

Climate-Smart Agronomic Practices for Sustainable Crop Production

Kiran N. More¹, Apeksha M. Suryawanshi², Shrikrishna B. Narale³

Introduction:

Agriculture is highly dependent on climate, and even small changes in temperature, rainfall, humidity, wind speed and the frequency of extreme weather events can influence crop growth and productivity. Rising temperatures, irregular monsoon rainfall, prolonged dry periods, floods, heat waves and the changing incidence of pests and diseases are creating new challenges for farmers. At the same time, the demand for food, fibre and other agricultural commodities continues to increase. Therefore, the future of agriculture depends not only on producing more, but also on producing **efficiently, sustainably and with greater resilience to climate variability**. Climate-Smart Agriculture (CSA) provides an integrated approach to address these challenges. The Food and Agriculture Organization (FAO) describes climate-smart agriculture as an approach that simultaneously addresses **food security, adaptation to climate change and,**

where possible, mitigation of greenhouse - gas emissions. Climate-smart agronomy translates these broad objectives into practical field-level decisions involving crop selection, sowing time, tillage, soil management, irrigation, nutrient management, weed control, pest management, crop diversification and efficient use of farm resources.

In India, climate-smart agronomic technologies are particularly important because agriculture supports millions of farming households and large areas remain vulnerable to drought, floods, heat stress and declining soil and water resources. ICAR research has demonstrated several climate-smart technologies involving water conservation, soil-carbon improvement, resilient cultivars and resource-efficient crop management. The objective of climate-smart agronomy is not simply to obtain higher yields. A truly climate-smart production system should **maintain or improve**

Kiran N. More¹, Apeksha M. Suryawanshi², Shrikrishna B. Narale³

¹ Ph.D. Scholar, Department of Agronomy, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth (DBSKKV), Dapoli, Maharashtra, India.

² Department of Animal Husbandry and Dairy Science (AHDS), Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, India.

³ Ph.D. Scholar, Department of Biochemistry, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, India.

productivity, conserve natural resources, reduce production risks and remain economically viable for farmers.

Understanding Climate-Smart Agronomy

Climate-smart agronomy refers to the application of scientific crop and soil management practices that help crops withstand climatic stresses while improving the efficiency of water, nutrients, energy and other inputs. It combines traditional agricultural knowledge with modern technologies, improved crop varieties, weather information and precision management. Important dimensions of climate-smart agronomy include:

1. **Water-smart agriculture**
2. **Soil-smart agriculture**
3. **Nutrient-smart agriculture**
4. **Crop and cropping-system diversification**
5. **Weather-smart crop management**
6. **Integrated pest and disease management**
7. **Energy-efficient farming**
8. **Carbon-smart agriculture**
9. **Digital and precision agriculture**

ICAR research has similarly highlighted water-smart, weather-smart, nutrient-smart, crop-smart, energy-smart, carbon-smart and knowledge-smart technologies as important components of climate-smart agronomy.

The most important feature of CSA is that there is **no single practice suitable for every farm**. Climate-smart practices must be selected according to soil type, rainfall, irrigation availability, crop, farming system, local climate and farmers' economic conditions.

1. Climate-Resilient Crops and Varieties

The first step towards climate-smart crop production is selecting crops and varieties capable of performing under anticipated climatic conditions. Farmers should prefer varieties with tolerance to **drought, heat, salinity, waterlogging, diseases and other climate-related stresses**, wherever suitable varieties are available.

Short-duration varieties can help farmers escape terminal drought or late-season heat. Similarly, flood-tolerant varieties can be useful in areas frequently affected by waterlogging, while drought-tolerant crops and varieties can reduce yield losses in rainfed regions. Crop diversification is another important strategy. Growing only one crop increases the risk associated with climate extremes. Diversification through cereals, pulses, oilseeds, vegetables, fodder crops and agroforestry can distribute production risk and improve farm income.

2. Conservation Agriculture for Soil Health

Healthy soil is the foundation of sustainable and climate-resilient agriculture. Climate-smart agronomy therefore emphasizes **minimum soil disturbance, permanent soil cover and crop diversification**—the three major principles of conservation agriculture promoted by FAO. Reduced tillage or zero tillage can decrease soil disturbance, save fuel and labour, and help conserve soil moisture. Retaining crop residues on the soil surface protects the soil from erosion and reduces direct evaporation.

Crop residues should preferably be incorporated or retained as mulch rather than burned. Residue management can increase soil organic matter, improve soil structure and support beneficial soil organisms. FAO recommends direct seeding, protective soil cover, crop rotations and integrated soil fertility management as important components of climate-smart soil management. In the Indo-Gangetic Plains, conservation agriculture has particular importance in rice–wheat systems where intensive tillage, residue burning and excessive water use can contribute to resource degradation. Climate-smart management can improve the resilience of these systems to temperature, water and rainfall stresses.

3. Efficient Water Management

Water scarcity is one of the most serious threats to agricultural sustainability. Climate change is expected to increase

uncertainty in rainfall and increase the frequency of drought conditions in many regions. Therefore, every drop of water must be used efficiently.

Important water-smart practices include:

1. Drip and sprinkler irrigation
2. Alternate wetting and drying in suitable rice systems
3. Laser land levelling
4. Mulching
5. Rainwater harvesting
6. Farm ponds and water-storage structures
7. Proper irrigation scheduling
8. Conservation tillage
9. Drought-tolerant crops and varieties
10. Efficient drainage in flood-prone areas

Irrigation should be based on crop requirement rather than a fixed calendar. Soil moisture, crop growth stage and weather forecasts can be used to determine when irrigation is actually required. Rainwater harvesting and soil-water conservation are particularly useful in rainfed agriculture. Maintaining crop residues and increasing soil organic matter can improve the soil's capacity to retain water.

4. Balanced and Efficient Nutrient Management

Climate-smart nutrient management aims to provide crops with the **right nutrient, in the right amount, at the right time and in**

the right place. Excessive application of nitrogen fertilizers not only increases production costs but can also contribute to environmental pollution and greenhouse-gas emissions. Therefore, fertilizer application should be based on soil testing, crop requirement and expected yield.

Integrated nutrient management combines:

1. Chemical fertilizers
2. Farmyard manure
3. Compost
4. Green manure
5. Crop residues
6. Biofertilizers
7. Legume-based crop rotations

Organic inputs improve soil organic matter and nutrient cycling, while mineral fertilizers can supply nutrients rapidly when crops require them. Combining both approaches can improve nutrient-use efficiency. Split application of nitrogen according to crop demand can reduce nutrient losses. Site-specific nutrient management and precision fertilizer application can further improve fertilizer-use efficiency.

5. Crop Diversification and Improved Cropping Systems

Diversification is one of the simplest ways to reduce climate risk. A diversified farm is generally better able to withstand failure of a particular crop caused by drought, flood, pest outbreaks or abnormal temperatures. Crop

rotation with cereals, pulses and oilseeds can improve soil fertility and interrupt pest and disease cycles. Legume crops are particularly valuable because biological nitrogen fixation can reduce dependence on external nitrogen inputs.

Intercropping can also improve resource utilization. Combining crops with different rooting patterns, maturity durations and nutrient requirements can increase the efficient use of available water, nutrients, sunlight and land. Integrated crop–livestock systems provide another opportunity for climate resilience. Crop residues can provide livestock feed, while animal manure can return nutrients and organic matter to the soil.

6. Integrated Weed, Pest and Disease Management

Climate change can alter pest and disease behaviour. Changes in temperature, humidity and rainfall may influence pest multiplication, migration and disease development.

Climate-smart crop protection should therefore emphasize **Integrated Pest Management (IPM)** rather than excessive dependence on pesticides. FAO identifies integrated pest management as a major component of sustainable crop production intensification.

IPM involves:

1. Regular field monitoring

2. Use of resistant varieties
3. Crop rotation
4. Biological control
5. Mechanical and cultural methods
6. Need-based pesticide application
7. Conservation of natural enemies
8. Use of pheromone and light traps where appropriate

Farmers should avoid unnecessary pesticide applications. Correct identification of pests and diseases and spraying only when economically justified can reduce production costs and protect beneficial organisms.

9. Precision Agriculture and Digital Technologies

Modern digital technologies are making climate-smart farming more precise. Remote sensing, drones, GPS, sensors, satellite imagery, mobile applications and artificial intelligence can help farmers monitor crop health and identify areas requiring specific management.

Instead of treating an entire field uniformly, precision agriculture allows farmers to identify variations in soil fertility, crop growth and moisture status. Inputs can then be applied according to actual field requirements.

Drones and satellite images can help identify crop stress, nutrient deficiency, weed infestation and water stress. Soil and weather sensors can support irrigation and fertilizer decisions. However, technology should be

selected according to farm size, affordability, availability of technical support and expected economic benefits. Climate-smart agriculture is not necessarily high-tech agriculture; a simple mulch, improved variety or better irrigation schedule can sometimes provide greater benefits than expensive technology.

10. Agroforestry and Carbon-Smart Farming

Integrating trees with crops and livestock can provide multiple environmental and economic benefits. Agroforestry systems can improve biodiversity, reduce wind erosion, provide shade and contribute to carbon storage.

Trees can also provide additional products such as fruits, fodder, fuelwood, timber and medicinal products, thereby diversifying farm income. Carbon-smart agriculture aims to reduce greenhouse-gas emissions and increase carbon storage. Practices such as conservation agriculture, residue management, agroforestry, efficient nitrogen use and improved water management can contribute to this objective.

Thus, climate-smart agriculture should be viewed not merely as a method of adapting to climate change but also as an opportunity to improve the environmental performance of agriculture.

11. Mechanization and Energy Efficiency

Agricultural mechanization can improve timeliness and reduce labour requirements, but excessive or inefficient use of machinery can increase fuel consumption and soil degradation.

Climate-smart mechanization emphasizes:

1. Energy-efficient machinery
2. Reduced tillage
3. Timely field operations
4. Zero- or minimum-tillage seeders
5. Precision equipment

6. Proper machinery selection

7. Renewable-energy-based irrigation where feasible

For example, direct seeding technologies can reduce the number of field operations and thereby save fuel, time and labour.

A Farmer-Centred Approach is Essential

Technology alone cannot make agriculture climate-smart. Farmers must be involved in selecting, testing and adapting

Major Climate-Smart Agronomic Practices and Their Benefits

Climate-smart practice	Major application	Key benefit
Drought/heat/flood-tolerant varieties	Stress-prone areas	Reduces climate-related yield losses
Crop diversification	Cereals–pulses–oilseeds and mixed systems	Reduces production risk
Crop rotation	Sequential cropping	Improves soil health and breaks pest cycles
Zero/minimum tillage	Rice–wheat and other cropping systems	Saves energy and conserves soil moisture
Residue retention/mulching	Field soil management	Reduces evaporation and erosion
Drip/sprinkler irrigation	Horticultural and field crops	Improves water-use efficiency
Rainwater harvesting	Rainfed areas	Stores water for critical crop stages
Soil-test-based fertilization	All major crops	Improves nutrient-use efficiency
Split nitrogen application	Cereals and high-demand crops	Reduces nutrient losses
Organic manures and green manuring	Soil fertility management	Builds soil organic matter
Integrated pest management	All crops	Reduces unnecessary pesticide use
Weather-based advisories	Crop planning and operations	Improves decision-making under variable weather
Precision agriculture	Input and crop monitoring	Improves resource-use efficiency
Agroforestry	Cropland and farm boundaries	Diversifies income and stores carbon
Conservation agriculture	Field crops	Protects soil and improves resilience
Integrated crop–livestock farming	Mixed farming systems	Recycles resources and diversifies income

technologies to local conditions. A practice that works successfully in one region may not produce the same results elsewhere.

For example, zero tillage can provide major benefits under suitable soil and cropping conditions, but it requires appropriate machinery, weed-management strategies and timely sowing. Similarly, drip irrigation can save water, but its economic feasibility depends on crop value, farm size, water availability and installation costs. Therefore, climate-smart agriculture should be **location-specific, economically viable and socially acceptable**. Extension agencies, Krishi Vigyan Kendras, agricultural universities, ICAR institutes, farmer-producer organizations and private organizations have important roles in promoting these technologies. Farmer training and demonstration plots are especially important because farmers can observe the benefits and limitations of a practice before adopting it on a large scale.

Conclusion

Climate change is emerging as one of the major challenges to sustainable crop production, affecting crop growth, productivity, soil health, water availability and the incidence of pests and diseases. Climate-smart agronomic practices provide an effective approach for addressing these challenges while maintaining farm productivity and profitability. Practices such as conservation

tillage, residue management, crop diversification, efficient irrigation, balanced nutrient management, integrated pest management, climate-resilient varieties, weather-based advisories and precision farming can improve resource-use efficiency and reduce production risks.

The successful adoption of climate-smart agriculture requires **location-specific, economically feasible and farmer-friendly technologies**. Integration of indigenous knowledge with modern scientific approaches, digital technologies and improved extension services can further strengthen climate resilience. Farmers should be encouraged to adopt a combination of practices rather than depending on a single technology. Ultimately, climate-smart agronomy can contribute to higher and more stable crop yields, improved soil and water conservation, reduced environmental impacts and enhanced food and nutritional security. Thus, adopting climate-smart practices today is essential for building a **productive, profitable, resilient and sustainable agriculture system for future generations**.

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