of sulfur dioxide (SO<sub>2</sub>) (Lohan *et al.*, 2018). Burning straw releases about 70% of the carbon as CO<sub>2</sub>, 7% as CO, 0.66% as CH<sub>4</sub>, and

2.09% of nitrogen as nitrous oxide (N<sub>2</sub>O). Around 85% of CH<sub>4</sub> emissions from Field Burning of Agricultural Residues (FBAR) come from rice, wheat, and sugarcane.

<b>Table-3</b> Amount of crop residue generated, burnt, and GHG emissions in India over the years and their projected emissions				
<b>Year</b>	<b>Residue generatet (Tg)</b>	<b>Residue burnt (Tg)</b>	<b>CH<sub>4</sub> (Gg)</b>	<b>Reference</b>
2000	163	36	110	(Gupta <i>et al.</i> , 2004)
2003-04	375	89	547	(Ravindra <i>et al.</i> , 2019)
2005	239	60	164	(Sahai <i>et al.</i> , 2011)
2008-09	620	98	-	(Jain <i>et al.</i> , 2014)
2010	253	63	174	(Sahai <i>et al.</i> , 2011)
2017-2018	516	116	313	(Venkatramanan <i>et al.</i> , 2021)
* Tg= Teragrams (10 <sup>12</sup> g) *Gg= Gigagrams (10 <sup>9</sup> g)				

## Mitigation of Methane Emissions from Rice Field

### a. Crop Diversifications

Cumulative methane (CH<sub>4</sub>) emissions from tropical rice ecosystems can be reduced by cultivating appropriate upland crops, which shorten the period of soil submergence during the annual cropping cycle. The highest CH<sub>4</sub> flux occurred in a rice-rice rotation, while the rice-potato-sesame rotation proved to be the most effective cropping system in terms of minimizing greenhouse gas emissions. Introducing crop diversification in lowland rice ecosystems could be a practical strategy for reducing overall CH<sub>4</sub> emissions.

### b. Water Management

Four different drainage systems continuous flooding, tillering stage drainage, mid-season drainage, and multiple drainage were found to be highly effective in reducing methane (CH<sub>4</sub>) efflux from paddy fields. Mid-season drainage reduced CH<sub>4</sub> efflux by 36.7% compared to continuous flooding, while multiple drainage resulted in a 41% decrease in CH<sub>4</sub> efflux. The International Rice Research Institute (IRRI) in the Philippines developed an alternate wetting and drying (AWD) technology for methane mitigation, which not only improves water use efficiency but also boosts rice productivity. This technique can cut CH<sub>4</sub> emissions by 50% compared to rice grown under continuous flooding.

### c. Biological Mitigation

Use of biological measure to lessen the negative impacts of hazardous event. Selecting and cultivating rice cultivars that allocate the majority of their photosynthates to panicle growth and

grain development, rather than to vegetative growth (such as roots, leaf sheaths, and culms), is an effective biological strategy for mitigating methane (CH<sub>4</sub>) emissions through conversion of food into grains and production of biomass is minimum. Higher biomass production produces more methane by various ways like burning and decomposing.

#### **d. Chemical Fertilizer Amendments Technology**

The addition of nitrate as a chemical fertilizer to flooded soils reduces methane (CH<sub>4</sub>) production by altering the soil's redox potential. The lowest CH<sub>4</sub> emissions were observed in plots treated with a mixture of prilled urea and Nimin, a nitrification inhibitor that prevents the autotrophic oxidation of NH<sub>4</sub><sup>+</sup> to NO<sub>2</sub>. Kimura *et al.*, suggested that foliar applications of nitrogen fertilizers could also reduce CH<sub>4</sub> fluxes from flooded paddy soils. Fertilizers containing ammonical nitrogen (NH<sub>4</sub><sup>+</sup>-N) inhibit CH<sub>4</sub> uptake in terrestrial ecosystems. Three main mechanisms have been proposed to explain the inhibitory effect of nitrogenous fertilizers, particularly NH<sub>4</sub><sup>+</sup>-N fertilizers, on CH<sub>4</sub> oxidation.

- (i) An immediate inhibition of methanotrophic enzyme system;
- (ii) Secondary inhibition through NO<sub>2</sub><sup>-</sup> production from methanotrophic NH<sub>4</sub><sup>+</sup> oxidation;
- (iii) Dynamic alteration of microbial communities of soil.

#### **e. Potassium Fertilizer Application Technology**

Muriate of Potash (MOP) significantly lowered methane (CH<sub>4</sub>) emissions from flooded alluvial soil planted with rice. Potassium application helped maintain the redox potential, reduced the levels of active reducing substances, and lowered Fe<sub>2</sub><sup>+</sup> concentrations in the rhizosphere soil. In addition to promoting higher biomass and grain yield, potassium amendments can effectively reduce CH<sub>4</sub> emissions from flooded soils.

#### **f. Incorporation of Green Manure**

Dual cropping of Azolla alongside urea significantly reduces methane (CH<sub>4</sub>) emissions without affecting rice yields, making it a practical mitigation option for minimizing CH<sub>4</sub> flux from flooded paddy fields. Additionally, using composted livestock manure in rice cultivation helps mitigate CH<sub>4</sub> emissions while re-utilizing livestock waste. Green manure increased rice yield while mitigating CH<sub>4</sub> emissions and lowered the dissolved organic carbon in the soil, limiting the substrates available for methanogens and regulated the activities of methanogens.

#### **g. Time of Transplanting**

In rainfed rice cultivation, late transplanting with older seedlings can lead to a substantial reduction in CH<sub>4</sub> emissions without negatively impacting yield. By adopting a more integrated approach to rice paddy irrigation and fertilizer application, significant reductions in CH<sub>4</sub> emissions can be achieved:

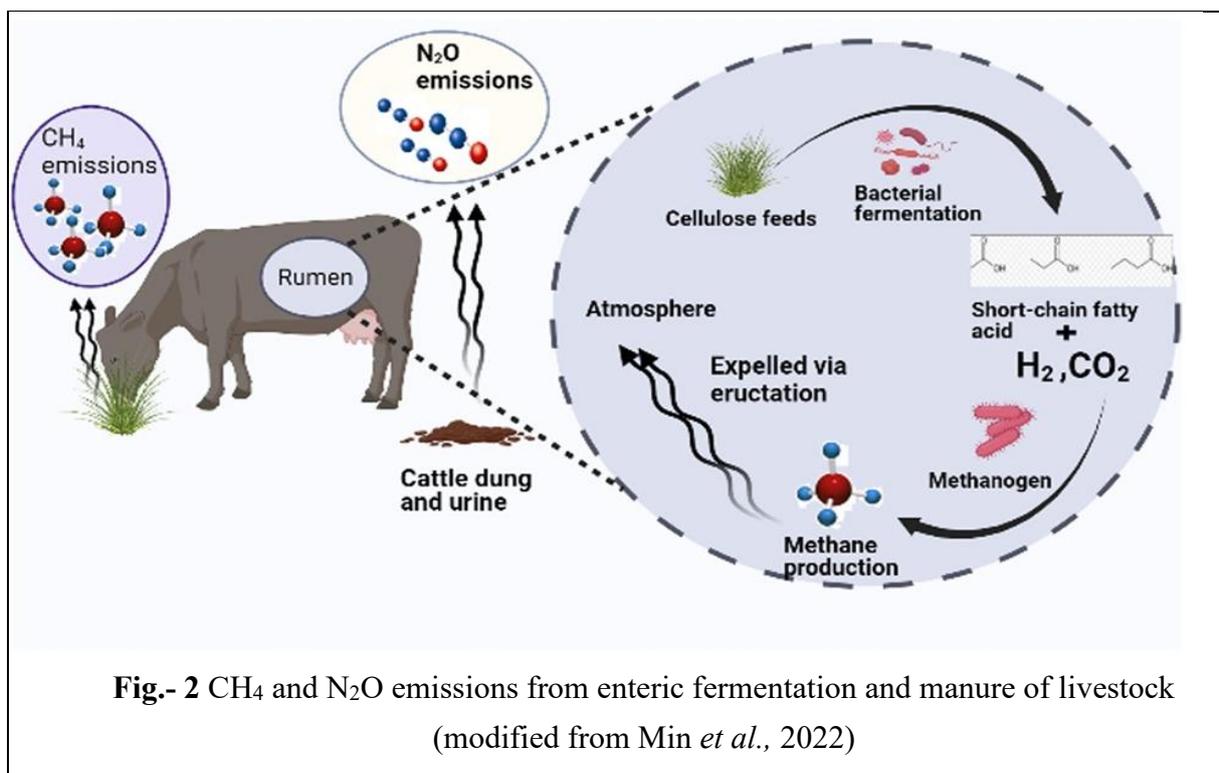
- i) Growing rice varieties in drier conditions can notably reduce CH<sub>4</sub> emissions without any loss in yield.
- ii) Improved rice varieties have the potential to produce larger crops per unit area, further reducing CH<sub>4</sub> emissions without decreasing rice production.
- iii) Adding compounds like ammonium sulfate, which promote the activity of microbial groups other than methanogens, has been effective in reducing CH<sub>4</sub> production in rice fields.

<b>Table-2</b> Studies showing CH <sub>4</sub> mitigation in rice cultivation using various methods		
<b>Objective/method</b>	<b>Emission reductions</b>	<b>References</b>
AWD irrigation system over continuous flooding of rice	20–70% of CH <sub>4</sub>	(Richards and Sander 2014)
Use of sprinkler irrigation over continuous flooding over the 3-year experiment	40% CH <sub>4</sub>	(Fangueiro <i>et al.</i> , 2017)
System of rice intensification (SRI) practices	CH <sub>4</sub> by 59.2%	(Mboyerwa <i>et al.</i> , 2022)
Bio-fertilization using blue-green algae and Azolla over control	CH <sub>4</sub> by 37.9%	(Senthilraja <i>et al.</i> , 2023)
Short-duration rice cultivars with delayed transplantation over long-duration cultivars	CH <sub>4</sub> (12%)	(Kaur <i>et al.</i> , 2024)

### **Methane Emission from Livestocks**

The rumen, located at the beginning of the digestive tract in ruminants, contains various types of microbes, including bacteria, protozoa, and fungi, which play a crucial role in breaking down lignocellulosic food that human cannot digest (Moumen *et al.*, 2008). These microbial activities are vital for the digestion of structural carbohydrates and the synthesis of high-quality microbial protein. The anaerobic fermentation of feed in the rumen results from both physical and microbiological processes, which convert dietary components into useful products, such as volatile fatty acids (VFA) and microbial protein, as well as by-products like methane and carbon dioxide, which are less beneficial to the host animal (Li *et al.*, 2014). Methane is produced during the fermentation of organic matter in the rumen, contributing to a 2–12% loss of gross energy (GE), which impacts the performance of ruminants (Ingale *et al.*, 2013; Li *et al.*, 2014). Over the past 150 years, methane levels have more than doubled due to human activities, such as fossil fuel use and intensive farming.

Approximately 37% of global agricultural methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions come from animal sources, with the remainder linked to cropping and deforestation (EPA, 2011). Ruminant livestock, including cattle, buffalo, sheep, and goats, are responsible for the majority of methane emissions from agriculture (Fig.-2).



**Fig.- 2** CH<sub>4</sub> and N<sub>2</sub>O emissions from enteric fermentation and manure of livestock  
(modified from Min *et al.*, 2022)

### Mitigation Options for Enteric Methane Emissions

Methane and CO<sub>2</sub> are the primary by-products of microbial fermentation of carbohydrates in the rumen, both of which are greenhouse gases. Methane is generated in the anaerobic environment of the rumen by archaea. In ruminants, most enteric methane production occurs in the reticulo-rumen, with only a small portion of emissions coming from rectal emissions (Munoz *et al.*, 2012).

#### a. Dietary Composition

The type of feed provided to ruminants significantly influences methane production. Studies on enteric methane emissions from sheep and cattle reveal an inverse relationship between feed intake and methane yield, indicating potential opportunities to reduce methane emissions per unit of feed and animal production. Most of these studies have focused on animals fed conserved feeds, particularly silages and grains (Hammond *et al.*, 2013). When forages were fed at the maintenance level of nutrition, methane energy loss was 6 to 7% of gross energy intake (GEI), which decreased to 2-3% when high-grain concentrates (>90%) were fed. Additionally, grinding and pelleting forages can significantly reduce methane production (Moss *et al.*, 2000). The relationship between methane emissions and dry matter intake (DMI) or GEI is not fixed; it decreases as intake increases. Consequently, methane emissions per energy-corrected milk (ECM) decrease as DMI and milk yield rise (Knapp *et al.*, 2014).

#### b. Genetic Selection of Animals

An effective and cost-efficient long-term mitigation strategy would involve utilizing natural variation to breed animals with lower methane (CH<sub>4</sub>) yield. Yan *et al.*, (2010) found that selecting dairy cows with high milk production and energy utilization efficiency is an effective approach to reduce CH<sub>4</sub> emissions from lactating cows.

Key approaches to reducing emissions include:

- (i) Improving productivity and efficiency in livestock management
- (ii) Minimizing wastage within the farming system
- (iii) Selecting animals based on measurable emissions when possible.

### **c. Lipid Additions**

Dietary fat presents a promising nutritional strategy for reducing ruminal methane production without lowering ruminal pH, unlike concentrates. Lipids, including fatty acids and oils, have been explored both *in vitro* and *in vivo* for their impact on methanogenesis. Adding oils to ruminant diets has been shown to reduce methane emissions by up to 80% *in vitro* and about 25% *in vivo* (Singh, 2010). Oils from plants like coconut kernel, sunflower seeds, and cottonseed are potential candidates for mitigating enteric methane production.

For example, supplementing 5% linseed oil of dry matter (DM) to lactating dairy cows resulted in a 55.8% decrease in methane emissions per day. Among oils, coconut oil is widely used for methane reduction, with its effectiveness varying from 13–73%, depending on factors such as inclusion level, diet, and ruminant species (Machmüller *et al.*, 2000).

### **d. Bacteriocins**

The potential to enhance animal productivity through the use of bacteriocin-producing bacteria (BPB) lies in their ability to inhibit specific microbial groups (Russell and Mantovani, 2002). BPB that produce bacteriocins capable of targeting methanogenic bacteria could improve feed efficiency by reducing methane emissions, thereby minimizing the carbon lost as methane. Additionally, bacteriocins could support the dominance of cellulolytic bacteria, such as *Streptococcus bovis*, in the rumen, leading to improved cellulose degradation.

### **e. Vaccine**

There are concerns regarding the safety of adding chemical additives to livestock diets, as all animal products (such as milk, meat, and eggs) are eventually consumed by humans, raising questions about their safety. To address this, a novel artificial immunity technique has been developed to enhance nutrient utilization in farmed ruminants and, more recently, to reduce methane emissions. This technique involves injecting a vaccine into animals to stimulate their immune system to produce antibodies against methanogens (Clark, 2013). In a study by Wright *et al.*, (2004), two vaccines, VF3 (based on three methanogen strains) and VF7 (based on seven methanogen strains), resulted in a 7.7% reduction in methane per dry matter intake (DMI). However, they estimated that the vaccine, prepared with three *Methanobrevibacter* strains, targeted only 20% of the methanogens. In another study, the same research group developed a vaccine using five methanogen strains, administered in three doses to sheep. Although this vaccine targeted 52% of the methanogens in the sheep's rumen, methane output actually increased by 18% following vaccination (Williams *et al.*, 2009).

### **f. Defaunation**

Defaunation, the process of removing protozoa from the rumen, has been used to explore the role of protozoa in rumen function and their impact on methane production. Methanogens have been found to be associated with protozoal species, suggesting possible hydrogen transfer between the two. It is estimated that methanogens, both intracellularly and extracellularly associated with

ciliate protozoa, are responsible for 9 to 37% of methane production in the rumen (McAllister and Newbold, 2008). The removal of protozoa from the rumen has been linked to reduced methane production. However, the effect of defaunation on methane output appears to be diet-dependent. Additionally, a study found that removing protozoa and feed particles from rumen contents via centrifugation led to the removal of 76% of the methanogens present. Depending on the diet, protozoa elimination could reduce methane production by up to 50% (Hegarty, 1999).

#### g. Ionophores

Ionophores, such as monensin, are antimicrobials commonly used in ruminant livestock to enhance performance. Recent studies have demonstrated that monensin can reduce methane production by mixed rumen microbes in vitro (van Nevel and Demeyer, 1992). This effect is thought to result from the selective antimicrobial action of monensin on rumen microbes. It inhibits gram-positive microorganisms that supply methanogens with substrates necessary for methanogenesis. At the same time, monensin favors the growth of gram-negative microorganisms, leading to a shift towards propionate production in the rumen (Russell and Storbel, 1989). Thus, it is hypothesized that monensin reduces methane production not by directly inhibiting methanogens, but by limiting the growth of bacteria and protozoa that provide substrates for methanogenesis.

#### h. Plants Secondary Compounds

Certain plant extracts, which are rich in bioactive compounds such as saponins, tannins, and essential oils (EOs), show potential for inhibiting methane production in the rumen. However, the exact mechanisms and effects of many plant secondary metabolites (PSM) on rumen methanogenesis are not yet fully understood (Patra and Saxena, 2010). In recent years, there has been growing interest in supplementing ruminant diets with plant extracts to mitigate CH<sub>4</sub> emissions. These plant-based alternatives are gaining popularity as they are seen as more natural alternatives to chemical additives and are more favorably accepted by consumers.

**Table 4.** CH<sub>4</sub> emission reductions in livestock by various methods

Objective/method used	Emission reductions	References
Acidification of cattle slurry during storage	67–87% of CH <sub>4</sub>	(Petersen <i>et al.</i> , 2012)
Improved fertility in dairy cattle	10–24% of CH <sub>4</sub>	(Grossi <i>et al.</i> , 2019)
Forage with lower fiber content straw that have high flavonoids and phenols	49.3% and 26.8% of CH <sub>4</sub> respectively	(Bhatt <i>et al.</i> , 2021)
Utilizing crop byproducts as feed without affecting the production and health of dairy cows	13.46% reduction in enteric emissions	(Wang <i>et al.</i> , 2024)
Proper collection and storage of solid manure	25-30 % of CH <sub>4</sub>	(Tagaeva and Savina 2024)
Pyrolysis to treat manure	80-90 % of CH <sub>4</sub>	-

Feeding seaweeds, viz., <i>Asparagopsis armata</i> steeped in edible oil (AspOil) in dairy cows at different bromoform concentrations	Up to 38% of CH <sub>4</sub> Production	(Alvarez-Hess <i>et al.</i> , 2024)
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### Mitigation Options for Manure Methane Emissions

Manure management involves various processes such as the accumulation of manure in animal houses, its collection, storage, processing, and application, as well as its direct deposition on pasture. During these activities, emissions of CH<sub>4</sub>, N<sub>2</sub>O, and NH<sub>3</sub> occur. While NH<sub>3</sub> is not a greenhouse gas (GHG), it can lead to indirect N<sub>2</sub>O emissions. The majority of CH<sub>4</sub> emissions from manure are produced under anaerobic conditions during storage, with minimal emissions occurring during land application. Various methods can be employed to mitigate the methane emission which emits from the mismanage manures.

#### a. Feeding

Feed additives can significantly reduce CH<sub>4</sub> emissions from pig and poultry manure. For instance, adding thymol to sow diets has been shown to decrease CH<sub>4</sub> emissions from sow manure by up to 93% (Varel and Wells, 2007).

#### b. Housing

The impact of housing on CH<sub>4</sub> emissions is relatively minor since the primary source of CH<sub>4</sub> is from animal eructation. However, CH<sub>4</sub> emissions from manure are much higher in dairy barns where manure is stored for extended periods (such as in gravity-flow systems) compared to barns where manure is frequently removed (such as in flush systems).

#### c. Storage

During manure storage, CH<sub>4</sub> is emitted under anaerobic conditions. One method to reduce these emissions is to cover manure stores. The effectiveness of the cover depends on various factors, including its permeability, thickness, degradability, and management. Semi-permeable covers help reduce NH<sub>3</sub>, CH<sub>4</sub>, and odors, while impermeable covers can be more effective if the CH<sub>4</sub> captured is burned using a flare system or engine-generator to produce electricity (Hristov *et al.*, 2013). Additionally, mechanical or intermittent aeration of manure during storage can reduce CH<sub>4</sub> emissions. In cold climates, storing manure outside and cooling it to around 10°C can also help mitigate CH<sub>4</sub> emissions.

#### d. Composting

Composting offers several advantages in manure management, including better odour control, moisture management, pathogen reduction, organic matter (OM) stabilization, and increased farm profitability (Hristov *et al.*, 2013). The most significant benefit of composting is the reduction in CH<sub>4</sub> emissions when compared to the storage of manure under anaerobic conditions. Even in worst-case scenarios, the increase in nitrogen (N) emissions is minimal relative to the substantial reduction in CH<sub>4</sub> emissions, making composting a highly effective mitigation strategy.

#### e. Anaerobic digestion

Anaerobic digestion is a process where organic material is broken down by microorganisms in the absence of oxygen, producing methane (CH<sub>4</sub>), carbon dioxide (CO<sub>2</sub>), and other gases as by-products. Anaerobic digesters serve as a source of renewable energy, generating biogas that typically contains 60% to 80% CH<sub>4</sub>, depending on the substrate and operational conditions. The

use of anaerobic manure digesters is highly recommended as an effective strategy for mitigating CH<sub>4</sub> emissions.

#### **f. Manure application**

Subsurface injection of manure slurries into the soil can result in localized anaerobic conditions surrounding the buried liquid manure, which, together with an increased degradable C pool, may result in higher CH<sub>4</sub> emissions than with surface applied manure. Apply the manure to the land during periods of good weather and soil conditions.

#### **g. Pyrolysis to treat manure**

Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen and can be used to treat manure, transforming into valuable products such as biochar, bio-oil and syngas. This process can help manage manure waste, reduce greenhouse gas emissions and produce energy. Pyrolysis involves heating organic material, such as manure to high temperature (typically between 300°C and 700°C) in the absence of oxygen. This process breaks down complex organic compounds into simpler substances, producing solid, liquid and gas products.

### **Government Policies Related to Mitigation of Methane Emissions from Agriculture**

In 2014, the Government of India introduced the **National Policy for Management of Crop Residue (NPMCR)** to address the challenges of crop residue management. This initiative is part of the broader framework of India's **National Action Plan on Climate Change (NAPCC)**, launched on June 30, 2008, which encompasses eight National Missions aimed at combating climate change and promoting sustainable development. These missions align with the nation's greenhouse gas (GHG) emission reduction goals, particularly within the agricultural sector.

One key initiative under the NAPCC is the **National Mission for Sustainable Agriculture (NMSA, 2014)**, which includes the **Paramparagat Krishi Vikas Yojana (PKVY, 2015)**. This sub-component focuses on promoting sustainable organic farming practices that integrate modern and traditional knowledge to preserve soil fertility, conserve resources, and address climate change through both adaptation and mitigation strategies. PKVY aims to promote nutrient cycling in farming, reduce the use of hazardous chemicals; lower farming costs, and produces healthy, nutrient-rich food with minimal environmental impact.

**National Solar Mission (NSM, 2010)** seeks to address India's energy security challenges while promoting ecologically sustainable growth. As agriculture becomes more mechanized, there is a focus on using energy-efficient and renewable energy sources, such as solar power, to operate agricultural machinery. For example, the use of solar irrigation pumps and solar drying technologies can reduce dependency on fossil fuels and lower farmers' costs.

**National Mission on Strategic Knowledge for Climate Change (NMSKCC, 2010)** emphasizes research and the sharing of knowledge about climate change, focusing on key sectors like agriculture, health, natural ecosystems, biodiversity, and coastal zones. This mission fosters both basic and applied research to support informed decision-making and strategies for climate resilience.

Additionally, the **National Agroforestry Policy (NAP, 2010)** recognizes the role of agroforestry in reducing poverty, enhancing livestock and crop productivity, and building resilience to climate change risks, thereby contributing to sustainable development goals in agriculture.

## Conclusions

The dynamics of methane emissions in agriculture are complex and influenced by a variety of factors, including farming practices, soil conditions, livestock management, and crop types. Fully mitigating methane emissions in agriculture requires an integrated approach that combines technological innovations, improved management practices, and policies that incentivize sustainable farming methods. Reducing methane emissions from agriculture is essential for addressing climate change and enhancing the resilience of food production systems to environmental changes. With continued research and the adoption of effective mitigation strategies, agriculture can contribute to a more sustainable and low-carbon future.

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# Efficient Resource Utilization for Climate-Smart Agriculture

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## Introduction

The degradation of land and groundwater resources plunges down the total growth rate of agriculture. Further, the declining natural resource base is shrinking and degrading the production and carrying capacity of the ecosystem. Food production is unable to match consumption as crop yields level off globally, ocean health turns down, and natural resources get scarce. The burgeoning global population and their changing diets are the major drivers of increased food demands. Nearly 690 million people, i.e., 8.9% of the global population are starving (Anonymous, 2020). The issues of food security will only become grave in the coming days. The world will need to produce about 70% more food by 2050 to feed an estimated 9 billion people (Anonymous, 2009). Agriculture's vulnerability to climate change further challenges food insecurities. The alarming rising temperatures, shifts in precipitation patterns, frequent extreme weather abnormalities, invasive crops, and pest incidences, shifting ecosystem boundaries, and loss of ecosystem bio-diversities are the key indicators of climate change. These undermine agricultural production systems especially, in developing countries where poverty, hunger, and malnutrition are customary. At the farm level, the ill effects of climate change are advocated by lowering crop yields, the poor nutritional quality of products, and diminishing livestock efficiency. These demand extensive adaptations to maintain optimum yield levels and meet food quality requirements. However, agriculture is not only prey to climate change but also its major contributor. Globally, agriculture accounts for 19-29% of total greenhouse gas emissions (GHGE) (Vermeulen *et al.*, 2012). Crop and livestock production, forestry, fisheries, and aquaculture, which form an integral part of agriculture, are major contributors to GHGE.

To surmount the challenges, and resolve the issues of sustainable agricultural productivity, adapting to climate change, and mitigating the accumulation of greenhouse gases in the atmosphere, FAO developed a concept in 2009 known as "climate-smart agriculture". Climate-Smart Agriculture (CSA) is an approach for sustainably increasing productivity, adaptation, and resilience to climate change, and reducing or removing greenhouse gases (GHGs) emissions (Anonymous, 2010). It is an integrated approach to managing landscapes including cropland, livestock, forests, and fisheries that address the interlinked challenges of food security and climate change. This approach guides agriculture management practices in responding to climate change and reorienting agricultural development under the realities of climate change (Lipper *et al.*, 2014). CSA is the synergy and trade-off among agricultural productivity, climate change adaptation and resilience capacity, and reducing greenhouse gas emissions.

## Climate-Smart Agriculture

- i. Climate-smart agricultural technologies provide opportunities for adaptation and mitigation of the adverse effect of climate change. the mitigation of GHGs emissions from agriculture can be achieved by sequestering C in soil and reducing the emissions of methane and nitrous oxide from the soil through changes in land-use management and enhancing the input-use efficiency.
- ii. Climate-smart agriculture (CSA) is “an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support the development and ensure food security in a changing climate” (FAO, 2013).

## Why Climate-smart agriculture (CSA)

**Rising Global Population:** The world population is projected to grow to 9.7 billion by 2050 (United Nations, 2019). With such growth, food demand is expected to increase by 70% compared to 2010 levels (FAO, 2013). This puts immense pressure on agricultural systems to produce more while dealing with limited land and resources. Climate-smart agriculture (CSA) focuses on sustainable intensification by improving crop yields using eco-friendly methods, ensuring that food needs are met for future generations without over-exploiting resources.

**Impact of Climate Change on Agriculture:** Climate change poses significant risks to agriculture through rising temperatures, shifting rainfall patterns, and extreme weather events. It is estimated that global crop yields could decline by 10-25% by 2050 if adaptation measures are not taken (IPCC, 2014). Furthermore, agriculture itself contributes around 19–29% of global greenhouse gas emissions, making it both a victim and a contributor to climate change. CSA provides innovative solutions like drought-resistant crops, sustainable irrigation, and climate-adaptive practices to minimize vulnerabilities while mitigating emissions.

**Depleting Natural Resources:** Agriculture is the largest consumer of natural resources, utilizing over **70% of global freshwater** (World Bank, 2020). However, water scarcity is projected to affect **40% of the global population by 2030**, and soil degradation has already impacted **33% of arable land worldwide** (FAO, 2015). Depleting resources threaten future food production. CSA tackles these challenges by promoting resource-efficient practices such as drip irrigation, conservation agriculture, and organic farming, ensuring sustainable use of water and soil.

**Enhancing Farmer Resilience:** Smallholder farmers, responsible for producing about **80% of the world’s food**, are disproportionately affected by climate change (IFAD, 2020). They face risks from unpredictable rainfall, crop failures, and market volatility. CSA helps enhance resilience by introducing farmers to climate-resilient crops, early warning systems, and access to insurance and financial tools. These measures enable farmers to recover from shocks and maintain productivity, ensuring their livelihoods are safeguarded.

**Ensuring Food Security:** Food insecurity affects **828 million people globally** (FAO, 2022), with climate change worsening the situation. CSA focuses on improving productivity through sustainable practices like crop diversification and integrated nutrient management.

Additionally, by reducing post-harvest losses and stabilizing farmer incomes, CSA ensures a consistent food supply, contributing to global food security goals.

**Environmental Sustainability:** Agriculture is a leading cause of biodiversity loss, deforestation, and pollution, with unsustainable practices damaging ecosystems. CSA emphasizes environmentally sustainable techniques such as agroforestry, which integrates trees with crops, and crop rotation to enhance soil health. By promoting practices like integrated pest management and minimal tillage, CSA not only reduces environmental harm but also conserves biodiversity and improves the ecosystem's long-term resilience.

### The Three Pillars of Climate Smart Agriculture (CSA)

**Productivity:** CSA aims to sustainably increase agricultural productivity and incomes from crops, livestock and fish, without having a negative impact on the environment. This, in turn, will raise food and nutritional security. A key concept related to raising productivity is sustainable intensification.

**Adaptation:** CSA aims to reduce the exposure of farmers to short-term risks, while also strengthening their resilience by building their capacity to adapt and prosper in the face of shocks and longer-term stresses. Particular attention is given to protecting the ecosystem services which ecosystems provide to farmers and others. These services are essential for maintaining productivity and our ability to adapt to climate changes.

**Mitigation:** Wherever and whenever possible, CSA should help to reduce and/or remove greenhouse gas (GHG) emissions. This implies that we reduce emissions for each calorie or kilo of food, fiber and fuel that we produce. That we avoid deforestation from agriculture. And that we manage soils and trees in ways that maximizes their potential to acts as carbon sinks and absorb CO<sub>2</sub> from the atmosphere.



Three Pillars of Climate Smart Agriculture

Fig.1 Three Pillars of Climate Smart Agriculture

### Climate Smart Agriculture Techniques

Climate Smart Agriculture (CSA) techniques focus on enhancing the resilience of agricultural systems to climate change while ensuring food security and reducing greenhouse gas emissions. Here are some key CSA techniques.

## Carbon Smart Agriculture (CSA)

Carbon Smart Agriculture practices focus on sequestering carbon in agricultural systems, reducing greenhouse gas (GHG) emissions, and enhancing the resilience of farming systems to climate change. These practices align with climate-smart goals while prioritizing carbon management. Below are the key Carbon Smart Agriculture practices:

### a. Agro-forestry

The actual aim of farmers and government institutions behind agroforestry was improving rural livelihood and meeting various needs, viz. food, fuel, timber, fodder of the farmers. But in recent era of climate change, agroforestry became economically and ecologically very attractive tool for mitigating harmful effect of GHGs. Since, the Kyoto Protocol allowed industrialized countries with a GHG reduction commitment so as to invest in mitigation projects in the developing and least developed countries under the Clean Development Mechanism (CDM) and there is an attractive opportunity for major practitioners of agroforestry, especially the resource poor farmers (Nair et al. 2009). IPCC (2007) also indicated in its special report that the conversion of wasteland and grassland to agroforestry has the best potential to soak up atmospheric CO<sub>2</sub> other than direct benefits. Since CO<sub>2</sub> is the major greenhouse gas, representing 77% of total anthropogenic GHG emissions, its reduction is very essential from the atmosphere. Carbon sequestration is the capturing atmospheric CO<sub>2</sub> and storing for long term through natural (soils/vegetation) and engineering techniques (Schrag 2007). Among all the natural techniques, agroforestry provides a win-win opportunity to achieve the objectives of carbon sequestration and climate change mitigation and adaptation. Although agroforestry systems (AFS) are not primarily designed for carbon sequestration, there are many recent studies to substantiate the evidence that agroforestry systems can play a major role in storing carbon in aboveground biomass (Murthy et al. 2013) as well as in belowground biomass (Nair et al. 2009).

**Table1.** Carbon sequestration potential (CSP) of trees in India

Agroforestry system	Tree/Crop	Age (year)	Sequestration-rate (Mg C/ha/Y)	References
Silvipasture	Acacia nilotica +Natural pasture	5	1.9-5.4	Rai <i>et al.</i> , (2001)
Agrisilviculture	Populus deltoides	-	0.513	Gupta <i>et al.</i> , (2009)
Farm forestry	Mangifera indica	30	1.7	Hooda <i>et al.</i> , (2007)
	Mixed plantation	30	5.9	
Hortipasture	Prunus persica	-	1.08	AICRPAF (2006)
Forest plantation	Eucalyptus spp.	6	2.18	Peichl <i>et al.</i> , (2006)
Intercropping system	Hybrid poplar+ Barley	13	1.04	Peichl <i>et al.</i> , (2006)

## b. Livestock Management

Ruminant animals are important sources of CH<sub>4</sub> and N<sub>2</sub>O through enteric fermentation and manure disposals. Enteric fermentation produces CH<sub>4</sub> when micro-organisms break down complex carbohydrates into simple sugars that can be assimilated into the animal's body. Up to 7 % of an animal's feed can be lost as CH<sub>4</sub>; hence, attempts to increase animals' digestive efficiency can lessen CH<sub>4</sub> emissions (Mushi et al. 2015). This can also reduce feed costs. Various climate-smart options exist to minimize the levels of CH<sub>4</sub> and N<sub>2</sub>O emissions in the livestock sector.

- **Grazing Land Management:** One option for climate-smart livestock is better management of grazing systems. This can be accomplished through rotational grazing, increasing livestock mobility, reducing grazing pressure and improving the soil's physical condition through drainage to prevent soil degradation or restore grazing lands. Wet soils are compacted easily by grazing animals, which increases their anaerobicity, denitrification conditions and potential for N<sub>2</sub>O emissions (Mushi *et al.* 2015). Restoring degraded grasslands enhances soil health, carbon sequestration and water retention, and establishes climate-resilient grazing systems.
- **Pasture Management:** Practices for managing pasture to lower GHG emissions by livestock include fertilization and cutting regimes, irrigation, controlled grazing regime, the introduction of earthworms, fire management and the use of improved grass species with regard to yields, environmental adaptation and digestibility (e.g. perennial fodders, pastures and legumes). Increasing the digestibility of feeds by improving the quality of grass and crop residues, or supplementing diets with concentrates reduces CH<sub>4</sub> emissions (Lal 2004).
- **Nutrition:** (Mushi *et al.* 2015) stated that emission per animal and per unit of product is normally higher when the animal is fed a poor diet. Therefore, better nutrition can improve efficiency by reducing CH<sub>4</sub> emissions per unit of animal product, in the same way that better animal husbandry and maintenance of health can improve productivity and reproductive rates and reduce mortality rates of animals. Some of the measures that can increase the amount of output for a given level of emissions include feeding animals on young pastures (i.e. harvested early before lignification) or feed resources with a low carbon footprint (e.g. feed crops that have been produced through CA practices or grown in cropping areas that have not been recently extended from forests or natural pastures), mixing legumes in pure pasture stands and applying chemical treatment to crop residues (e.g. wheat straw).
- **Manure Management:** Manure emits CH<sub>4</sub> and N<sub>2</sub>O as it breaks down in the soil. Similarly, manure stored in central tanks or lagoons releases CH<sub>4</sub> during anaerobic decomposition. Innovative technologies such as anaerobic digestion facilitate the capture of CH<sub>4</sub> produced in such a manner and its conversion to energy (biogas) or direct usage. This offsets GHG emissions from burning fossil fuels; provides energy for electric generators, heating and lighting; reduces odour from animal manure; and lowers labour costs associated with removal of manure from the barns (Schahczenski and Hill 2009; Branosky and Greenhalgh 2007; UNFCCC 2008). Other good practices exist to manage manure and reduce N<sub>2</sub>O and CH<sub>4</sub> emissions, such as solid disposal of manure, minimal compaction of manure

heaps, regular and complete removal of manure from the barns, and the application of slurry from manure—rather than fresh manure—to wet grassland soils.

### c. Conservation tillage

Conservation tillage is an agricultural practice that reduces soil disturbance and preserves soil health by minimizing tillage operations. The goal of conservation tillage is to promote soil conservation, improve soil health, and reduce environmental impacts. Conservation tillage as any tillage and planting system in which at least 30 per cent of the soil surface is covered by residue after planting in order to reduce soil erosion. (Whyte, 1987).

- **No-till or Zero tillage:** It is a system of planting (seeding) crops into untilled soil by opening a narrow slot trench or band only of sufficient width and depth to obtain proper seed coverage. No other soil tillage is done.” Conventional tillage completely inverts the soil, while no-till causes only negligible soil disturbance and the residues from previous crops remain largely undisturbed at the soil surface as mulch. Seeding systems that till and mix more than 50% of the soil surface while seeding cannot be classified as no-tillage.
- **Reduced Tillage:** decreases the number of passes with a tillage implement and reduces carbon emissions from burning fossil fuels. Conservation tillage uses less soil-disturbing tillage practices to maintain  $\geq 30\%$  residue coverage on the soil surface. When using a no-tillage system, the soil is not disturbed at all, except for potential compaction from the weight of field implements, and maintains soil structure and soil aggregation that protects soil organic matter from microbial decomposition and CO<sub>2</sub> release. Reducing tillage frequency and intensity also decreases the rate of breakdown of plant roots.
- **Cover cropping:** it helps to maintain living plant roots in the soil year-round, which helps sustain resilient microbial communities, atmospheric CO<sub>2</sub> capture through photosynthesis, and provides additional surface residues. Growing high biomass cover crops with high carbon to nitrogen ratios can help increase carbon sequestration in the soil. These high carbon to nitrogen ratio residues are more resistant to microbial decomposition and increase soil organic matter, especially when no-tillage or reduced tillage practices are also implemented. Cover crops are versatile in that different cover crops can be mixed and planted in the same field, allowing several different species to uniquely benefit soil health and contribute to soil carbon storage.



Fig.2: Soil management practices for C sequestration

### Water Smart Agriculture

Water-Smart Agriculture refers to the practice of managing water resources efficiently to enhance agricultural productivity, ensure sustainability, and build resilience to water-related risks such as droughts, floods, and changing rainfall patterns.

**Rainwater harvesting (RWH):** Rainwater harvesting is an adaptation strategy for people living with high rainfall variability both for domestic supply and to enhance crops, livestock and other forms of agriculture. (Rockstrom *et al*, 2009) suggested that rainwater harvesting structures can be very useful for semi-arid and dry, as well as sub-humid regions, especially in the regions where water scarcity is caused by extreme variability of rainfall rather than the amount of rainfall. IPCC (2014) advocated that rainwater harvesting structures are extremely important for mitigating the impact on agriculture and increasing agricultural productivity.

**Laser land levelling:** Laser land levelling is a proven agricultural on-farm technology that not only reduces farm irrigation needs but is also highly useful to reduce irrigation time and increase water use efficiency. A more levelled and smooth soil surface reduces the consumption of seeds, fertilizers, chemicals and fuel. The use of a laser leveler for land levelling has increased many-fold in some states – Haryana, Punjab, Uttar Pradesh and Madhya Pradesh, etc. Laser levelling could save 20–25% of irrigation water (Naresh *et al*. 2011). Most of the farmers in the Haryana state of India hire the equipment on an hourly basis. Farmers pay between 600 and 700 rupees per hour to use the machinery. Wakchaure *et al*. (2015) reported that precision levelling significantly improved the soil and canopy micro-environment and favored increasing the sorghum yield by 27–73% and substantially saved irrigation water (30.9%) compared to unlevelled fields.

**Furrow irrigated raised beds:** Raised beds of 1 to 1.5 m width alternating with furrows are often constructed for growing vegetables, medicinal and aromatic and cereal crops. Two rows of plants are usually raised on two sides of a bed or ridge. A furrow runs between two rows of the adjacent ridges of beds and supplies water to the plant rows. The method ensures saving a large amount of water. The surface soil of beds or ridges remains dry, and the creeping plants and their fruits are not damaged. Water from the furrow moves laterally into the soil below

the bed or ridge to meet the crop need. It prevents the accumulation of salts at the base of plants and reduces the salt injury to crops in areas where raised bed and furrow salt is a problem. This method offers a more effective control over irrigation and drainage as well as rainwater management during the monsoon.

**Re-use of waste water in agriculture:** Due to water scarcity in the agriculture sector, recycling of wastewater is becoming more popular to augment water demand for agriculture in many parts of arid regions of the world (Alrajhi *et al.* 2015). Re-use and recycling of municipal wastewater and industrial effluent are significant to minimize the pollution load in the receiving water and the reduction in the requirement of freshwater for various uses. Re-use of municipal wastewater after treatment is necessary to meet industrial water requirements and is being used for horticulture, watering of lawns and even for flushing public sewers and toilets. Freshwater resources can be preserved using municipal recycled wastewater and stormwater for irrigation. Phytotrid is a wastewater treatment constructed wetland technology for the treatment of municipal, urban, agricultural and industrial wastewater. The system is based on specific plants, such as elephant grass (*Pennisetum purpurem*), cattails (*Typha sp.*), reeds (*Phragmites sp.*), *Cannas sp.* and yellow flag iris (*Iris pseudocorus*), normally found in natural wetlands with filtration and treatment capability. Some ornamental, as well as flowering plant species such as golden dharanda, bamboo, nerium, colosia, etc., can also be used for treatment as well as landscaping purposes.

**Plastic mulching:** Plastic mulching, a technique to cover the soil around the root zone of a plant with a plastic film, is a useful practice to restrict weed growth, conserve moisture and reduce the effect of soil-borne diseases. The states in India that have played a dominant part in implementing the mulching activity in horticulture are Manipur (21%), Assam (20%), Uttarakhand (17%) Meghalaya (13%) and Nagaland (12%), with a combined share of about 83% in the total programme of mulching. Plastic film mulch is one of the most extensively used forms of plasticulture, and it is currently used on a vast scale in China, India, Israel and Italy. While plastic mulch is used to enhance water savings of micro-irrigation in developed countries, its adoption in developing countries is often independent of micro irrigation technology. China accounts for 40% of the world's plastic mulch use. Plastic mulch performs a variety of functions, including soil disinfestation by solar energy (solarisation); covering the soil for heat collection; preventing the growth of weeds; minimizing evaporation and escape of fertilizer; repelling or attracting insects; and manipulating soil temperature. Gao *et al.* (2019) carried out a meta- analysis to quantify and analyze the effects of plastic film mulching and residual plastic on yield and water use efficiency (WUE) of maize, wheat, potato and cotton in China. They reported a significant increase in crop yield (24.32%) and WUE (27.63%). Use of plastic mulching increases the potato yield by 30.62% and WUE 30.34% in China.

**Cloud seeding:** Cloud seeding has been applied to many agricultural areas around the world where rain is scarce and needed for crop survival. It is a form of weather modification or making artificial rain from clouds. It is also used to suppress hail, and has been practised in Israel for the last 30 years and is being used in many other countries. Originally, seeding with the aid of silver iodide began with the use of ground incinerators. The process has been improved, and special aircraft are used for this purpose, including the use of brine as the

seeding material. Bangsund & Leistriz (2009) analyzed the economic impacts of cloud seeding on agricultural crops in North Dakota and reported that the cloud seeding increased the amount of precipitation and reduced the risk of hail in the western North Dakota counties. The attempts helped to improve agricultural production and were a huge economic benefit to the region. Cloud seeding is also helpful to prevent the development of hail storms which cause severe damage to crops. Seeding has had a significant effect on increasing rainfall in many areas, especially in the Kinneret Basin (Sharon 1977). It is assumed that a significant increase of 10–15% in rainfall in the northern part of the country has materialized (Sharon 1977). However, it has been noted that the limited cloud occurrence in drought years limits the benefits of cloud seeding when most needed.

**Greenhouse Technology:** Greenhouse crops are one of the most innovative modern agriculture technologies. Use of greenhouses is useful in conserving water while simultaneously enhancing agricultural productivity. Greenhouses offer a stable alternative to traditional open-air farming practices, as they allow for consistent, year-round crop growth, all while reducing water usage (Connor & Mehta 2016). It is one of the highest human-made forms of agricultural activity, because of its intense technological and bio-agronomic input in confined portions of the farm environment. Greenhouse farming reduces water consumption as compared to open-air agriculture, mainly due to reduced evapotranspiration rates inside greenhouses. Use of drip irrigation systems improves the efficiency of water usage. By increasing the efficiency of irrigation, drip irrigation systems reduce water usage by 30–50% when compared with regularly used surface irrigation (Harmanto *et al.* 2005; Connor & Mehta 2016)

**Micro-irrigation (technology of more crops per drop of water):**

Drip irrigation is one of the advanced methods of irrigation by which water can be supplied directly into the root zone of the soil. There are several methods of pressure irrigation, such as sprinkler irrigation, center pivot and LEPA, micro-jets, drip/micro- or trickle irrigation and surface or subsurface irrigation. Drip irrigation systems are more efficient than other surface irrigation methods in terms of water savings, yield and water use efficiency. There is an increase in crop yields and reduction in the cost of fertilizers, pesticides and power for irrigation when using this method of irrigation. Thus, drip irrigation minimizes conventional losses such as deep percolation, runoff and evaporation. The total potential of micro-irrigation in India is estimated at around 69.5 Mha. However, the coverage of micro-irrigation is only 7.7 Mha (FICCI 2016). Under drip irrigation the area covered was 3.37 Mha while sprinkler irrigation total coverage area was 4.36 Mha ha.

**Nutrient Smart Agriculture:**

Fertilizer consumption has been increasing over the years; however, agricultural productivity has become stagnant. Overuse of chemical fertilizers has increased soil compaction, increased pest infestation and pesticide application, polluted air and water, and released greenhouse gases, causing a hazard to human health and the environment. Therefore, to minimize the adversities, the adoption of nutrient smart practices like site-specific nutrient management, integrated nutrient management (INM), use of nano-fertilizers, etc., becomes important.

- a. **Site-Specific Nutrient Management (SSNM):** It provides guidance relevant to the context of farmers' fields. SSNM maintains crop yields while increasing fertilizer use efficiency. Minimizing fertilizer overuse can reduce greenhouse gas emissions. SSNM reduces N<sub>2</sub>O emissions by reducing total N application and/or timing applications to crop needs, thus avoiding N losses to volatilization, leaching, and runoff.

**Components of Site-Specific Nutrient Management**

- **Remote Sensing:** Precision agriculture depends on remote sensing to collect data on crop growth, status, and geographical variability. Remote sensing technologies include handheld, airborne, and satellite-based sensors. Past 30 years, agricultural remote sensing has advanced and there uses viz., soil moisture, crop nutrient, pest and disease monitoring, crop growth, yield calculation, and other precision farming applications. These technologies collect data on soil, vegetation, crop health, soil moisture, crop growth stage and other remote sensing factors (Prajapati *et al.* 2023).

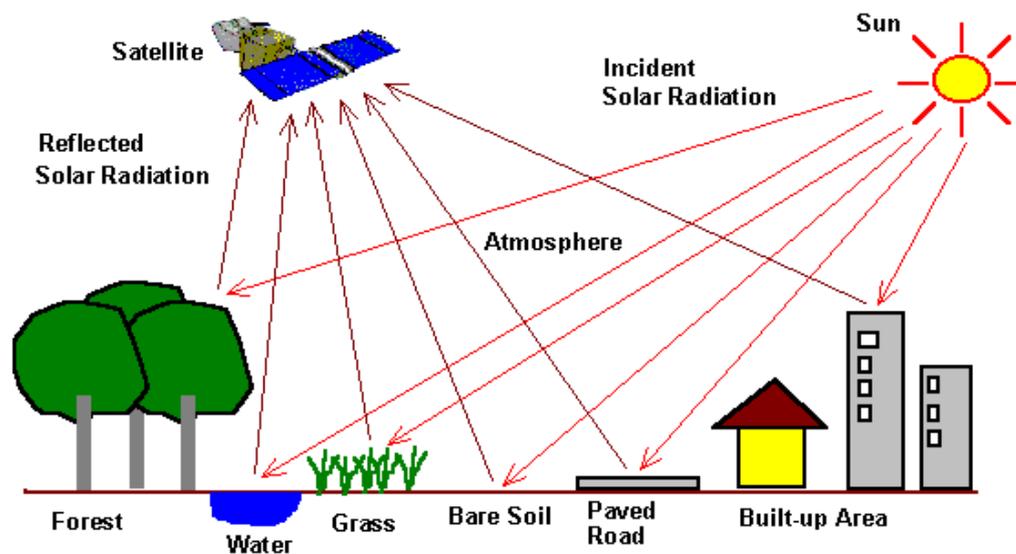


Fig.3

Principle component of Remote Sensing

- **Global Positioning System (GPS):** It is crucial in precision farming, enabling farmers to locate specific areas for sampling and treatments accurately. While not yet widely used, GPS technology is gaining ground in agriculture, with innovative applications such as a precise GPS-enabled crop duster emerging (Hadeed *et al.*, 2024).
- **Geographic Information System (GIS):** In agricultural GIS uses computer software and hardware to create maps with location and feature attributes. It is used to stores layer of information such as soil survey maps, yield data, and remotely sensed data. It facilitates the exchange of information between different systems and users, and offers services for information management, message exchange and updates, decision analysis, and information release (Prajapati *et al.* 2023).
- **Variable Rate Technologies (VRT):** VRT adapts agricultural inputs to individual field requirements. VRT technology necessitates specialized machinery and controllers, equipped with Differential Global Positioning System (DGPS) receivers, to precisely apply inputs based on pre-determined maps. VRT systems are widely used in precision farming for site-

specific nutrient management, particularly for variable-rate applications (Prajapati *et al.* 2023).

- **Yield Monitoring:** Yield monitoring and mapping aid site-specific farming. It measures geographical yield variability, allowing farmers to evaluate factors affecting crop production. Instant feedback, including yield and moisture documentation, maps, and pest data, helps make better management decisions. It also creates a GIS database to understand yield variability and improve variable-rate decisions.

- **Leaf color chart (LCC):** It is used for real-time management of N and synchronizing N application with crop demand. The use of LCC reduced the global warming potential of the rice-wheat cropping system by 10.5% and also significantly increased crop yields, N-use efficiency, and carbon efficiency ratio (Bhatia *et al.*, 2012).

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**Fig.4** Leaf Color Chart (LCC)

- **Chlorophyll Meter:** The Soil Plant Analysis Development (SPAD) chlorophyll meters help assess the chlorophyll content in plant leaves, which can indicate the nitrogen status of crops. This information is valuable for adjusting (reduces) nitrogen fertilizer application rates in site-specific nutrient management (Choudhary *et al.*, 2023).

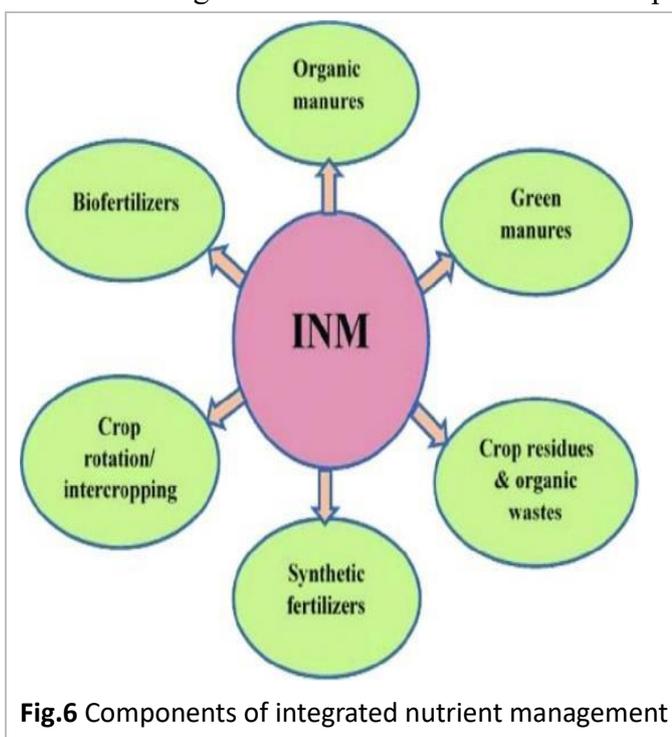
- **Green Seeker Sensor:** Green Seeker is sensors, detect wavelength of reflected light from crop canopy and produces Normalized Difference Vegetation Index value (NDVI) and can be used to determine variable fertilizer application rate based on the actual needs of the plants, contributing to the precision aspect of plant nutrient management. Image 5: Green seeker (Choudhary *et al.*, 2023).



**Fig.5** Green Seeker Sensor

b. **Integrated nutrient management (INM):** INM is a holistic approach to nutrient management that combines organic and inorganic sources of nutrients to optimize crop yields, improve soil health, and reduce environmental impacts. the practice of lowering the GHGs emission is the adoption of INM. It ensures the Soil-plant- atmospheric continuum in a promising way by sequestering more carbon to soil than emissions. Nitrogenous fertilizers are prone to losses through denitrification, volatilization, and leaching which in turn may cause air and water pollution.

- **Organic and Inorganic Nutrient Sources:** Organic nutrient sources include crop residues, Compost, manure, and green manures. Organic nutrient sources provide not only nutrients but also organic matter that improves soil health. However, organic nutrient sources have variable nutrient contents and release nutrients slowly, making it difficult to synchronize nutrient supply with crop demand. Inorganic nutrient sources include synthetic fertilizers, such as urea, ammonium nitrate, and potassium chloride. Inorganic nutrient sources have high nutrient contents and release nutrients quickly, making it easier to meet crop nutrient requirements. However, inorganic nutrient sources do not



**Fig.6** Components of integrated nutrient management

provide organic matter and can have negative environmental impacts if used excessively. INM combines organic and inorganic nutrient sources to optimize crop nutrition while minimizing environmental impacts. For example, applying compost or manure before planting can provide a slow-release source of nutrients, while applying synthetic fertilizers during critical growth stages can provide a quick-release source of nutrients. Similarly, using legume cover crops can reduce the need for inorganic nitrogen fertilizers, while applying inorganic phosphorus fertilizer can overcome the low phosphorus availability in some soils.

## Weather Smart Agriculture

Climatic vagaries and weather abnormalities can be controlled by adopting weather smart practices. Weather forecasting helps farmers plan for their day-to-day activities. Decision on Irrigation scheduling, time to fertilizer application, pesticide application, etc. Can be framed. It minimizes crop wastage and increases crop productivity and enhances soil health. Various satellites launched by the Government of India.

### a. Weather smart technique

- **Weather Forecasting:** Real-time weather updates and forecasts form the critical bulk of agro-advisory services. Forecasts usually range from short-term (1-3 days), medium-term (weekly), and long-term (seasonal) predictions and enable the farmers to plan ahead for the weather. Other parameters like rainfall probability, temperature variation, humidity, and wind speed may determine when irrigation, pesticides, or planning should be executed.
- **Monitoring of Soil Health:** Crop productivity depends also upon the quality of soil, and in monitoring health of the soil, a farmer would efficiently use fertilizers. Soil test data could be integrated with agro-advisory platforms to support farmers in getting recommendations regarding nutrient management, organic amendments, and corrective measures to improve fertility and pH.
- **Crop-Specific Advice:** It provides planting dates, seed varieties, nutrient requirements, and growth stages for crops. The crop alert service gives you crop disease information, pest infestation, growth milestones along with recommendations about pesticides, organic practices, and optimum harvesting time for maximum yield and quality
- **Irrigation Management:** Irrigation management is important in water-scarce regions. This is through the agro-advisory services, which educate farmers on the proper irrigation schedules based on outputs from remote sensors, satellite imagery, and weather forecasts. Thus, wastage of water is minimized, and irrigation expenses are cut by saving crops from water stress.
- **Pest and Disease Surveillance:** Real-time monitoring helps in diagnosing outbreaks of pests and diseases at early stages, thereby avoiding large-scale damage to crops. Advisory platforms can analyze data collected from the field, weather conditions, and pest cycles that give alerts and recommend measures of control. This proactive approach limits the use of pesticides to a greater extent and minimizes its environmental effects while maintaining crop health.

- **Crop modelling:** Crop modelling may be a creative and newly developed tool for dealing risks in Agriculture Computer aided simulation models plays a very important role in approaching the techniques that build crop management responses and forecast crop yield. Simulation models significantly assist the work of higher crop development and recommend valid crop management. Models can guide to seek out the possible risk of climate variation on future crop yields, climate smart agriculture development and mitigation procedures. Like new management options and suitable genotypes which are important factors for better yield, crop simulation models are essential tools in field experiments to make new crop management approaches. During this point of view, two crop management systems are APSIM (Agricultural Production System Simulator) and DSSAT (Decision Network for Agro Technology Transfer) mostly utilized in the entire world (Ahmad et al., 2014).
- **Weather based crop insurance scheme:** Weather-Index Insurance (WII) is an innovative form of index insurance that covers farmers against weather related extreme events. Under the scheme, payment method was planned in manner that it covers uncertain rainfall may be deficit or excess during Kharif season and during rabi season it covers adverse incidence in weather parameters like frost, heat, relative humidity and un-seasonal rainfall.
- **Remote Sensing and Satellite Imagery:** Satellite data allows for a qualitative understanding of crop health, soil moisture, and temperature fluctuations in a large area. Remote sensing technology can help in the observation of growth stages of crops, detection of drought or disease stress, and estimation of vegetation indices, and hence provide valuable inputs for advisory services.
- **Mobile Applications and SMS Services:** Since mobile phones are ubiquitous, most agro-advisory services send information through SMS or smartphone applications. This way, farmers can receive direct weather, pests, market prices, and crop management updates on their handsets real-time, ensuring that advice is both timely and actionable.

### **Energy Smart Agriculture**

Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress. However, with the rapid depletion of conventional energy sources and increasing energy demand, worldwide primary energy consumption has grown by 1.8% in 2012. Due to certain environmental issues, many related organizations have encouraged intensive research for more efficient and green power plants utilizing advanced technology. Since environmental protection concerns are increasing, both clean fuel technologies and new energies are being intensively pursued and investigated. In fact, fossil fuel and renewable energy prices, social and environmental costs are moving in opposite directions and the economic and policy mechanisms needed to support the widespread dissemination of sustainable markets for renewable energy systems are rapidly evolving. It is clear that future growth in the energy sector is primarily in the new regime of renewable. Therefore, shifting to renewable energy can help us meet the dual goals of reducing greenhouse gas emissions, thereby limiting future extreme weather and climate impacts, and ensuring reliable, timely, and cost-efficient delivery of energy. Investing in renewable energy can have significant dividends for our energy security.

### **Energy smart agriculture has been classified into two types:**

**a. Renewable energy sources:** Renewable energy sources play a vital role in climate-smart agriculture, enabling farmers to reduce their dependence on fossil fuels and decrease greenhouse gas emissions. (Omar *et al*, 2014.).

- **Solar energy:** Solar energy is a vital component of energy smart agriculture, enabling farmers to power their operations in a sustainable and cost-effective manner. Solar panels can be used to generate electricity for irrigation systems, farm equipment, and rural communities, reducing dependence on fossil fuels and decreasing greenhouse gas emissions.

- **Wind energy:** Wind energy is a promising renewable energy source that can power agricultural operations, reducing dependence on fossil fuels and decreasing greenhouse gas emissions. Wind turbines can generate electricity for irrigation systems, farm equipment, and rural communities, improving energy security and reducing energy costs. Wind energy can power water management systems, optimizing water usage and reducing waste (Mukunda *et al*. 2018).

- **Hydropower:** Hydropower is a renewable energy source that can power agricultural operations, reducing dependence on fossil fuels and decreasing greenhouse gas emissions. Small-scale hydropower systems can be installed on farms to generate electricity from water flows, powering irrigation systems, farm equipment, and rural communities. Hydropower can also be used for water management, optimizing water usage and reducing waste.

- **Bio-energy:** Bio-energy is a renewable energy source derived from organic matter such as crops, waste, and residues. In energy smart agriculture, bio energy can be produced from agricultural waste and residues, providing a sustainable alternative to fossil fuels. Bio-energy can power farm operations, reduce greenhouse gas emissions, and enhance energy security.

- **Geo thermal energy:** Hydropower is generated from water moving in the hydrological cycle, which is driven by solar radiation. It is the flow of water in rivers, driven by the force of gravity to move from higher to lower elevations that can be used to generate hydropower. Hydropower plants.

### **b. Conservation tillage operations:**

Conservation tillage is a multifaceted farming paradigm that synergistically integrates soil conservation, energy efficiency, and sustainable agricultural practices. This approach is pivotal in energy smart agriculture, as it mitigates soil degradation, optimizes energy utilization, and promotes eco-friendly farming systems.

- **No till:** No-till was initially developed as a farming method for conserving the natural resources of soil and water. It has been proven that, with no-till, soil erosion can be reduced significantly, even to rates below soil formation rates. By comparison with ploughing, no carbon benefit or even carbon deficits have been found at soil depths below 20 cm. No-till makes little or no contribution to carbon sequestration in crop lands.

- **Mulch tillage:** Mulch tillage is a conservation tillage technique that involves applying a layer of organic mulch to the soil surface. This approach helps retain moisture, suppress weeds, and regulate soil temperature. Mulch tillage also promotes soil biota, reduces soil

erosion, and increases crop yields. Additionally, mulch tillage can reduce energy consumption by minimizing the need for tillage and other soil preparation operations. Overall, mulch tillage is a valuable strategy for promoting sustainable agriculture practices and reducing environmental impacts.

- **Reduced or minimum tillage:** Minimum tillage is a key component of energy smart agriculture which aim to reduce energy consumption and greenhouse gas emission in agriculture while promoting sustainable agricultural emission.
- **Ridge till:** Ridge tillage is a valuable conservation tillage practice that can be used in Energy-Smart Agriculture (ESA) to reduce energy consumption, promote soil health, and improve crop yields. The soil is tilled only in the ridge area, leaving the area between ridges untilled. By reducing tillage and promoting soil health, ridge tillage can help sequester carbon and reduce greenhouse gas emissions. Additionally, ridge tillage can lead to improved crop yields due to better soil health, reduced soil compaction, and more efficient water use. However, it requires careful planning, specialized equipment, and alternative weed management strategies to be successful. Overall, ridge tillage is a beneficial practice for ESA, offering energy savings, soil conservation, and improved crop yields.

## Conclusion

Climate-Smart Agriculture (CSA) is crucial for ensuring food security, mitigating climate change, and promoting sustainable agriculture practices. Efficient resource utilization is essential for achieving these goals. efficient resource utilization is critical for achieving the goals of Climate-Smart Agriculture. By adopting precision irrigation, conservation tillage, cover cropping, integrated nutrient management, renewable energy, energy-efficient equipment, and precision agriculture, farmers can optimize resource use, reduce waste, and promote sustainable agriculture practices. Policy and institutional support are essential for scaling up CSA practices and ensuring a food-secure future.

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# Geoinformatics: A Technology to Secure Agricultural Production in the Climate Change Situation

Arushi Chandel, Devrani Gupta, Neetika Nigam and Arun Kumar

## Introduction

There are numerous obstacles in agriculture. Climate change is one of them. climate change is considered as one of the major environmental problems of the 21 century and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e. more or fewer extreme weather events), Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period. typically, decades or longer. Some external influences, such as changes in solar radiation and volcanism, occur naturally and contribute to the total natural variability of the climate system. Other external changes, such as the change in composition of the atmosphere that began with the industrial revolution, are the result of human activities (IPCC, 2007). Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Further arguments are increasingly being framed in terms of "alternative" vs "conventional" agriculture in both the scientific literature and public discourse. Conventional agriculture refers to a current farming approach that heavily relies on synthetic chemical, mechanization and monoculture practices. This method aims to maximize crop yields and increase input use efficiency but often leads to environmental concerns, such as soil degradation and biodiversity loss. Certain characteristics of conventional agriculture are:

- Huge water consumption
- High use of agrochemicals
- High dependency on synthetic fertilizers
- Monocropping
- Aiming at maximizing the economical effectiveness of the production
- Higher GHG emissions per unit of area
- Decreased soil organic matter
- Increased soil loss & erosion
- Lower water holding capacity of soils
- Less effective carbon storage in the soil
- Loss of biodiversity in agricultural landscapes.

The current agriculture is driven by the technological interventions i.e. GIS, GPS, remote sensing etc. with the use of these technological interventions we can increase

agriculture production without exhausting our natural resources. And these technological intervention will bring a revolutionary change in present day agriculture.

## **Geoinformatics**

An informatics framework called geoinformatics is used to integrate and analyze earth-science data and applications in order to uncover new information. Supported by both domestic and foreign organizations, geoinformatics has developed to meet the increasing awareness that issues with major societal ramifications call for creative and integrative methods for managing, analyzing, modelling, and archiving large and varied data sets. An increased integration of informatics into the geosciences will be extremely beneficial to scientists tackling the global concerns of climate change, natural hazards, and the finding and management of natural resources. To address these issues, we place a strong emphasis on data and service integration.

**Geoinformatics can be defined as the science and technology that deals with the geoinformation, its acquisition, creation, storage, processing, presentation and dissemination. And, by spatial information and data we mean any information and data that can be linked to a location on Earth.**

### **Applications of Geoinformatics in Agriculture**

#### **a. Weather Prediction**

With the aid of GIS analytics, numerous weather conditions are monitored. Weather forecasting services employ GIS mapping technology in order to identify and represent weather conditions. This makes it possible to estimate how weather events may alter or migrate over time by tying meteorological data to geographic locations.

#### **b. Soil Mapping**

"Digital soil mapping" (DSM) is the most widely used term for the application of geospatial technology to soil mapping. In order to display the spatial distribution of each soil, soil mapping entails locating and identifying the many different types of soils that are out there, learning more about their characteristics, prospective applications, and nature, and documenting this knowledge on maps and in related publications. A soil map, which is a map or geographical representation of the area, shows the various types of soil and/or soil characteristics (soil pH, textures, organic matter, depths of horizons, etc.) in the area of interest.

#### **c. Crop Mapping**

It offers crucial information on the spatial distribution of crops, their water requirements, and data on their growth, health, and yield, it is a valuable resource for spatial agricultural monitoring and crop production. This is especially true for systems that depend on satellite EO to monitor agricultural resources (Ozdogan *et al.*, 2010; Atzberger, 2013). Agriculture's expansion, management, and sustainability (Justice *et al.*, 2007)

#### **d. Crop Yield Prediction**

Accurate yield prediction helps governments ensure food security and helps businesses anticipate income and plan their budgets. One of the most cutting-edge techniques in this area is the use of convolutional neural networks, also known as CNNs. We build an agricultural productivity measurement system using ConvNet DL. The algorithm is trained to find productivity trends by feeding it photos of crops whose yields are known. CNN's forecast accuracy is approximately 82%.

#### **e. Crop Health Monitoring**

Satellite imagery and local data can be used to assess environmental factors such as humidity, air quality, surface conditions, and more. GIS-based precision farming can help with this assessment and can also help you identify which crops require greater attention. Neural networks, including CNN, RBFN, Perceptron, and others, can also be used to assess the health of a crop.

#### **f. Irrigation Control**

Managing large agricultural fields and making sure that each crop gets enough water are made easier by geoinformatics. By evaluating images from high-resolution cameras on aircraft and satellites, artificial intelligence (AI) systems may detect visual patterns that underlie water shortages and assess each crop's level of water stress.

#### **g. Livestock Monitoring**

GIS software is used in animal husbandry to track the movements of specific animals. Because of this, farmers might find them on a farm and monitor their general health, fertility, and nutrition. Animal trackers that are affixed to the animals and a smartphone that gathers and shows the data from those trackers are the two GIS services that make this possible.

#### **h. Control of Insects and Pests**

Harmful insects and pests causes enormous costs in agriculture. Through the use of GIS, crop loss can be prevented by maintaining favorable conditions and being aware of harmful insects, pests, and diseases early enough.

#### **i. Disease Detection**

In order to prevent outbreaks, a great deal of data is collected and assessed in each disease monitoring system. Graphical Information Systems (GIS) are an excellent tool for visualizing and analyzing epidemiological data as well as for determining trends, dependencies, and correlations between variables (Kumar *et al.*, 2019; Tripathi *et al.*, 2022). GIS offers an integrated platform for surveillance efforts related to several diseases. It is possible to map public health resources, specific diseases, and other health events in relation to their local surroundings and existing social and health infrastructures. Combining these kinds of data creates a powerful tool for monitoring and managing epidemics.

### **Components of Geoinformatics**

It encompasses a broad range of disciplines including surveying and mapping, Remote Sensing, Geographic Information Systems (GIS), Global Positioning System (GPS), Geodesy and computer science.

#### **a. Computer Science**

The field of informatics includes both computer technologies, such as software and hardware. The importance of information stems from the fact that we must manage ever-increasing amounts of complex data in every field. To represent and process relevant information through the creation of hardware and software, computer science knowledge is a prerequisite. Nowadays, there is a greater emphasis on computer science, which enhances our research and activities.

As you study geoinformatics data collection, processing, product development, data visualization, distribution, etc., you will encounter many facts of the application of computer science to informatics.

#### **b. Geodesy**

The science of geodesy is concerned with the techniques of taking accurate measurements of the earth's surface and using those data to determine geographic locations on the planet. The two main branches of geodesy are geometric geodesy and physical geodesy. Additionally, there is a third one called Satellite Geodesy. "Dividing the earth and measuring the earth geometry" is how the dictionary defines geodesy. Because it deals with the geometry (size and shape) of the earth, geometric geodesy hence seems to be a strictly geometrical science.

Geodetic astronomy is the study of determining geographical placements on Earth's surface by the observation of celestial bodies, although geometric geodesy can also involve this. The majority of geodetic measurements, including those that are solely geometric, incorporate the earth gravity field, a physical phenomenon. The plumb line, which is the direction of the gravity vector, is crucial to leveling, triangulation, and geodetic astronomical measurement. As a result, astro-geodetic techniques that employ geodetic operations such as triangulation, trilateration, base measurement, and astro-determination of latitude, longitude, and azimuth may be regarded as being just as much a part of physical geodesy as gravimetric techniques.

#### **c. Cartography**

The science and art of creating, building, and creating maps is commonly referred to as cartography. It covers nearly every process, from initial fieldwork to final map printing and promotion. Additionally, it is regarded as a human communication science. According to the International Cartographic Association, cartography is the field that deals with the creation, distribution, and analysis of maps. A map is a representation of the entire or a portion of the Earth's surface at a specific scale on a flat surface. It is an illustration of the Earth, either by hand or by machine, that displays the locations and distribution of different natural and cultural phenomena. The fate of every map produced by different geoinformatics analyses depends on its cartographic depiction. Visualization of maps, which restricts the scope of map details by graphically presenting geographic information, including data, processes, relations, or concepts.

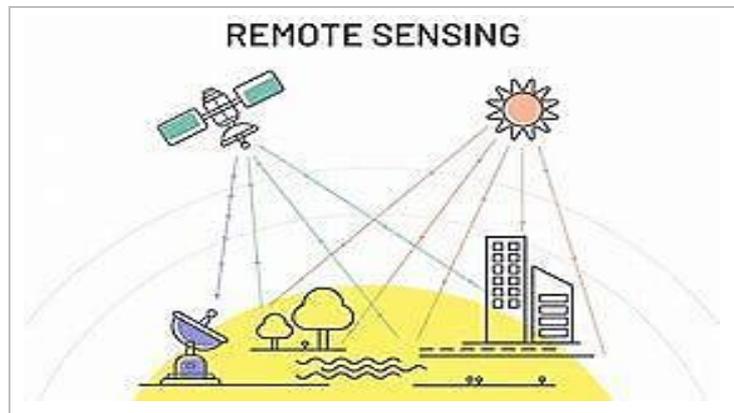
#### **d. Photogrammetry**

The technique created to ascertain an object's geometric characteristics from its photographic image is called photogrammetry. The measuring of an object's position and shape using photos is known as photogrammetry. Photogrammetry is "the art, science, and

technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena," according to the American Society for Photogrammetry and Remote Sensing (ASPRS).

#### e. Remote Sensing

Remote sensing is a technique used by scientists to measure or observe occurrences in the atmosphere, hydrosphere, biosphere, and lithosphere of the Earth. Humans and many other animal species use their sight, senses of smell, and hearing to help them do this. Typically, a mechanical instrument called a remote sensor is used for distant sensing. The ability to receive and record information about an object without coming into direct contact with it has significantly enhanced thanks to this device.



Using electromagnetic radiation as a means of contact, the science of identifying earth surface features and estimating their geo-biophysical attributes is known as remote sensing (RS). Target discrimination is facilitated by key sensor/target properties, including polarization, temporal, spatial, and spectrum fingerprints. Before spectral information is extracted, the earth surface data as perceived by the sensors at various wavelengths (reflected, scattered, and/or emitted) is adjusted geometrically and radiometrically.

#### Types of Remote Sensing

- **Passive Remote Sensing**

Source of energy is that naturally available such as the Sun. Most of the remote sensing systems work in passive mode using solar energy as the source of EMR. Solar energy reflected by the targets at specific wavelength bands are recorded using sensors onboard airborne or space borne platforms. In order to ensure ample signal strength received at the sensor, wavelength / energy bands capable of traversing through the atmosphere, without significant loss through atmospheric interactions, are generally used in remote sensing.

- **Active Remote Sensing**

Energy is generated and sent from the remote sensing platform towards the targets. The energy reflected back from the targets are recorded using sensors onboard the remote sensing platform. Most of the microwave remote sensing is done through active remote sensing.

#### f. The Global Positioning System (GPS)

The global positioning system (GPS) is a navigation and mapping system that combines real-time interpretation or post-processing of electromagnetic (EM) signals from satellites to pinpoint the exact time and place. This satellite-based navigation system allows

users to find objects anywhere on the planet. Anywhere on or close to the globe's (and occasionally the earth's) surface, users of the GPS, a radio positioning system based in space, can get information about their position and velocity in time and three dimensions with the right equipment.

In countries like India, the agricultural sector provides 18% of the GDP while also employing 50% of the labor force. Growth in the agricultural sector will encourage agricultural livelihoods, which will subsequently hasten rural change and eventually lead to structural change (Mogili & Deepak, 2018; Shah *et al.*, 2019).

GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use. The Global Positioning System (GPS), originally Navstar GPS, is a satellite-based radio navigation system owned by the United States government and operated by the United States Air Force.

### Component of GPS

- **Space Segment**

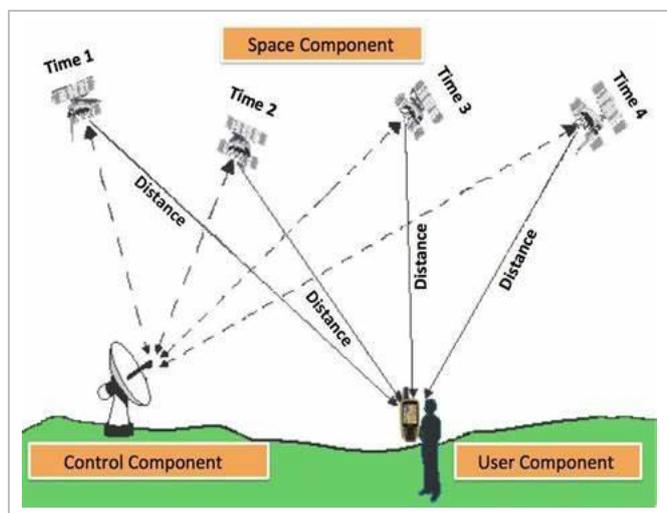
Consisting of satellites that send signals from space, the system measures the user's position and time. A constellation is a group of satellites. The 24 satellites that make up NAVSTAR are arranged in 6 orbital planes, are angled 55 degrees toward the equator, and have a 12-hour period.

- **Control Segment**

Three antennas, a master control station, and five ground-based monitor stations make up the control segment. The Master Control facility is situated in Colorado at the former Falcon AFB, now known as Schriever Air Force Base. The master control station receives data from the monitor stations, which continuously measure signals from the space vehicles (SVs). Clock correction coefficients and satellite ephemeris are computed by the master control station and sent to an antenna. At least once every day, the antenna sends the data to every satellite. Subsets of the orbital ephemeris are then transmitted by the SVs via radio transmissions to GPS receivers.

- **User Segment**

GPS User Segment consists of the GPS receivers and the user community. The typical receiver is composed of an antenna and pre-amplifier, radio signal microprocessor, control and display device, data recording unit, and power supply. GPS receivers convert SV signals into position, velocity, and time estimates. A minimum of four satellites are required to compute the four dimensions of X, Y, Z (position) and Time. (time is added as Fourth dimension here to getting real time position)



### **g. The Geographic Information System (GIS)**

Data and information regarding particular areas on the planet's surface can be entered, altered, analyzed, and displayed using an information system known as a geographic information system (GIS) (Tripathi et al., 2022). It consists of data workers, hardware, and computer software. A GIS is a computer-based system that gathers, organizes, evaluates, and displays georeferenced data to aid in decision-making. Using modern information technology, a geographic information system (GIS) gathers, stores, retrieves, analyzes, and displays spatial data that depicts the environmental conditions and land features of a particular geographic area as well as events that take place on Earth. GIS combines the special map-based display and spatial analytical advantages with standard database functions like querying and statistical analysis.

- **G: Geographic:** This involves an interest in the location or spatial identification of certain entities on, beneath, or above the earth's surface.
- **I: Information:** This suggests that in order to make decisions, one must be informed. In order to develop information that is helpful for making decisions, data or basic facts must be interpreted.
- **S: System:** This involves the requirement for personnel, computer equipment, and processes that can create the information needed for decision-making, i.e., data collecting, processing, and display.

#### **Component of GIS**

- **DATA**

Data is a set of values of subjects with respect to qualitative or quantitative variables. Data and information or knowledge is often used interchangeably. You may also define data as a collection of facts, such as numbers, words, measurements, observations or even just descriptions of things.

- **Hardware**

Hardware is a Computer on which GIS software runs. There are a different range of computers like Desktop or server based. The good computer hardware components must have high capacity. Examples of hardware components are: server, digitizer, PC, Printer, plotter, Hard driver, processor, graphics card, etc. These all component function together to run GIS software smoothly.

- **Software**

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are (a) a database management system (DBMS) (b) tools for the input and manipulation of geographic information (c) tools that support geographic query, analysis, and visualization (d) a graphical user interface (GUI) for easy access to tools. GIS software are either commercial software or software developed on Open Source domain, which are available for free. However, the commercial software is copyright protected, can be expensive and is available in terms number of licensees. Currently available commercial GIS software includes Arc/Info, Intergraph, MapInfo,

Gram++ etc. Out of these Arc/Info is the most popular software package. And, the open-source software are AMS/MARS etc.

- **User**

IS technology is of limited value without the users who manage the system and to develop plans for applying it. GIS users range from technical specialists who design and maintain the system to those who use it to help them do their everyday work. These users are largely interested in the results of the analyses and may have no interest or knowledge of the methods of analysis. The user-friendly interface of the GIS software allows the nontechnical users to have easy access to GIS analytical capabilities without needing to know detailed software commands. A simple User Interface (UI) can consist of menus and pull-down graphic windows so that the user can perform required analysis with a few key presses without needing to learn specific commands in detail.

- **Methods**

A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization.

## **GIS & Remote Sensing Application in Agriculture for Increasing Crop Production**

### **a. Land Suitability Assessment and Land Use Planning**

GIS provides an excellent platform for assessing the quality of land for suitable applications. Multi-criteria decision-making (MCDM) approach based on GIS is the most popular choice among researchers for land use planning. Researchers use different features offered by GIS such as soil type distribution, soil texture map, buried deep underground water level distribution, soil fertility distribution, soil pollution distribution, hydraulic conductivity of soil (Ks), slope (S), soil texture (ST), depth to water-table (DTW), and electrical conductivity of groundwater (ECw), climate conditions, topography, and satellite data, and identify the variety of interactions, dependencies, and the impact of these interacting factors on sustainable land use. GIS-based MCDM model with IRS P6 LISS-IV images have been used as input for the evaluation of agricultural practices in hilly regions. The rank of influential criteria was determined by correlation analysis and recommendations from scientific literature. The combined use of remote sensing and GIS turned out to be beneficial for land suitability evaluation. Analytic Network Process (ANP) model was deployed for assessing the interdependence of strategic input features for site suitability evaluation of citrus crops. The ANP coupled with GIS–MCDM identified critical factors for maximizing yield and minimizing production loss. AHP integrated with geo-statistics had proven its merit for maize cultivation land suitability mapping in calcareous and saline-sodic soils. These powerful GIS tools enable land reclamation planning with suitable conservation practices.

### **b. Water Resource Management**

Abundance of water supply is a primary requirement for meeting the demand for food production by the ever-increasing global population. As indicated earlier, farmers have the responsibility of feeding about 10 billion people in 2050 which demands a 50% increment in

food production compared to (2013) level. In this challenging scenario, water resource management is the key to success. Irrigation is the best solution for meeting the water requirement in agriculture. GIS technology backed by remote sensing has already proved its merit for the management of water resources. Many researchers supported the potential of GIS for groundwater management. Tripathi et al. integrated the MODFLOW groundwater model with the GIS for watershed prioritization. Singh et al. combined GIS and remote sensing for delineating groundwater potential zones. Lineament and hydro-geomorphological maps were prepared from remote sensing images. The delineated groundwater potential zones have been found to show synergy with the well-yield data. When sub-watershed level runoff and sediment yield were assessed using the combination of GIS and remote sensing data it reduced the time of the input data process and produced good results compared to actual runoff and sediment yield. Determining the suitability of irrigation for a given geography is one of the most popular applications of GIS. A study conducted in UAE accounted for non-renewable sources like desalination and treated sewage effluent (TSE) to assess irrigation suitability. This type of water-scarce region needs optimization of water resources management. Land management, topography, climate conditions, soil capabilities, and water potential were used in the analytical hierarchical process (AHP) GIS model to assess crop suitability.

### **c. Soil Health and Fertility Management**

Studies have reported that biotic crop damage, caused by insects, fungi, and other pests, can cause 15-70% yield loss. This scenario impacts the demand and supply chain and also affects the economy of farmers. The changing pattern of weather makes the crops susceptible to pests and diseases. The availability of crop protection methods is quite beneficial for tackling crop health, but the lack of timely information about the pests and diseases makes the damage irrepressible. GIS technology holds immense potential for site-specific pest and disease management. Remote sensing and GIS-based forewarning systems are boon to farmers to arrest the yield and economic loss. Anjan and Vinayak advocated that pest and disease forecasting systems allow farmers to apply the control measures in time to reduce the cost of production. Apart from the forewarning system, the pest population density map also plays a crucial role in identifying the hotspots and extending advisory to farmers. According to, information about the geospatial density of oriental fruit moth, *Grapholita molesta*, had the scope of reducing the crop injury and pest population by applying geographically suitable management measures. The difference in current and predicted geospatial distribution of two polyphagous and invasive *Icerya species* clearly indicated the impact of climate change in modifying the pest attack patterns. Such pest distribution maps enable farmers, agricultural experts, and policymakers to prepare management strategies to combat pest attack in the future. Tracking the migratory patterns of pests is of utmost importance given the instances of a sudden outbreaks of cutworm, *Agrotis ipsilon*, and fall armyworm, *Spodoptera frugiperda*, in different continents than their usual geographical locations. Remote sensing and GIS are important tools for monitoring habitats of pest species such as western tarnished plant bug, *Lygus hesperus*, and Migratory and Australian Plague locusts. Remote sensing and GIS are rapid and cost-effective technology for assessing the extent of crop damage by pests and diseases. Researchers had demonstrated the feasibility of

pest and disease type detection and severity mapping from remote sensing images. These damage assessment maps hold key spatial information about the damaged crop acreage and its trend across multiple years over different geographical units. These maps have the potential to act as an aid for insurance settlement for the farmers and for those seeking government subsidies and benefits.

#### **d. Crop Monitoring and Yield Prediction**

Monitoring of crop growth, health, and accurate or near accurate prediction of yield is crucial not only for estimating economic return but also for assessing the food production thereby helping in the management of food security. Many studies showed that traditional methods of crop yield estimation could lead to poor assessment and inaccurate crop area appraisal. These methods require time-consuming, labour-intensive, and expensive crop and yield data collection. This is where technologies like remote sensing (RS), GPS, and GIS provide a huge advantage as they can be used to assess temporal and spatial variability of crop dynamics and yield output. The use of two key partner technologies, RS and GIS, with required input from others can provide an efficient solution for monitoring crop health and developing models for predicting crop yields across diverse spatial scales. While remotely sensed images and associated analytics permit the tracking of crop health and predicting the yield, GIS technology enables the collection, storage, retrieval, and visualization of data that were linked geographically. Remotely sensed geospatial data acquired by satellites, aircrafts, or unmanned aerial vehicles (UAVs) can be used to gather information on several features of the crops and the characteristics of the soils supporting their growth thereby enabling the assessment of crop health. The images gathered can be used for assessing general vigor, disease or pest infestations, or deviations from expected growth due to drought or other abiotic stresses. Geospatial data collected in a spatiotemporal manner and the associated analysis techniques help in assessing the changes in the health of crops thereby permitting management interventions while providing predictions on anticipated yields based on the growth and health of the crops. A commonly used method for assessing crop health is based on the determination of vegetation indices that are calculated based on surface reflectance from crop canopies at two or more wavelengths. Many vegetation indices are available for evaluating the extent and vigour of vegetation, crop growth dynamics, stress due to biotic or abiotic factors, and other useful assessments. Adhav et al. used multiple vegetation indices that included Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Chlorophyll Vegetation Index (CVI), and Difference Vegetation Index (DVI) to determine crop health as well as variations in health conditions. To further improve the efficiency of health assessment, they have combined all vegetation indices using ArcMap 10.5 software and reclassified the merged indices which were then used for categorical representation of health scenarios. Such a representation helps farmers to identify areas that need immediate management intervention. Determination of crop health is particularly critical in smallholder farms as the subsistence and livelihood of these farmers depend on the productivity of their crops. As per a recent study, small farms were found to account for 84% of all farms worldwide but they operate only on around 12% of all agricultural land and produce about 35% of world's food. Use of UAVs for gathering and

leveraging data for assessing crop growth and dynamics has proven to be crucial for farmers to take timely and appropriate corrective measures to maintain or increase productivity.

#### **e. Biomass Assessment**

Renewable sources of energy are crucial to achieving climate change and sustainability goals. Agricultural residues are a promising source of biomass-based energy the demand for which is rapidly increasing around the globe. One challenge with agricultural residues for efficiently channelling them for energy production is the fact that their availability is seasonal and is geographically widely distributed. A solution that can address this spatial-temporal variability, seasonal fluctuations in biomass supply levels, and identification and transport of residues to power plants is a critical prerequisite for biomass-based energy generation. GIS, in combination with remote sensing, can be a great tool for precise identification and assessment of the crop residues and for planning a given region's feedstock material for renewable energy and its economical transportation to power plants. GIS-based estimation of bioenergy potential enables a technologically advanced solution for leveraging the residues from existing cropping practices that promise even more benefits as the farmers shift from conventional to smart farming. Some of the efforts in leveraging GIS and its partner technologies to this end are discussed below. Methods that can predict biomass potentials of a given region containing weather and crop production variations are of high value for enabling an efficient supply chain from biomass to power plants. By using BioSTAR, a carbon-based crop model, have calculated biomass potentials for maize, triticale, and cup plant, and linked them with a GIS map of the soil dataset of Hannover region in Germany and demonstrated the utility of this method for predicting agricultural potentials under diverse environmental and crop management practices and conditions. In a study that mapped rice cropland in a rural area in India, images from WorldView-2 satellite were used and the resulting map along with agricultural production statistics was analyzed in GIS for assessing the availability of rice straw as a feedstock for generating bioenergy. In addition, the study also estimated the annual rice straw availability and the electrical power it could generate, thus providing valuable information for energy developers and policymakers for planning. Since the success and sustainability of a biomass-based energy generation project depend on several factors that include the feedstock resource, logistics, and environmental considerations, the role and value of GIS and key associated tools and technologies need to be understood prior to establishing the supply chain and the power plants. Two tools can help to address this task: GIS and life cycle assessment (LCA). While GIS is critical for assessing the resources dispersed in small or large areas, LCA is useful in evaluating the environmental impacts of bioenergy production projects. A comprehensive review on the application of LCA, especially spatial LCA, in understanding the impact of biomass-based energy generation on different ecosystem services and the value of integrating LCA and GIS to conduct a holistic assessment of environmental benefits in connection with bioenergy production recommended the inclusion of LCA as an essential component in planning bioenergy projects. To assess the spatial and temporal availability of crop residues and to pinpoint locations for ideal power plants along with cost considerations, an integrated GIS-based biomass, site optimization, and logistics cost model was developed by using soil

erosion, soil conditioning index (SCI), and crop residue yield indicators. To estimate crop residues, prediction models based on artificial neural networks (ANNs) were developed for each of these indicators and were implemented on a GIS platform. The utility of this model was also demonstrated using a sustainable assessment of cotton stalks (CS) that are used to produce fuel pellets. An advantage of this model is that its use can be extended to assessment of multiple types of crop residues. Models based on GIS and multi-criteria inclusion-exclusion analysis and facility location-allocation were also developed for the identification of sustainable crop biomass at larger spatial and longer temporal scales and to suggest ideal biogas plants along with cost considerations for biomass delivery.

## Conclusion

The use of GIS, GPS & remote sensing in agriculture has increased at a rapid pace during the recent decades and the number of applications and the prominence of GIS has further amplified in the recent years due to advances in digital technologies that have been leveraging GIS, GPS & remote sensing as an essential partner technology for assessing crops, soils, and their environments. GIS, GPS & remote sensing is being used at all stages of agricultural value chain. In addition to the historical, current, and popular uses of GIS in land suitability/use planning and management of water, soil, and biotic and abiotic stresses, the advent of digital agricultural tools and technologies has increasingly leveraged the capabilities of GIS in new and emerging applications in high fidelity crop monitoring, yield prediction, for both primary produce and biomass utilization towards energy production. The multitude of capabilities and insights provided by GIS, including the recent enhancements to collect and analyze data in real time, has further elevated its importance in providing location/spatial intelligence needed for improving the productivity and profitability of farms through practices and it helps in achieving sustainable agricultural productivity.

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